ESSAYS ON OPERATIONS STRATEGIES

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ESSAYS ON OPERATIONS STRATEGIES

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To Judy, Brian, Patrick, and Mitchell,

I owe you big time!

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SUMMARY

Operations strategies, whether prompted by competitive or regulatory forces, can greatly impact firm performance. While operations strategies cover a wide spectrum of issues – supply chain management, technology choice, capacity allocation, etc. – this dissertation focuses on two such issues, namely, sustainability and product development. The thesis comprises three essays. The first essay (Chapter 2) examines a regulatory aspect of sustainability strategy, product take-back, a form of Extended Producer Responsibility (EPR). With a stylized model, we analyze the trade-offs between assigning full responsibility for product recovery to a single echelon in a multi-echelon supply chain versus sharing responsibility between echelons. We demonstrate how the sharing of EPR program costs between the echelons can move the supply chain closer to the coordinated profit benchmark. The second essay (Chapter 3) examines a voluntary aspect of sustainability from an empirical perspective. We investigate the impact from various types of corporate environmental initiatives and environmental awards and certifications on the market value of the firm. We find that the market is selective in reacting to environmental performance, with certain types of initiatives and awards even valued negatively. The third essay (Chapter 4) is an empirical examination of the shareholder value effects that result from the restructuring of firms' product development activities. We find that, on average, the stock market reacts positively to product development restructuring, and that the reaction is dependent on the firm's prior financial performance, restructuring objective, R&D expenditures, and size.

CHAPTER I

INTRODUCTION

Given that Operations Management encompasses the design, operation, and improvement of the systems that create and deliver the firm's primary products and services, effective operations strategies are critical to any business. Well-designed operations strategies enhance the firm's abilities to compete effectively in the ever-changing economic environment. Operations strategies cover a wide spectrum of issues: supply chain management, technology choice, capacity allocation, etc. This dissertation focuses on two such issues that are of increasing importance and interest, namely, sustainability and product development. Emphasis on sustainability continues to expand for several compelling reasons: escalating energy and material costs, increasing public pressure for improved environmental, health, and safety performance, shifting consumer preference for "green" products, and sharpening stakeholder focus on sustainability performance. Similarly, the escalating pace of technological change and product churn, as well as increasing competition, has elevated the criticality of product development to the market success and financial health of the firm. The dissertation comprises three essays: the first two examine specified regulatory and voluntary aspects of firms' sustainability strategies, and the third is a study of the strategies involved in product development restructuring. The first essay uses an analytical modeling approach to determine the sustainability strategy that maximizes firm and supply chain profit. The second and third essays empirically estimate the impact of sustainability and product development strategies, respectively, on financial performance.

The first essay, presented in Chapter 2, analyzes product take-back, a form of Extended Producer Responsibility (EPR). EPR aims to shift responsibility for end-of-life products from society to the beneficiaries of products and, thus, to incent producers to provide more environmentally-friendly designs. EPR programs typically hold the producer – a single actor defined by the regulator – responsible for the environmental impacts of end-of-life products. This is despite emphasis on the need to involve all actors in the supply chain in order to best achieve the aims of EPR. In this chapter, we explore the important economic and environmental implications of sharing EPR program costs. We develop and present a steady-state, two-echelon supply chain model to examine the impacts of product collection and recycling mandates on the incentive to recycle, and resulting profits in the integrated and decentralized supply chains. For the decentralized supply chain, we demonstrate how the sharing of EPR program costs between the echelons can move the supply chain closer to the coordinated profit benchmark and suggest a contract menu that can Pareto-improve profits. To examine both the economic and environmental performance associated with the sharing of program costs, and assess the overall effectiveness of EPR programs, we propose a social welfare construct that considers supply chain profit, consumer surplus, and the environmental externalities associated with virgin material extraction, product consumption, and disposal of non-recycled products. Using a numerical example, we discuss how EPR program cost sharing may or may not improve social welfare. The results of this research are of value to firms either anticipating or subject to product recovery legislation, and to social planners that attempt to balance economic and environmental outcomes and ensure the fairness of such legislation.

The second essay, presented in Chapter 3, empirically investigates the impact from various types of corporate environmental initiatives and environmental awards and certifications on the market value of the firm. This research analyzes the shareholder value effects of environmental performance by measuring the stock market reaction associated with announcements of environmental performance. We examine the market reaction to two categories of environmental performance. The first category includes 430 announcements of Corporate Environmental Initiatives (CEIs) that provide information about self-reported corporate efforts designed to avoid, mitigate, or offset the environmental impact of the firm's goods, services, or processes. Such initiatives include environmental business strategies, environmental philanthropy, voluntary emission reductions, eco-friendly products, renewable energy, recycling, and miscellaneous. The second category includes 381 announcements of Environmental Awards and Certifications (EACs) that provide information about recognition granted by third parties specifically for environmental performance. Awards include those granted by federal governments, state or local governments, and non-governmental agencies. Certifications include ISO14001 and LEED. Although the market does not react significantly to the aggregated CEI and EAC announcements, we do find statistically significant market reactions for certain CEI and EAC subcategories. Specifically, announcements of philanthropic gifts to environmental causes are associated with significant positive market reaction, voluntary emission reductions are associated with significant negative market reaction, and ISO 14001 certifications are associated with significant positive market reaction. Thus, we find that the market is highly selective in reacting to environmental efforts; when the market does react, it does not do so uniformly as the market reactions to certain environmental efforts are even negative.

The final essay, presented in Chapter 4, empirically examines the shareholder value effects of restructuring product development. Given its potential impact on competitive advantage, product development is the subject of many product and platform level strategies to improve its effectiveness. One firm level improvement strategy is product development restructuring (PDR), which includes reorganizing, realigning, refocusing, and streamlining the product development function. This chapter analyzes the shareholder value effects of PDR by measuring the stock market reaction associated with announcements of PDR. We estimate the average abnormal return for a sample of 114 firms around the date when information about PDR is announced. On average, announcements of PDR result in a statistically significant 1.60% increase in stock value. To understand how market reaction to PDR is influenced by characteristics of the firm and the restructuring, we develop and test hypotheses that relate the stock market reaction to the announcing firm's prior financial performance, primary restructuring objective, R&D expenditures, and size. We find that the market reaction to PDR is more positive for announcing firms that financially underperform than for those that financially outperform their industry group. We also find that the market reaction to PDR is not significantly affected by whether the firm's primary PDR objective is to cut costs or to increase revenues. However, the interaction between the firm's prior financial performance and its primary PDR objective is significant. For firms that are financial underperformers (outperformers), the market reaction to PDR is more positive if the firm's primary objective is to cut costs (increase revenues). We also find that the market reaction to PDR is more positive for announcing firms with higher R&D intensity. Last, we find that the market reaction to PDR by small firms is more positive than it is to PDR by large firms. Thus, PDR, on average, creates statistically and economically significant shareholder value.

CHAPTER II

SHARING RESPONSIBILITY FOR PRODUCT RECOVERY ACROSS THE SUPPLY CHAIN

2.1 Introduction and Literature Review

As residential and industrial waste continues to grow, alternatives are being sought to deal with end-of-life products. Extended Producer Responsibility (EPR) has emerged as one such alternative. The OECD defines EPR as "...an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle" (OECD 2001). EPR aims to shift financial or physical responsibility for end-of-life products from society to beneficiaries of the products, thus incentivizing producers to provide environmentally-friendly products with efficient use of materials and lower hazardous material content.

The means to accomplish these goals within the framework of EPR are varied and include deposit/refund schemes, advance disposal fees, raw material taxes, producer taxes to subsidize waste treatment, minimum recycled content standards, leasing/servicizing, and product take-back. Each of these instruments has advantages and limitations (OECD 2001). Examples of mandated EPR programs include recovery[1] of packaging materials (e.g., Bell 1998, Fishbein 1998, Tojo et al. 2003), and take-back of electronic goods (e.g., Tojo 2001, Appelbaum 2002, Walls 2006), among others. Examples of voluntary efforts are discussed in Davis et al. (1997) and Fishbein (2000). In some cases, voluntary programs are indeed economically advantageous (Toffel 2004, Heese et al. 2005).

The focus of this paper is on the product recovery element of EPR and its impact

[1] We use the term *product recovery* to generally refer to collection and recycling activities.

on the economic and environmental performance of the supply chain. Product recovery encompasses the collection of end-of-life products and their appropriate treatment, be it reconditioning, remanufacturing, recycling, or disposal. Recovery programs typically include targets – both for collection as well as for salvage of used products. A commonly cited example is the European Union's (EU) Waste Electrical and Electronics Equipment (WEEE) Directive, enacted in 2003. Legislative transpositions of the directive specify targets both for product collection and recycling. In general, responsibility for product recovery can be either financial or physical (infrastructural). Financial responsibilities are often mandated through instruments such as cost-sharing formulas, advance disposal fees, or end-user fees while the physical organization of product recovery is typically left to the discretion of the producer(s) provided the mandated targets are met (Tojo et al. 2003).

A key question in the EPR context is the definition of *producer* and the corresponding allocation of responsibility. With many different actors in the supply chain from raw material suppliers to retailers, who should be identified as the "producer" and be held responsible for end-of-life products? Researchers have highlighted the need to extend responsibility across the supply chain so that every party involved has an incentive to minimize the environmental impacts of products (Davis et al. 1997). However, the determination of the responsible firm(s) can be complex and contentious (Fishbein 2000). Despite the OECD's statement that "...allocating responsibility and determining who is the producer are two of the most important [EPR] policy design issues ..." (OECD 2001), most EPR programs identify a single actor within the supply chain as the responsible party. For example, within the packaging supply chain are the paper and plastics manufacturers, the converters who turn paper and plastic into containers, the firms that pack or fill the containers, and the distribution chain consisting of distributors, wholesalers, retailers, and consumers. Which of these parties should be responsible? In most EU member states, consensus has been that the packers and fillers should be the responsible "producers" (Fishbein 1998). Similarly, the WEEE directive names a single actor, the "importer of record," as the producer. An exception is the packaging recovery program in the UK. The program allocates costs between supply chain echelons, with the largest portion (48%) assigned to the retailers (UK-DEFRA 2003, Walls 2006). There has been considerable debate as to whether this particular allocation is fair or whether the administrative burden of involving multiple parties is worthwhile (Bell 1998, Scarlett 1999, Bailey 2000). But are any of these responsibility allocations optimal for providing incentives to each of the firms within the chain to operate in an environmentally responsible manner? In comparison to the published literature regarding the motivation, history, and workings of EPR, research analyzing the impact of EPR on interactions within a supply chain is less prevalent. We therefore address the following research questions in this paper

1. *What are the impacts of collection and recycling targets under an EPR program, on the incentive to recycle and resulting quantities and profits in the supply chain? How do the above impacts depend upon supply chain structure (i.e., whether integrated or decentralized)?*

2. *What are the profitability implications of sharing responsibility for product recovery across the supply chain? How might the level of sharing be set?*

3. *What effect does sharing responsibility have on the more holistic measure of social welfare that considers virgin material extraction, consumption, and disposal externalities together with supply chain profit and consumer surplus?*

To address the above research questions, we develop and analyze steady-state models of both an integrated and a decentralized two-echelon supply chain. For the decentralized supply chain we examine the two cases where product recovery responsibility rests solely with the downstream echelon and where responsibility is shared between the two echelons. The context for our model is a supplier who provides raw material to a manufacturer; the manufacturer's product is recyclable and the recycled material can be substituted for virgin raw material (e.g., a raw steel producer supplying to a fabricator).

We find that the collection and recycling targets impact recycling incentives and, hence, supply chain quantities and profits in interesting ways. The targets always negatively impact supply chain profits. Whereas the targets reduce the amount of virgin material consumed in the integrated supply chain, they may in fact increase the amount of virgin material consumed in the decentralized supply chain under certain conditions, analogous to the "Jevons effect" (Hentwich 2005). For the decentralized supply chain, we demonstrate how the sharing of EPR program costs between the echelons can move the supply chain closer to the coordinated profit benchmark, and suggest a contract menu that can Pareto-improve supply chain profits. However, the sharing of program costs increases the amount of virgin material used as well as the total quantity produced. Therefore, to holistically assess the societal impacts of EPR regulation and program cost sharing, we propose a social welfare construct that explicitly considers the externalities associated with virgin material extraction, product consumption, and disposal, in addition to supply chain profits and consumer surplus. Using a numerical example, we discuss how program cost sharing may or may not improve social welfare.

Our work attempts to bridge two streams of literature – the operations management literature that treats the interface between operational decisions and the environment, and the pertinent literature on environmental economics and industrial ecology that aims to characterize the societal or indirect impacts of economic activity. The operations management literature contains a substantial and growing number of articles pertaining to closed-loop supply chains with product remanufacturing (see surveys by Corbett & Kleindorfer 2001, Kleindorfer et al. 2005, Guide

& Van Wassenhove 2006, Souza 2008, and Atasu et al. 2008). The extant literature mainly treats strategic, tactical, and operational issues related to product collection and remanufacturing, and the influence of economic and competitive drivers on product recovery decisions. Of particular relevance are recent papers that explore the interface of product recovery regulation and supply chain management. Plambeck and Taylor (2007) examine the effectiveness of manufacturers' testing of competitors' products as a strategy to improve compliance with Restriction of Hazardous Substances (RoHS)-type regulation. Subramanian et al. (2009) demonstrate that supply chain coordination can result in superior environmental design of a remanufacturable product subject to EPR regulation. Plambeck and Wang (2009) explore the impact of e-waste regulation (WEEE) on the timing of new product introductions. Atasu et al. (2009) model an economic system comprising the regulator, manufacturer, and consumer, to investigate the competitive impacts of and possible improvements to weight-based product recovery targets. Consistent with the spirit of these papers, our focus is not *per se* to critique the variety of EPR instruments but rather to explore their impacts that are of managerial relevance, including the important implications of sharing responsibility for product recovery across supply chain echelons. In addition, we propose a social welfare construct that considers both economic and environmental performance and highlights the associated trade-offs.

To assess the environmental impacts of product recovery targets and the sharing of recovery responsibility, we draw upon the related environmental economics literature that attempts to characterize environmental externalities and measure their societal impacts (see survey by Cropper & Oates 1992). The externalities considered in our analysis include those associated with the extraction of virgin material, consumption of the product, and the disposal of both collected and uncollected product. Externalities associated with virgin material extraction include land use, untreated runoff, reclamation, and resource depletion (Söderholm 2006). The social costs of product disposal include land aesthetics, leakage, and future remediation costs (Huhtula 1997, Runkel 2003). Product consumption is associated with the societal costs of energy use, material flows, and intensity of land usage (Spangenberg 2004). The classic remedies for mitigating environmental externalities include taxes and subsidies. However, and more recently, the need for upstream and goal-oriented policy interventions such as EPR has been emphasized in the environmental economics literature (Fullerton & Wu 1998, Calcott & Walls 2000, Walls 2006). We also note the pertinent work in the area of industrial ecology, specifically life-cycle assessments (LCAs), which provide measures of indirect costs associated with economic activity (Matthews & Lifset 2007).

This paper is organized as follows. Section 2.2 introduces the model. Section 2.3 analyzes the impacts of collection and recycling targets on the optimal profit and quantities in the integrated supply chain while Section 2.4 examines the effects of these targets in the decentralized supply chain. Section 2.5 discusses the implications of sharing program costs and introduces a contract menu that can Pareto-improve profits in the supply chain. Section 2.6 discusses the results in light of our social welfare construct, and includes a numerical example that motivates how program cost sharing affects social welfare. Section 2.7 concludes the paper with a summary of our main results and key managerial insights.

2.2 Model

The context for our model is a *supplier* S (referred to as *she*) supplying raw material to a *manufacturer* M (referred to as *he*). The manufacturer transforms the raw material into product demanded by customers; we generally refer to the transformation activities as *production*. Each firm's objective is to maximize profit. We focus our attention on firm-level interactions under EPR with mandates on both product collection and recycling. Some EPR instruments, including advance disposal fees and deposit/refund systems, require that consumers share the costs of managing end-of-life products. This could possibly be modeled in addition, but our focus is on the production side of the supply chain.

In classic EPR programs, a single actor in the supply chain is typically held responsible for the collection, recycling, or disposal of end-of-life products. As is the case with most EPR programs, our model treats the manufacturer as the *producer* who is held responsible for product recovery costs. We assume that product returns are recyclable; however, the yield in recycling could be less than 100% (although we model a 100% yield without loss of generality). Recycling only occurs at the supplier and only if it is economically attractive to her. Under regulation, the manufacturer, who is responsible for ensuring that the mandated targets are met, must sufficiently incentivize the supplier to recycle at or above the mandated level. As is true in several process industry settings (e.g., metals and plastics), we assume that recycled raw material and virgin raw material are identical to the manufacturer. Also, we assume the supply of virgin material to be unconstrained for the purposes of our problem. We focus on a representative steady state period in which virgin material is processed by the supplier and transformed into product by the manufacturer, and products sold to customers in a prior period are collected, recycled, and possibly disposed of.

Governments may elect to establish product recovery programs with either a target collection rate, target recycling rate, or both (Tojo et al. 2003). Examples include the EU's End-of-Life Vehicle (ELV) directive with recycling targets only and transpositions of the WEEE directive with both collection and recycling targets. Policy choices are often a function of the industry's infrastructure, e.g., industries without established collection or recycling activities may first be given only a collection target while industries that currently collect and recycle may be given a recycling target instead.[2] Collection mandates alone (without recycling targets) may be implemented if the product is hazardous, if proper disposal is required, if there is no market for the recycled product, or if recycling possibilities are limited. Commonly cited examples include batteries and automotive tires. Recycling mandates alone (without collection targets) could be the case in industries with some level of collection and recycling history where the regulatory program's objective is to boost the already-established recycling efforts. Examples include automobiles and packaging materials. Establishing both collection and recycling targets could be a recognition that not all of the collected product is recyclable due to the quality of returns or particular market conditions, but a high collection target is desired in order to ensure adequate recovery and appropriate disposal of products. Waste electronics is an example. To permit study of the above possibilities, our model includes two principal product recovery program parameters τ and ρ, which are the mandated minimum (or target) rates for product collection and recycling, respectively, and are modeled as fractions of the total production quantity. Logically, we have $\tau > \rho$. In addition, we assume that regulation constrains "business-as-usual", implying that ρ is greater than the supplier's optimal recycling rate in the absence of regulation.

We denote each quantity with two subscripts, i.e., q_{ki}. Subscript k identifies the quantity type, i.e., whether <u>V</u>irgin, <u>C</u>ollected, <u>R</u>ecycled, <u>D</u>isposed, or <u>T</u>otal. Subscript i identifies the scenario of either <u>N</u>o regulation or <u>R</u>egulation. For example, the quantity of virgin material processed by the supplier under regulation is q_{VR}. The quantities recycled by the supplier in the absence and presence of regulation are denoted as q_{RN} and q_{RR}, respectively. Any material collected but not recycled must be disposed of; the disposed quantity is denoted as q_{Di}. The total quantity produced by the manufacturer is denoted as q_{Ti}, which is the sum of production quantities using virgin and recycled material (i.e., $q_{Ti} = q_{Vi} + q_{Ri}$). We assume a linear inverse

[2] In some cases, the recycling target may be specified as a percentage of the collected amount.

demand function $p = a - bq_{Ti}$ where p is the unit price paid by the end customer.

To create a baseline for comparisons, we begin by analyzing the integrated supply chain. The integrated supply chain is equivalent to a vertically integrated manufacturer who bears full responsibility for EPR-related costs. As the next step, we analyze the decentralized supply chain to study the interactions associated with the existence and sharing of EPR-related costs. In the decentralized supply chain, the supplier charges wholesale price $w_i > 0$ to the manufacturer per unit of material supplied. Under regulation, the manufacturer may have to collect product to ensure that the mandate is met; the manufacturer offers this collected product to the supplier at a unit transfer price of η (possibly < 0). Since material may be collected by either the integrated firm, or the supplier/manufacturer in the decentralized supply chain, we add the superscript $j \in \{\underline{\text{I}}\text{ntegrated Supply Chain, } \underline{\text{S}}\text{upplier, } \underline{\text{M}}\text{anufacturer}\}$ to the collected quantities, i.e., q_{Ci}^{j}. For example, the quantity collected by the manufacturer for the purpose of meeting collection and recycling mandates in the decentralized supply chain is denoted as q_{CR}^{M}. Profits are denoted as Π_i^j.

Collection and recycling costs are functions of the total collected and recycled quantities, respectively, i.e., we have $C_j(q_{Ci}^{j})$ and $R(q_{Ri})$, where $i \in \{N, R\}$, and $j \in \{I, M, S\}$. Given the increasing marginal effort in collecting end-of-life products, we assume $C_j' > 0$ and $C_j'' > 0$ (e.g., Ferguson & Toktay 2006). Recycling, on the other hand, typically exhibits economies of scale; we therefore assume $R' > 0$ and $R'' < 0$ (e.g., Callan & Thomas 2001, Toyasaki et al. 2008). We assume a constant marginal cost of disposal D, consistent with the common per-unit-weight or volume assessments of disposal costs. Since we analyze the supply chain in steady state, we assume that the marginal costs of collection, recycling, disposal, virgin material processing (V) for the supplier, and production (M) for the manufacturer, are time-invariant. Also, without loss of generality, we assume fixed costs to be zero; profit-maximizing firms will not collect or recycle if profit does not at least cover fixed costs.

Table 2.1 summarizes the notation used in the model.

Table 2.1: Model Notation

	Symbol	Definition
Quantities	q_{Vi}	Virgin material quantity; $i \in \{\underline{N}\text{o regulation}, \underline{R}\text{egulation}\}$
	q^j_{Ci}	Collected quantity; $j \in \{\underline{I}\text{ntegrated Supply Chain}, \underline{M}\text{anufacturer}, \underline{S}\text{upplier}\}$
	q_{Ri}	Recycled quantity
	q_{Di}	Disposed quantity; $q_{Di} = q^j_{Ci} - q_{Ri}$
	q_{Ti}	Total quantity produced; $q_{Ti} = q_{Vi} + q_{Ri}$
Cost Functions	$C_j(q^j_{Ci})$	Collection cost as a function of collected quantity; $C_j(q^j_{Ci}) := c_j \left[q^j_{Ci}\right]^2$
	$R(q_{Ri})$	Recycling cost as a function of recycled quantity; $R(q_{Ri}) := r_0 q_{Ri} - r_1 \left[q_{Ri}\right]^2$
Marginal Costs	D	Disposal cost
	V	Supplier's cost of acquiring and processing virgin material
	M	Manufacturer's cost of production using either virgin or recycled material
	E^k	Environmental externality; $k \in \{\underline{c}\text{onsumption}, \underline{d}\text{isposal}, \underline{v}\text{irgin material extraction}\}$
Fractions	τ	Mandated collection rate; $\tau \leq 1$
	ρ	Mandated recycling rate; $0 < \rho < \tau$
	γ_i	Recycling rate (decision)
	ψ	Portion of program cost shared by supplier; $\psi \in (0, 1)$
Prices	η	Transfer price charged by manufacturer for his collected material (possibly < 0)
	w_i	Wholesale price charged by supplier
	p	End product price charged by manufacturer; $p = a - bq_{Ti}$
Objectives	Π^j_i	Profit; $j \in \{\underline{I}\text{ntegrated Supply Chain}, \underline{M}\text{anufacturer}, \underline{S}\text{upplier}, \underline{T}\text{otal Supply Chain}\}$
	SW	Social Welfare

2.3 Integrated Supply Chain

We first consider the integrated supply chain to establish a baseline for comparisons. The integrated supply chain is equivalent to a vertically integrated manufacturer with full responsibility for product recovery. Several examples of vertical integration still exist. Steel mills with their own rolling or fabrication shops, consumer products companies with internal paper mills or plastics shops, and machining facilities with their own foundries are all examples of vertically integrated firms with internal suppliers providing both virgin material and recycled material.

2.3.1 Integrated Supply Chain: Recycling under No Regulation

Even in the absence of regulation, recycling may be conducted if it is economically viable. This has historically been the case with materials such as automotive scrap metal and industrial scrap copper. Under no regulation (i.e., $i = N$), we denote the recycling rate chosen by the integrated firm as γ_N and refer to it as the "business-as-usual" recycling rate. Using $q_{RN} = \gamma_N q_{TN}$, $q_{VN} = (1 - \gamma_N)q_{TN}$, and $q^I_{CN} = q_{RN}$ since the firm will only collect as much product as it chooses to recycle (i.e., $q_{DN} = 0$), the profit of the integrated supply chain in any steady-state period is:

$$\begin{aligned}\Pi^I_N &= [p - M][q_{VN} + q_{RN}] - V q_{VN} - C_I(q^I_{CN}) - R(q_{RN}) \\ &= [a - M - (1 - \gamma_N)V]q_{TN} - bq^2_{TN} - C_I(\gamma_N q_{TN}) - R(\gamma_N q_{TN})\end{aligned}$$

For convenience, we define the *program* cost under no regulation as $P^I_N(q_{TN}, \gamma_N) := C_I(\gamma_N q_{TN}) + R(\gamma_N q_{TN})$.[3] Thus, the objective of the integrated supply chain under no regulation is:

$$\max_{q_{TN} \geq 0,\ \gamma_N \geq 0} \Pi^I_N = [a - M - (1 - \gamma_N)V]q_{TN} - bq^2_{TN} - P^I_N(q_{TN}, \gamma_N) \qquad (2.1)$$

Proposition 2.1 $\Pi := [a - M - (1 - \gamma)V]q - bq^2 - P(q, \gamma)$ *is jointly concave in* q *and* γ *when* $P(q, \gamma)$ *is sufficiently convex increasing in* q *and* γ.

Proof: The first and second order derivatives of Π with respect to q and γ are:

$$\frac{\partial \Pi}{\partial q} = a - M - (1 - \gamma)V - 2bq - P_q \qquad \frac{\partial^2 \Pi}{\partial q^2} = -2b - P_{qq} < 0, \text{ since } P_{qq} > 0$$
$$\frac{\partial \Pi}{\partial \gamma} = qV - P_\gamma \qquad \frac{\partial^2 \Pi}{\partial \gamma^2} = -P_{\gamma\gamma} < 0, \text{ since } P_{\gamma\gamma} > 0$$

The determinant of the Hessian matrix of Π with respect to q and γ is:

$$D_H := \begin{vmatrix} -2b - P_{qq} & V - P_{q\gamma} \\ V - P_{q\gamma} & -P_{\gamma\gamma} \end{vmatrix} = (2b + P_{qq})P_{\gamma\gamma} - (V - P_{q\gamma})^2$$

[3] Similarly, in Section 2.3.2, we define $P^I_R(q_{TR}, \gamma_R)$ as the program cost for the integrated supply chain under regulation.

$D_H > 0$ when P_{qq} and $P_{\gamma\gamma}$ are sufficiently large. □

For the remainder of the paper, we assume that program costs are sufficiently convex increasing in the total quantity (q_{Ti}) and the recycling rate (γ_i), so that steady-state profits per period for the firm in the integrated supply chain and for the manufacturer in the decentralized supply chain (Section 2.4.2), are jointly concave in the total quantity and the recycling rate.

Assumption 2.1 *Program costs are sufficiently convex increasing in the total quantity and recycling rate.*

So as to provide further structure to our problem, we specify functional forms for the total costs of collection and recycling. We specify collection and recycling costs as:

$$C_j(z) = c_j z^2; \;\; R(z) = r_0 z - r_1 z^2$$

where $c_j > 0$, $j \in \{I, M, S\}$; and $r_0 > 0$, $r_1 > 0$ are such that $R' > 0$ and $R'' < 0$. In other words, collection costs are convex increasing in the quantity collected (diseconomies of scale) whereas recycling costs are concave increasing in the quantity recycled (economies of scale). The conditions on c_j, r_0, and r_1 for ensuring joint concavity of profit (in q_{Ti} and γ_i as mentioned above) turn out to be straightforward. For example, it can be shown that for the integrated supply chain under no regulation, $c_I > r_1$ ensures the joint concavity of Π_N^I in q_{TN} and γ_N. We assume $c_j > r_1$ (i.e., that the cost of collection is sufficiently large) for the remainder of the paper. Proposition 2.2 presents the optimal recycling rate and total quantity for the integrated supply chain under no regulation.

Assumption 2.2 *Total collection and recycling costs are of the form $C_j(z) = c_j z^2$ and $R(z) = r_0 z - r_1 z^2$, where $c_j > r_1$, and $r_0 > 0$, $r_1 > 0$ are such that $R' > 0$ and $R'' < 0$.*[4]

[4] *Logically, we have $c_I \leq \min\{c_M, c_S\}$.*

Proposition 2.2 *The optimal recycling rate for the integrated supply chain under no regulation is* $\gamma_N^I := \max\left\{\frac{(V-r_0)b}{(a-M-V)(c_I-r_1)},\ 0\right\}$.

Proof: Under Assumption 2.2, it can be shown that Π_N^I in (2.1) is jointly concave in q_{TN} and γ_N. Equating the first order derivatives of Π_N^I with respect to q_{TN} and γ_N to 0 and solving simultaneously, we obtain:

$$\begin{aligned} \gamma_N^I &:= \max\left\{\frac{(V-r_0)b}{(a-M-V)(c_I-r_1)},\ 0\right\} \\ q_{TN}^I &:= \frac{a-M-V}{2b} \end{aligned} \tag{2.2}$$

□

In order to avoid trivial situations, we require that the mandated minimum recycling rate (ρ) be such that it exceeds the rate at which the firm would recycle in absence of regulation (i.e., γ_N^I). Put differently, the term $V - r_0$ captures the difference between virgin material and recycling costs. The greater this difference, the more economically attractive recycling is to the firm. From (2.2), we can see that if $V - r_0$ is sufficiently great, γ_N^I would approach 1 and regulation would become irrelevant. Therefore, we restrict our attention to the case where $V - r_0$ is bounded such that regulation affects business-as-usual.[5]

Assumption 2.3 *We assume* $V - r_0 < \frac{\rho(a-M-V)(c_I-r_1)}{b}$ *so that regulation constrains business-as-usual for the integrated supply chain.*

Corollary 2.1 *The optimal virgin material quantity, recycled quantity, and profit for*

[5] Assumption 2.4 in Section 2.4.1 specifies a similar bound on $V - r_0$ for the decentralized supply chain.

the integrated supply chain under no regulation, are:[6]

$$\begin{aligned} q_{VN}^I &:= \frac{a-M-V}{2b} - \frac{[V-r_0]^+}{2(c_I-r_1)} \\ q_{RN}^I &:= \frac{[V-r_0]^+}{2(c_I-r_1)} \\ \Pi_N^I &= \frac{(a-M-V)^2}{4b} + \frac{([V-r_0]^+)^2}{4(c_I-r_1)} \end{aligned}$$

2.3.2 Integrated Supply Chain: Recycling under Regulation

Under regulation, we denote the recycling rate chosen by the integrated firm as γ_R. Recall that ρ and τ represent the mandated minimum recycling and collection rates, respectively ($\rho < \tau$). With Assumption 2.3 above, it can be shown that it is never optimal for γ_R to exceed τ. Using $q_{RR} = \gamma_R q_{TR}$, $q_{VR} = (1-\gamma_R)q_{TR}$, and $q_{CR}^I = \tau q_{TR} = q_{RR} + q_{DR}$ so that $q_{DR} = (\tau - \gamma_R)q_{TR}$, the profit for the integrated supply chain in any steady-state period is:[7]

$$\begin{aligned} \Pi_R^I &= [p-M][q_{VR}+q_{RR}] - Vq_{VR} - C_I(q_{CR}^I) - R(q_{RR}) - Dq_{DR} \\ &= [a-M-(1-\gamma_R)V]q_{TR} - bq_{TR}^2 - C(\tau q_{TR}) - R(\gamma_R q_{TR}) - D[\tau-\gamma_R]q_{TR} \end{aligned}$$

With the functional forms in Assumption 2.2, the objective of the integrated firm under regulation is:

$$\max_{q_{TR}\geq 0,\ \gamma_R \geq \rho} \Pi_R^I = [a-M-(1-\gamma_R)V]q_{TR} - bq_{TR}^2 - P_R(q_{TR},\gamma_R) \tag{2.3}$$

where $P_R(q_{TR},\gamma_R) = c_I\tau^2 q_{TR}^2 + r_0\gamma_R q_{TR} - r_1\gamma_R^2 q_{TR}^2 + D[\tau-\gamma_R]q_{TR}$ is the program cost under regulation. Proposition 2.3 presents the optimal choice of γ_R.

Proposition 2.3 *The optimal recycling rate γ_R^I for the integrated supply chain under regulation, is:*

$$\gamma_R^I := \begin{cases} \tau & \textit{if} \;\; \Pi_R^I(q_{TR}^I(\tau),\tau) \geq \Pi_R^I(q_{TR}^I(\rho),\rho) \\ \rho & \textit{otherwise.} \end{cases}$$

[6] *Note:* $[V-r_0]^+ = \max\{V-r_0,\ 0\}$.

[7] Note here that q_{DR} is not necessarily 0 since γ_R could be less than τ.

where $q^I_{TR}(\tau) := \frac{a-M-V+\tau(V-r_0)}{2b_1(\tau)}$*;* $q^I_{TR}(\rho) := \frac{a-M-V+\rho(V-r_0)-(\tau-\rho)D}{2b_1(\rho)}$*; and* $b_1(\cdot) := b + c_M\tau^2 - r_1(\cdot)^2$.

Proof: Expanding (2.3) and taking the first and second order derivatives with respect to γ_R, we have:

$$\frac{\partial \Pi^I_R}{\partial \gamma_R} = (V - r_0 + D)q_{TR} + 2r_1\gamma_R q^2_{TR}; \qquad \frac{\partial^2 \Pi^I_R}{\partial \gamma^2_R} = 2r_1 q^2_{TR} > 0 \tag{2.4}$$

Thus, Π^I_R is convex in $\gamma_R \in [\rho, \tau]$, implying that the integrated firm's profit under regulation will be maximized at one of the extreme values, namely, ρ or τ. It can be shown that Π^I_R in (2.3) is concave in the total quantity q_{TR} if $c_I > r_1\left(\frac{\gamma_R}{\tau}\right)^2$, which is implied by Assumption 2.2 and the fact that it is not optimal for the firm to choose $\gamma_R > \tau$. Taking the first order derivative of Π^I_R with respect to q_{TR} and equating to 0, we obtain:

$$q^I_{TR}(\gamma_R) \;:=\; \frac{a - M - V + \gamma_R(V - r_0) - (\tau - \gamma_R)D}{2b_1(\gamma_R)} \tag{2.5}$$

□

Table 2.2 summarizes the optimal quantities and profits for the integrated supply chain both under no regulation (Section 2.3.1) and under regulation (Section 2.3.2). We observe that $\Pi^I_N > \Pi^I_R$, i.e., regulation decreases the profit of the integrated firm. Corollaries 2.2 and 2.3 contrast the total and virgin material quantities in the presence and absence of regulation.

Corollary 2.2 *For the integrated supply chain,* $q^I_{TR} < q^I_{TN}$ *and* $q^I_{VR} < q^I_{VN}$*.*

Proof: For $\gamma^I_R = \tau$, $q^I_{TR} < q^I_{TN}$ is true if:

$$\frac{a_2(\tau)}{2b_1(\tau)} < \frac{a_1}{2b}; \qquad \text{i.e., if } \; V - r_0 < \frac{\tau a_1(c_I - r_1)}{b}$$

which follows from Assumption 2.3 and that $\tau > \rho$. Also, since $q^I_{VR} = (1 - \gamma^I_R)q^I_{TR}$ and $q^I_{VN} = (1 - \gamma^I_N)q^I_{TN}$ where $\gamma^I_R > \gamma^I_N$, we have $q^I_{VR} < q^I_{VN}$. The proof is similar for $\gamma^I_R = \rho$. □

Table 2.2: Results for the Integrated Supply Chain

Note: $a_1 := a - M - V$; $a_2(\cdot) := a_1 + (\cdot)[V - r_0] - [\tau - (\cdot)]D$; $b_1(\cdot) := b + c_I\tau^2 - r_1(\cdot)^2$

	No Regulation ($i = N$)		**Regulation** ($i = R$)	
	$(V - r_0) < 0$	$(V - r_0) \in \left[0, \frac{\rho(a_1)(c_I - r_1)}{b}\right)$	$\Pi_R^I(q_{TR}^I(\tau), \tau) < \Pi_R^I(q_{TR}^I(\rho), \rho)$	$\Pi_R^I(q_{TR}^I(\tau), \tau) \geq \Pi_R^I(q_{TR}^I(\rho), \rho)$
γ_i^I	0	$\frac{(V-r_0)b}{a_1(c_I - r_1)}$	ρ	τ
q_{Vi}^I	$\frac{a_1}{2b}$	$\frac{a_1}{2b} - \frac{V-r_0}{2(c_I-r_1)}$	$\frac{(1-\rho)a_2(\rho)}{2b_1(\rho)}$	$\frac{(1-\tau)a_2(\tau)}{2b_1(\tau)}$
q_{Ri}^I	0	$\frac{V-r_0}{2(c_I-r_1)}$	$\frac{\rho a_2(\rho)}{2b_1(\rho)}$	$\frac{\tau a_2(\tau)}{2b_1(\tau)}$
q_{Di}^I	0	0	$\frac{(\tau-\rho)a_2(\rho)}{2b_1(\rho)}$	0
q_{Ti}^I	$\frac{a_1}{2b}$	$\frac{a_1}{2b}$	$\frac{a_2(\rho)}{2b_1(\rho)}$	$\frac{a_2(\tau)}{2b_1(\tau)}$
Π_i^I	$\frac{a_1^2}{4b}$	$\frac{a_1^2}{4b} + \frac{(V-r_0)^2}{4(c_I-r_1)}$	$\frac{[a_2(\rho)]^2}{4b_1(\rho)}$	$\frac{[a_2(\tau)]^2}{4b_1(\tau)}$

Corollary 2.3 *For the integrated supply chain under regulation, if* $V - r_0 > -D - \frac{2r_1\rho a_2(\rho)}{b_1(\rho)}$*, [i.]* $q_{TR}^I(\tau) > q_{TR}^I(\rho)$*, and [ii.]* $\exists\ \underline{\tau}_I, \overline{\tau}_I$ *such that* $q_{VR}^I(\tau) > q_{VR}^I(\rho)$ *for* $\tau \in [\underline{\tau}_I, \overline{\tau}_I]$.

Proof: From (2.5), we have:

$$\begin{aligned}\frac{\partial q_{TR}}{\partial \gamma_R} &= \frac{(V - r_0 + D)b_1(\gamma_R) + 2r_1\gamma_R[a_2(\gamma_R)]}{2[b_1(\gamma_R)]^2} \\ &> 0, \text{ if } V - r_0 > -D - \frac{2r_1\gamma_R a_2(\gamma_R)}{b_1(\gamma_R)}.\end{aligned}$$

The first part of Corollary 2.3 follows from the fact that $\rho < \tau$, $a_2(\rho) < a_2(\tau)$, and $b_1(\rho) > b_1(\tau)$. The second part follows from the fact that $q_{VR}^I(\tau) = (1 - \tau)q_{TR}^I(\tau)$, $q_{VR}^I(\rho) = (1 - \rho)q_{TR}^I(\rho)$, $\rho < \tau$, and that the quantities (as functions of the recycling rates) are well behaved. □

Note that the extensive environmental economics literature discusses alternatives that drive $\Pi_R^I(q_{TR}^I(\tau), \tau) > \Pi_R^I(q_{TR}^I(\rho), \rho)$ and, hence, $\gamma_R^I = \tau$ (also see (2.4)). Economic interventions such as higher virgin material taxes (i.e., increasing V), tipping fees (i.e., increasing D), and recycling subsidies (i.e., decreasing r_0, increasing r_1), are examples. Corollary 2.3 shows that such interventions could result in greater overall consumption as well as increased virgin material use. However, note that if τ

is large enough, it is possible that $q^I_{VR}(\tau)$ can be less than $q^I_{VR}(\rho)$ despite that fact that $q^I_{TR}(\tau) > q^I_{TR}(\rho)$.

2.4 Decentralized Supply Chain

We model the decentralized supply chain as a bilateral monopoly where the supplier (*she*) and manufacturer (*he*) are separate firms and each has a private objective to optimize. In each steady-state period under no regulation, the manufacturer purchases material from the supplier at a unit wholesale price w_N and incurs a unit manufacturing cost M; he sells each unit of end product at price p. Also, the manufacturer determines the total quantity q_{TN} that maximizes his profit while the supplier determines the (business-as-usual) recycling rate γ_N. Under regulation, the manufacturer decides the total quantity q_{TR} but must ensure both that the mandated quantity τq_{TR} is collected and that the supplier recycles at least the mandated quantity ρq_{TR}. Since he is responsible for ensuring that the collection and recycling mandates are met and since, by assumption, regulation constrains business-as-usual, the manufacturer too undertakes collection under regulation. The manufacturer charges a transfer price η (possibly < 0) to the supplier for his collected material, such that his profit is maximized subject to regulatory compliance. The supplier determines the wholesale price w_R to maximize her profit. We maintain Assumptions 2.1 and 2.2 for our analysis of the decentralized supply chain.

2.4.1 Decentralized Supply Chain: Recycling under No Regulation

Under no regulation, the manufacturer is not responsible for any collection or recycling costs. The three decision variables in this scenario are the total quantity q_{TN} (determined by the manufacturer), and wholesale price w_N and recycling rate γ_N (determined by the supplier). The setting implies a dynamic game of complete information and can be solved using backward induction (e.g., Tsay et al. 1999, Cachon

2002). The objectives for the manufacturer and supplier are:

$$\max_{q_{TN}\geq 0} \Pi_N^M = [p - w_N - M]q_{TN} \tag{2.6}$$

$$\max_{w_N\geq 0,\ \gamma_N\geq 0} \Pi_N^S = [w_N - V]q_{VN} + w_N q_{RN} - c_S q_{RN}^2 - \left[r_0 q_{RN} - r_1 q_{RN}^2\right] \tag{2.7}$$

Proposition 2.4 *The optimal recycling rate for the supplier in the decentralized supply chain under no regulation is* $\gamma_N^D := \max\left\{\frac{2(V-r_0)b}{(a-M-V)(c_S-r_1)},\ 0\right\}$.

Proof: Π_N^M in (2.6) is concave in q_{TN} and is maximized at $q_{TN}^*(w_N) = \frac{a-w_N-M}{2b}$. Substituting $q_{TN}^*(w_N)$ into (2.7) and with Assumption 2.2, it can be shown that Π_N^S is jointly concave in w_N and γ_N. Equating the first-order derivatives of Π_N^S with respect to w_N and γ_N to 0 and solving simultaneously, we obtain:

$$\gamma_N^D := \max\left\{\frac{2b[V-r_0]}{[a-M-V][c_S-r_1]},\ 0\right\} \tag{2.8}$$

$$w_N^D := \frac{a-M+V}{2}$$

□

Similar to Assumption 2.3, we assume that the parameters of the model are such that regulation constrains business-as-usual for the decentralized supply chain as well.

Assumption 2.4 *We assume* $V - r_0 < \frac{\rho(a-M-V)(c_S-r_1)}{2b}$ *so that regulation constrains business-as-usual for the decentralized supply chain.*

Corollary 2.4 *The optimal quantities and profits for the decentralized supply chain* *under no regulation, are:*

$$\begin{aligned}
q_{VN}^{D} &:= \frac{a-M-V}{4b} - \frac{[V-r_0]^+}{2(c_S-r_1)} \\
q_{RN}^{D} &:= \frac{[V-r_0]^+}{2(c_S-r_1)} \\
q_{TN}^{D} &:= \frac{a-M-V}{4b} \\
\Pi_N^M &= \frac{(a-M-V)^2}{16b} \\
\Pi_N^S &= \frac{(a-M-V)^2}{8b} + \frac{([V-r_0]^+)^2}{4(c_S-r_1)} \\
\Pi_N^D &:= \Pi_N^M + \Pi_N^S \\
&= \frac{3(a-M-V)^2}{16b} + \frac{([V-r_0]^+)^2}{4(c_S-r_1)}
\end{aligned}$$

Comparing the results for the decentralized supply chain in Corollary 2.4 to those for the integrated supply chain in Table 2.2, we can see that $q_{TN}^D = \frac{1}{2}\left(q_{TN}^I\right)$ and $\Pi_{TN}^D < \Pi_{TN}^I$ due to double marginalization. Corollary 2.5 compares the virgin material quantities in the decentralized and integrated supply chains under no regulation.

Corollary 2.5 *For* $c_S \lesseqgtr c_I + \Delta_S$, *where* $\Delta_S = \frac{a-M-V}{2b(V-r_0)}(c_I - r_1)(c_S - r_1)$, $q_{VN}^D \lesseqgtr q_{VN}^I$.

Thus, under no regulation, although the total quantity for the decentralized supply chain is lower than that for the integrated supply chain, the virgin material quantity could be greater for the decentralized supply chain if the supplier's collection cost is sufficiently high.

2.4.2 Decentralized Supply Chain: Recycling under Regulation

Under regulation, the manufacturer is responsible for ensuring that both the collection mandate and the recycling mandate (which is greater than the supplier's business-as-usual recycling rate γ_N^D), are met. For tractability and to avoid trivial scenarios merely because the manufacturer is responsible for meeting the mandates, we assume that absent any incentive offered by the manufacturer for additional recycling activity, the supplier continues to recycle at rate γ_N^D. Therefore, the manufacturer must collect the quantity $q_{CR}^M = (\tau - \gamma_N^D)q_{TR}$, decide the optimal amount of this collected quantity to be recycled and offer it to the supplier at a unit transfer price η (possibly < 0), and dispose of the remainder.[8] Thus, for the decentralized supply chain under regulation, the manufacturer has three decision variables, namely, q_{TR}, $\gamma_R(\geq \rho > \gamma_N^D)$, and η. The supplier chooses wholesale price w_R.

We assume that sufficient material is available for collection in steady state so that the supplier's and manufacturer's collection costs can be written as $C_S(q_{CN}^S) = c_S[\gamma_N^D q_{TR}]^2$ and $C_M(q_{CR}^M) = c_M[(\tau - \gamma_N^D)q_{TR}]^2$, respectively.[9] The manufacturer's and supplier's objectives are:

$$\max_{q_{TR}\geq 0, \gamma_R \geq \rho, \eta} \Pi_R^M = [p - w_R - M]q_{TR} + \eta[\gamma_R - \gamma_N^D]q_{TR} - c_M[(\tau - \gamma_N^D)q_{TR}]^2 - D[\tau - \gamma_R]q_{TR} \tag{2.9}$$

$$\max_{w_R \geq 0} \Pi_R^S = w_R q_{TR} - V[1 - \gamma_R]q_{TR} - \eta[\gamma_R - \gamma_N^D]q_{TR} - c_S[\gamma_N^D q_{TR}]^2 - [r_0 \gamma_R q_{TR} - r_1 (\gamma_R q_{TR})^2] \tag{2.10}$$

Π_R^M in (2.9) is increasing in η. However, it can be shown that the supplier will accept η and undertake recycling at the rate γ_R if $\eta(q_{TR}, \gamma_R) \leq V - r_0 + (\gamma_R + \gamma_N^D) r_1 q_{TR}$.

Therefore, the manufacturer's optimal choice of η is:

$$\eta^*(q_{TR}, \gamma_R) = V - r_0 + (\gamma_R + \gamma_N^D) r_1 q_{TR} \tag{2.11}$$

Proposition 2.5 presents the optimal recycling rate for the decentralized supply chain under regulation.

Proposition 2.5 *The optimal recycling rate for the decentralized supply chain under*

[8]Alternatively, the manufacturer could subsidize the supplier's collection and/or recycling costs to ensure that the mandates are met. The main insights, however, remain unchanged.
[9]Modeling the manufacturer's collection costs (say) as $c_M[(\tau q_{TR})^2 - (\gamma_N^D q_{TR})^2]$ does not structurally alter our results.

regulation, is:

$$\gamma_R^D := \begin{cases} \tau & \text{if } \Pi_R^M(q_{TR}^D(\tau),\tau) \geq \Pi_R^M(q_{TR}^D(\rho),\rho) \\ \rho & \text{otherwise.} \end{cases}$$

where $q_{TR}^D(\tau) := \frac{a_1+\tau(V-r_0)}{4b_2(\tau)}$; $q_{TR}^D(\rho) := \frac{a_1+\rho(V-r_0)-(\tau-\rho)D}{4b_2(\rho)}$; *and* $b_2(\cdot) := b + c_M[\tau - \gamma_N^D]^2 + c_S\frac{[\gamma_N^D]^2}{2} - r_1\left[(\cdot)^2 - \frac{(\gamma_N^D)^2}{2}\right]$.

Proof: Substituting $\eta^*(q_{TR},\gamma_R)$ in (2.11) for η in (2.9), we have that Π_R^M is concave in q_{TR}. Taking the first order derivative of Π_R^M with respect to q_{TR} and equating to 0, we obtain:

$$q_{TR}^*(w_R,\gamma_R) = \frac{a - w_R - M + (\gamma_R - \gamma_N^D)(V - r_0) - (\tau - \gamma_R)D}{2\left\{b + c_M\left(\tau - \gamma_N^D\right)^2 - r_1\left[(\gamma_R)^2 - (\gamma_N^D)^2\right]\right\}} \tag{2.12}$$

The convexity of Π_R^M in $\gamma_R \in [\rho,\tau]$ implies that the manufacturer's profit under regulation will be maximized at one of the extreme values, namely, ρ or τ. Substituting γ_R^D, $q_{TR}^*(w_R,\gamma_R^D)$ and $\eta^*(q_{TR}^*,\gamma_R^D)$ into (2.10), we have that Π_R^S is concave in w_R. Equating the first order derivative of Π_R^S with respect to w_R to 0, we obtain:

$$\begin{aligned} w_R^*(q_{TR}^*,\gamma_R^D) &= V - \gamma_N^D(V - r_0) \\ &+ \frac{[a - M - V + \gamma_R^D(V - r_0) - (\tau - \gamma_R^D)D]\{b + c_M(\tau - \gamma_N^D)^2 + c_S[\gamma_N^D]^2 - r_1[\gamma_R^D]^2\}}{2b_2(\gamma_R^D)} \end{aligned} \tag{2.13}$$

Substituting w_R^* in (2.13) for w_R on the RHS of (2.12), we obtain:

$$q_{TR}^*(\gamma_R^D) \quad = \quad \frac{a_1 + \gamma_R^D(V - r_0) - \left(\tau - \gamma_R^D\right)D}{4b_2(\gamma_R^D)}$$

□

Table 2.3 summarizes the results for the decentralized supply chain both under no regulation (Section 2.4.1) and under regulation (Section 2.4.2), incorporating the relationships in Corollary 2.6.

Table 2.3: Results for the Decentralized Supply Chain

Note: $a_1 = a - M - V$; $a_2(\cdot) := a_1 + (\cdot)[V - r_0] - [\tau - (\cdot)]D$;
$b_2(\rho) = b + c_M\tau^2 - r_1\rho^2$; $b_2(\tau) = b + c_M\left[\tau - \gamma_N^D\right]^2 + c_S\frac{[\gamma_N^D]^2}{2} - r_1\left[\tau^2 - \frac{[\gamma_N^D]^2}{2}\right]$

Table 2.3A: $\gamma_N^D = 0,\ \gamma_R^D = \rho$

	No Regulation ($i = N$)	Regulation ($i = R$)
w_i^D	$V + \frac{a_1}{2}$	$V + \frac{a_2(\rho)}{2}$
η^*	N/A	$V - r_0 + \frac{r_1\rho a_2(\rho)}{4b_2(\rho)}$
q_{Vi}^D	$\frac{a_1}{4b}$	$\frac{(1-\rho)a_2(\rho)}{4b_2(\rho)}$
q_{Ri}^D	0	$\frac{\rho a_2(\rho)}{4b_2(\rho)}$
q_{Ti}^D	$\frac{a_1}{4b}$	$\frac{a_2(\rho)}{4b_2(\rho)}$
Π_i^M	$\frac{a_1^2}{16b}$	$\frac{[a_2(\rho)]^2}{16b_2(\rho)}$
Π_i^S	$\frac{a_1^2}{8b}$	$\frac{[a_2(\rho)]^2}{8b_2(\rho)}$
Π_i^D	$\frac{3a_1^2}{16b}$	$\frac{3[a_2(\rho)]^2}{16b_2(\rho)}$

Table 2.3B: $\gamma_N^D = \max\left\{\frac{2b(V-r_0)}{a_1(c_S-r_1)},\ 0\right\},\ \gamma_R^D = \tau$

	No Regulation ($i = N$)	Regulation ($i = R$)
w_i^D	$V + \frac{a_1}{2}$	$V - \gamma_N^D(V - r_0) + \frac{a_2(\tau)\left[b + c_M(\tau - \gamma_N^D)^2 + c_S(\gamma_N^D)^2 - r_1\tau^2\right]}{2b_2(\tau)}$
η^*	N/A	$V - r_0 + \frac{r_1(\tau + \gamma_N^D)a_2(\tau)}{4b_2(\tau)}$
q_{Vi}^D	$\frac{a_1}{4b} - \frac{[V-r_0]^+}{2(c_S-r_1)}$	$\frac{(1-\tau)a_2(\tau)}{4b_2(\tau)}$
q_{Ri}^D	$\frac{[V-r_0]^+}{2(c_S-r_1)}$	$\frac{\tau a_2(\tau)}{4b_2(\tau)}$
q_{Ti}^D	$\frac{a_1}{4b}$	$\frac{a_2(\tau)}{4b_2(\tau)}$
Π_i^M	$\frac{a_1^2}{16b}$	$\frac{[a_2(\tau)]^2\left[b + c_M(\tau - \gamma_N^D)^2 - r_1\left(\tau^2 - [\gamma_N^D]^2\right)\right]}{16[b_2(\tau)]^2}$
Π_i^S	$\frac{a_1^2}{8b} + \frac{([V-r_0]^+)^2}{4(c_S-r_1)}$	$\frac{[a_2(\tau)]^2}{8b_2(\tau)}$
Π_i^D	$\frac{3a_1^2}{16b} + \frac{([V-r_0]^+)^2}{4(c_S-r_1)}$	$\frac{[a_2(\tau)]^2\left[3b + 3c_M(\tau - \gamma_N^D)^2 + c_S(\gamma_N^D)^2 - r_1\left(3\tau^2 - 2[\gamma_N^D]^2\right)\right]}{16[b_2(\tau)]^2}$

Corollary 2.6 *For the decentralized supply chain,* $\gamma_N^D > 0 \Rightarrow \gamma_R^D = \tau$*, and* $\gamma_R^D = \rho \Rightarrow \gamma_N^D = 0$.

Proof: From (2.8), we have $\gamma_N^D > 0 \Leftrightarrow V - r_0 > 0$. From (2.9) and using the envelope theorem, we have $V - r_0 > 0 \Rightarrow \frac{\partial \Pi_R^M}{\partial \gamma_R} > 0$ and, hence, $\Rightarrow \Pi_R^M(q_{TR}^D(\tau), \tau) > \Pi_R^M(q_{TR}^D(\rho), \rho) \Rightarrow \gamma_R^D = \tau$. Also, $\frac{\partial \Pi_R^M}{\partial \gamma_R} < 0 \Rightarrow V - r_0 < 0$, and $V - r_0 < 0 \Leftrightarrow \gamma_N^D = 0$.□

Comparing the results for the decentralized supply chain in Table 2.3 to those for the integrated supply chain under regulation in Table 2.2, we see that $q_{TR}^D < q_{TR}^I$ and $\Pi_R^T < \Pi_R^I$, again due to double marginalization. Also, it can be shown that $\Pi_N^M > \Pi_R^M$

and $\Pi_N^S > \Pi_R^S$, i.e., regulation decreases the profits of both the manufacturer and the supplier. Similar to Corollary 2.2 for the integrated supply chain, Corollaries 2.7 and 2.8 compare the total and virgin material quantities for the decentralized supply chain under no regulation and under regulation.

Corollary 2.7 *When $V - r_0 \leq 0$ (i.e., $\gamma_N^D = 0$), $q_{TR}^D < q_{TN}^D$ and $q_{VR}^D < q_{VN}^D$, regardless of whether $\gamma_R^D = \rho$ or τ.*

Proof: Follows from the expressions in Table 2.3, noting that $b_2(\cdot) > b$. □

Corollary 2.8 *When $V - r_0 > 0$ (i.e., $\gamma_N^D = \frac{2b(V-r_0)}{a_1(c_S-r_1)}$, and $\gamma_R^D = \tau$), [i.] $\exists\ \underline{\tau}_{DT}$, $\bar{\tau}_{DT}$ such that $q_{TR}^D > q_{TN}^D$ for $\tau \in [\underline{\tau}_{DT}, \bar{\tau}_{DT}]$. [ii.] $\exists\ [\underline{\tau}_D,\ \bar{\tau}_D] \subset [\underline{\tau}_{DT}, \bar{\tau}_{DT}]$ such that $q_{VR}^D > q_{VN}^D$ for $\tau \in [\underline{\tau}_D, \bar{\tau}_D]$.*

Proof: The first part of Corollary 2.8 follows from the expressions for q_{TN}^D and q_{TR}^D in Table 2.3B. The second part follows from the fact that $q_{VN}^D = (1 - \gamma_N^D)q_{TN}^D$, $q_{VR}^D = (1 - \tau)q_{TR}^D$, $\gamma_N^D < \tau$, and that the quantities (as functions of recycling rates) are well behaved. □

Corollary 2.8[i.] shows that, analogous to the "Jevons effect" (Hentwich 2005), for a particular range of the mandated collection target, regulation could increase the total quantity produced by the decentralized supply chain since the manufacturer who faces quadratic collection costs would rather offer his collected material to the supplier for recycling (and thereafter undertake production), than incur disposal costs. The interval $[\underline{\tau}_{DT}, \bar{\tau}_{DT}]$ depends on the manufacturer's collection cost (c_M) and disposal cost (D); for sufficiently small c_M and large D, $[\underline{\tau}_{DT}, \bar{\tau}_{DT}]$ approaches $(\rho, 1]$. Corollary 2.8[ii.] shows that additionally, for a subinterval of $[\underline{\tau}_{DT}, \bar{\tau}_{DT}]$, the virgin material quantity for the decentralized supply chain under regulation could exceed that under no regulation.

Having established the results for the decentralized supply chain with the manufacturer solely responsible for meeting the collection and recycling mandates, we next examine the potential for improving supply chain performance through the sharing of responsibility for product recovery.

2.5 Sharing Responsibility in the Decentralized Supply Chain

In this section, we analyze the impact of sharing responsibility for product recovery on profits in the supply chain. We recognize that there are multiple mechanisms by which responsibility can be shared, including the *financial* sharing of one or more of the components of the program costs (i.e., collection, recycling, and disposal), and the *physical* splitting of the target collection or recycling rates between the supply chain echelons. We illustrate the impact of sharing responsibility by analyzing a scenario where the additional collection cost (i.e., beyond business-as-usual, borne by the manufacturer as per regulation) is shared between the manufacturer and supplier in the decentralized supply chain. Note that the analysis would be similar if any of the other components of the program costs or if the recovery targets are shared across the echelons. Specifically, we model a collection cost-sharing parameter ψ, where $\psi \in (0, 1)$ is the portion of the additional collection costs shared by the supplier, and $1 - \psi$ is the portion borne by the manufacturer. While we demonstrate how such sharing of responsibility can improve overall supply chain profit, the additional attractiveness of responsibility sharing lies in the perception of regulatory "fairness" as well as congruence with the spirit of EPR as discussed earlier. Since the sharing of responsibility alters the cost structure of both the manufacturer and the supplier and affects their optimal quantity decisions, we provide an assessment of the impacts of such sharing on social welfare, including environmental externalities associated with virgin material extraction, product consumption, and disposal, in Section 2.6.

2.5.1 Sharing Collection Costs under Regulation

With the sharing of collection costs as described above, the manufacturer's and supplier's objectives are:

$$\max_{q_{TR}\geq 0,\gamma_R\geq\rho,\eta} \Pi_R^M = [p - w_R - M]q_{TR} + \eta[\gamma_R - \gamma_N^D]q_{TR} - [1-\psi]c_M[(\tau - \gamma_N^D)q_{TR}]^2 - D[\tau - \gamma_R]q_{TR} \quad (2.14)$$

$$\max_{w_R\geq 0} \Pi_R^S = w_R q_{TR} - V[1-\gamma_R]q_{TR} - \eta[\gamma_R - \gamma_N^D]q_{TR} - c_S[\gamma_N^D q_{TR}]^2 - [r_0\gamma_R q_{TR} - r_1(\gamma_R q_{TR})^2] - \psi c_M[(\tau - \gamma_N^D)q_{TR}]^2 \quad (2.15)$$

We follow a similar sequence of analysis as in Section 2.4.2.[10] For exposition, we focus on the scenario where $\gamma_N^D = 0$ and $\gamma_R^D = \tau$ (see Table 2.3B), noting that the other regulatory scenarios (i.e., $\gamma_N^D = 0$, $\gamma_R^D = \rho$, and $\gamma_N^D > 0$, $\gamma_R^D = \tau$) can be analyzed similarly. Table 2.4 summarizes the optimal outcomes with and without cost-sharing. The expressions in the left-hand column are replicated from Table 2.3B, while the right hand column includes the results under cost-sharing. The impacts of program cost sharing on profits in the supply chain are provided in Observations 2.1 through 2.3.

Observation 2.1 *Under cost sharing, Π_R^M is concave decreasing in ψ.*

Proof: The first and second order derivatives of Π_R^M with respect to ψ are:

$$\frac{\partial\Pi_R^M}{\partial\psi} = -\frac{\psi c_M^2\tau^4[a_2(\tau)]^2}{4[2b_2(\tau) - \psi c_M\tau^2]^3} < 0; \qquad \frac{\partial^2\Pi_R^M}{\partial\psi^2} = -\frac{c_M^2\tau^4[a_2(\tau)]^2[b_2(\tau) + \psi c_M\tau^2]}{2[2b_2(\tau) - \psi c_M\tau^2]^4} < 0$$

□

Observation 2.2 *Under cost sharing, Π_R^S is convex increasing in ψ.*

Proof: The first and second order derivatives of Π_R^S with respect to ψ are:

$$\frac{\partial\Pi_R^S}{\partial\psi} = \frac{c_M\tau^2[a_2(\tau)]^2}{4[2b_2(\tau) - \psi c_M\tau^2]^2} > 0; \qquad \frac{\partial^2\Pi_R^S}{\partial\psi^2} = \frac{c_M^2\tau^4[a_2(\tau)]^2}{2[2b_2(\tau) - \psi c_M\tau^2]^3} > 0$$

[10] For concavity of the manufacturer's profit in (2.14) with respect to q_{TR}, we reasonably assume that $b_2(\tau) - \psi c_M\tau^2 > 0$.

Table 2.4: Comparison of Results without and with Program Cost Sharing
(Scenario: $\gamma_N^D = 0$, $\gamma_R^D = \tau$)

Note: $a_2(\tau) := a - M - V + \tau(V - r_0)$; $b_2(\tau) := b + c_M\tau^2 - r_1\tau^2$

	Without Sharing (from Table 2.3B) $\psi = 0$	With Sharing $\psi \in (0,1)$
w_R^D	$V + \frac{a_2(\tau)}{2}$	$V + \frac{a_2(\tau)b_2(\tau)}{2b_2(\tau)-\psi c_M\tau^2}$
η^*	$V - r_0 + \frac{r_1\tau a_2(\tau)}{4b_2(\tau)}$	$V - r_0 + \frac{r_1\tau a_2(\tau)}{4b_2(\tau)-2\psi c_M\tau^2}$
q_{VR}^D	$\frac{(1-\tau)a_2(\tau)}{4b_2(\tau)}$	$\frac{(1-\tau)a_2(\tau)}{4b_2(\tau)-2\psi c_M\tau^2}$
q_{RR}^D	$\frac{\tau a_2(\tau)}{4b_2(\tau)}$	$\frac{\tau a_2(\tau)}{4b_2(\tau)-2\psi c_M\tau^2}$
q_{TR}^D	$\frac{a_2(\tau)}{4b_2(\tau)}$	$\frac{a_2(\tau)}{4b_2(\tau)-2\psi c_M\tau^2}$
Π_R^M	$\frac{[a_2(\tau)]^2}{16b_2(\tau)}$	$\frac{[a_2(\tau)]^2[b_2(\tau)-\psi c_M\tau^2]}{4[2b_2(\tau)-\psi c_M\tau^2]^2}$
Π_R^S	$\frac{[a_2(\tau)]^2}{8b_2(\tau)}$	$\frac{[a_2(\tau)]^2}{8b_2(\tau)-4\psi c_M\tau^2}$
Π_R^T	$\frac{3[a_2(\tau)]^2}{16b_2(\tau)}$	$\frac{[a_2(\tau)]^2[3b_2(\tau)-2\psi c_M\tau^2]}{4[2b_2(\tau)-\psi c_M\tau^2]^2}$

□

Observation 2.3 *Under cost sharing,* $\Pi_R^T := \Pi_R^M + \Pi_R^S$ *is increasing and convex-concave in* ψ*.*

Proof: The first and second order derivatives of Π_R^T with respect to ψ are:

$$\frac{\partial \Pi_R^T}{\partial \psi} = \frac{c_M\tau^2[a_2(\tau)]^2[b_2(\tau) - \psi c_M\tau^2]}{2[2b_2(\tau) - \psi c_M\tau^2]^3} > 0$$

$$\frac{\partial^2 \Pi_R^T}{\partial \psi^2} = \frac{c_M^2\tau^4[a_2(\tau)]^2[b_2(\tau) - 2\psi c_M\tau^2]}{2[2b_2(\tau) - \psi c_M\tau^2]^4} \gtrless 0 \text{ for } b_2(\tau) \gtrless 2\psi c_M\tau^2$$

□

The above results demonstrate that the sharing of program costs can in fact improve overall profitability of the decentralized supply chain. With the sharing of program costs, the manufacturer chooses a higher total quantity and charges a higher transfer price to the supplier for his collected material. However, with a *single* coordination parameter ψ specifying the sharing of program costs, the supplier appropriates an increasing share of supply chain profit as ψ increases because of her ability to recover (through the wholesale price) any rents accruing to the manufacturer.

2.5.2 Pareto-Improving Contract Menu

The preceding discussion hints at the possibility of a multi-parameter contract involving program cost sharing that can ensure that *both* the supplier and the manufacturer would be better off under the contract. Consider a menu of contracts $\big\{\big(w_R, \psi(w_R)\big)\big\}$ where the level of sharing is a function of the contracted wholesale price (or vice-versa). The manufacturer's and supplier's profit functions are the same as in (2.14) and (2.15), respectively, with the exception that the wholesale price w_R is now contracted rather than optimized by the supplier. As in Section 2.5.1, we focus on the scenario where $\gamma_N^D = 0$ and $\gamma_R^D = \tau$. For brevity, we do not present the expressions for the optimal quantities and profits, and omit proofs of the Observations below.[11]

Observation 2.4 *For any contracted w_R, Π_R^M is convex increasing in ψ.*

Observation 2.5 *For $V < w_R < \bar{w}_R := V + \frac{[a_2(\tau)-w_R+V]\big[b_2(\tau)+2\psi c_M\tau^2\big]}{2[b_2(\tau)-\psi c_M\tau^2]}$, Π_R^S is concave in ψ and is maximized at $\tilde{\psi}(w_R) := \max\Big\{\frac{b_2(\tau)[3(w_R-V)-a_2(\tau)]}{c_M\tau^2[(w_R-V)+a_2(\tau)]},\ 0\Big\}$.*

Observation 2.6 *For $V < w_R < \bar{w}_R$, $\Pi_R^T = \Pi_R^M + \Pi_R^S$ is concave in ψ and is maximized at*
$\hat{\psi}(w_R) := \frac{[w_R-V]b_2(\tau)}{c_M\tau^2 a_2(\tau)}$.

Thus, Observations 2.4 through 2.6 show the existence of multiple Pareto-improving combinations of the wholesale price and the cost-sharing level. We also note the following:

Corollary 2.9 *$\hat{\psi}(w_R) > \tilde{\psi}(w_R)$.*

Figure 2.1 presents a numerical illustration of the above Observations. Table 2.5 includes the parameter values used for this illustration. For ψ in the range $\big(0, \tilde{\psi}(w_R)\big]$, *both* the manufacturer's and the supplier's profits are increasing in the

[11] Available from the authors.

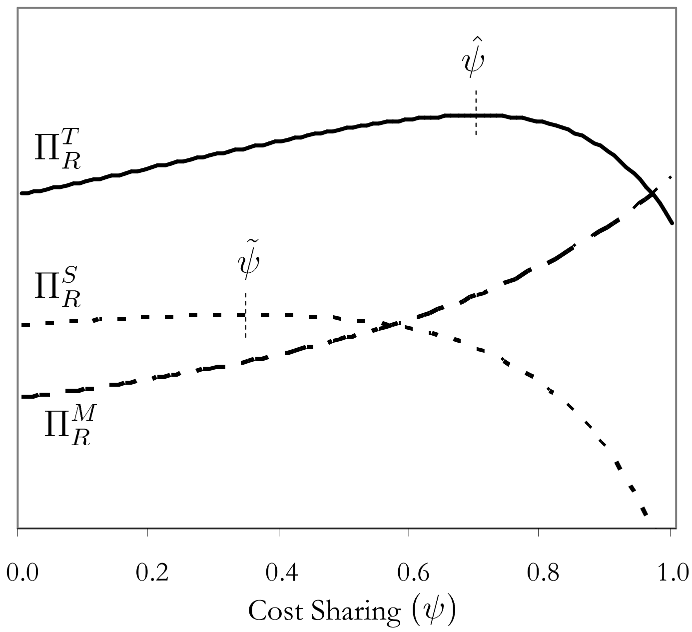

Figure 2.1: Profits under Shared Collection Cost and Contracted Wholesale Price (w_R)

(Scenario: $\gamma_N^D = 0$, $\gamma_R^D = \tau$)

level of cost sharing. Therefore, a straightforward approach is to select from the set $\{(w_R, \tilde{\psi}(w_R))\}$, since the manufacturer's profit is increasing in ψ whereas the supplier's profit is maximized at $\tilde{\psi}$. While a combination from $\{(w_R, \hat{\psi}(w_R))\}$ instead would result in an even higher total supply chain profit, a redistribution of profits would be required in order for the said combination to Pareto-dominate $\{(w_R, \tilde{\psi}(w_R))\}$.

Although program cost sharing has the benefit of improving profits in the supply chain, it also increases virgin material use and the total quantity produced. The impacts of program cost sharing on social welfare are therefore not obvious. Given that product recovery programs are motivated primarily by environmental or societal concerns, we construct a holistic measure of social welfare that incorporates the environmental externalities associated with virgin material extraction, product consumption, and disposal, in addition to supply chain profits and consumer surplus.

Table 2.5: Parameters Used in Numerical Illustrations
(Scenario: $\gamma_N^D = 0$ and $\gamma_R^D = \tau$)

Parameter	Figure 2.1 (Section 2.5.2)	Numerical Example (Section 2.6.2)
a	10	10
M	2	2
V	1	1
b	1	1
c_S	2	2
c_M	2	2
r_0	2	2
r_1	0.1	0.1
D	1	1
w_R	4.0	From Table 2.4
τ	0.75	[0,1]
λ	–	1.0
Low E^k	–	0.0
Medium E^k	–	1.5
High E^k	–	2.0

2.6 Social Welfare Impacts of Regulation and Cost Sharing

The environmental economics literature discusses the inclusion of externalities in social welfare assessments (e.g., Anderson 1992, Wierenga 2003). For our setting, social welfare is the sum of supply chain profit and consumer surplus, minus any externalities (i.e., area $stu + rsu - tuv$ in Figure 2.2a). EPR forces firms to internalize some of the externalities in the form of program costs. As shown conceptually in Figure 2.2b, adding program costs via EPR changes the optimal quantities, supply chain profit, consumer surplus, externalities and, hence, social welfare. However, even the most elaborate EPR programs cannot ensure the complete internalization of environmental externalities; externalities given by area tuv in Figure 2.2b persist. We attempt to characterize the externalities depicted by the area tuv in Figure 2.2b and propose their consideration in the measurement of social welfare.

We define the social welfare (SW) in any steady-state period as the sum of supply chain profit (Π_i^T; $i \in \{N, R\}$) and consumer surplus (CS), minus total environmental

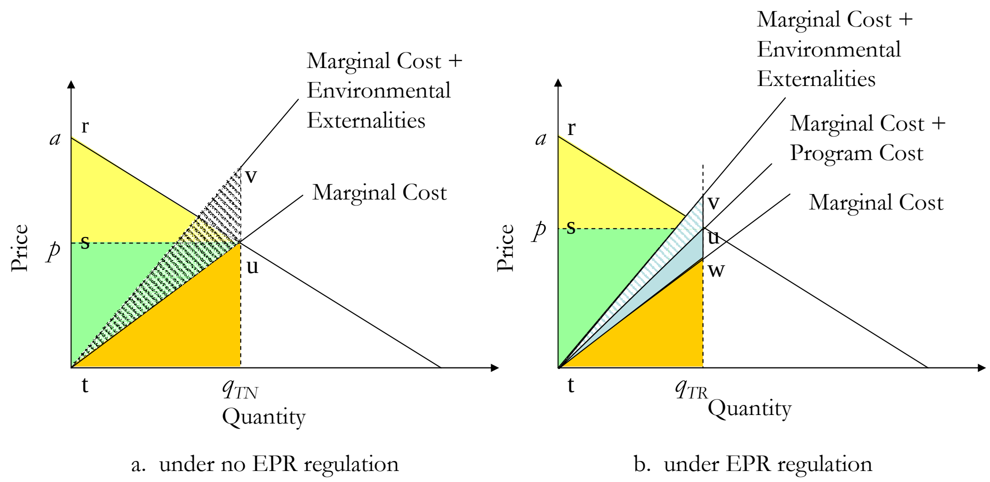

Figure 2.2: Impact of EPR on components of Social Welfare

externalities (TE_i), weighted by a factor $\lambda \geq 0$.

$$SW = \Pi_i^T + CS - \lambda TE_i;\ \lambda \geq 0 \tag{2.16}$$

The weighting factor λ may accommodate either inaccuracies in the estimation of externalities or varying emphasis on externalities due to political or economic reasons. The specific values of virgin material, total consumed (q_{Ti}), and disposed quantities, and total profit (Π_i^T) depend upon the specific case considered (i.e., either integrated or decentralized supply chain under no regulation/regulation). In all cases, consumer surplus $CS = \frac{1}{2}q_{Ti}[a-p] = \frac{1}{2}bq_{Ti}^2$. Next, we describe the *three* types of environmental externalities that constitute TE_i.

2.6.1 Environmental Externalities

The externalities relevant to our setting include those associated with: 1) virgin material extraction, 2) consumption of the product, and, 3) disposal of both collected and uncollected product.[12] The social costs of virgin material extraction include land use intensity, untreated runoff, reclamation, effects on flora and fauna, resource depletion,

[12]We assume that the costs of regulatory compliance outside of EPR are already captured in the supply chain costs V, M, $C_j(q_{Ci}^j)$, and $R(q_{Ri})$.

and acid rain (Söderholm 2006). For products collected but not recycled under an EPR program, the social costs of land use, aesthetics, leakage, and future remediation are not fully reflected in the marginal disposal cost D (Huhtula 1997, Runkel 2003). Additionally, products not collected at all do not even face the marginal disposal cost D. Finally, the consumption of products results in societal costs that can be measured through energy use, material flows, and intensity of land use (Spangenberg 2004). Although our model is analytical in nature, we recognize that the extensive literature on environmental economics attempts to measure the social costs described above through methods such as hedonic pricing, damage cost avoidance, replacement cost, and contingent choice and valuation (Wierenga 2003). In addition, industrial ecologists, through their work on life-cycle assessments (LCAs), provide measures of external costs associated with economic activity (Matthews & Lifset 2007) that can serve as a valuable resource to populate the parameters in modeling approaches such as ours.

Although the literature generally agrees that externalities are increasing in the corresponding quantities, the specific shapes of the functions are unknown (Kolstad 2000). We assume without loss of generality that the three externality types listed above have constant marginal social costs (as in Calcott & Walls 2000, Lai 2004, and Atasu et al. 2009), denoted as E^v, E^c, and E^d, respectively. The relative magnitudes of E^v, E^c, and E^d vary by product. For example, products that are natural resource-intensive, particularly those that require non-renewable resources, may exhibit large E^v but small E^c if the products are not energy-intensive to operate (e.g., petroleum-based plastic products and metal fabrications). Products with hazardous content or that otherwise require extraordinary disposal space or effort (e.g., certain electrical/electronic equipment, and mattresses) have large E^d values. Products that are energy-intensive to operate (e.g., automobiles, home appliances) have large E^c values.

Table 2.6: Marginal Environmental Externalities

Scenario	ME_i
No Regulation, $\gamma_N \geq 0$	$(1-\gamma_N)E^v + E^c + (1-\gamma_N)E^d$
Regulation, $\gamma_R = \rho$	$(1-\rho)E^v + E^c + (1-\tau)E^d + (\tau-\rho)(E^d - D)$
Regulation, $\gamma_R = \tau$	$(1-\tau)E^v + E^c + (1-\tau)E^d$

Denoting x as the fraction of total quantity q_{Ti} that is collected, and y as the fraction of total quantity that is recycled, TE_i in (2.16) can be written as:

$$TE_i = q_{Vi}E^v + q_{Ti}E^c + \left[(x-y)q_{Ti}(E^d - D) + (1-x)q_{Ti}E^d\right] \tag{2.17}$$

$x - y$ is the fraction of total quantity that is collected but not recycled, and $1 - x$ is the fraction that is not collected at all. We note that (2.17) could also be written as a weighted combination if the three externality types are to receive different levels of emphasis. Since $q_{Vi} = (1-y)q_{Ti}$, we can write TE_i as:

$$\begin{aligned} TE_i &= (1-y)q_{Ti}E^v + q_{Ti}E^c + \left[(x-y)q_{Ti}(E^d - D) + (1-x)q_{Ti}E^d\right] \\ &:= q_{Ti}ME_i \end{aligned}$$

where $ME_i := (1-y)E^v + E^c + \left[(x-y)(E^d - D) + (1-x)E^d\right]$ is the marginal environmental externality per unit of total quantity produced. Table 2.6 includes the expressions for the marginal externality (for both the integrated and the decentralized supply chains) under no regulation and under regulation. The expression for social welfare in (2.16) can therefore be rewritten as:

$$SW = \Pi_i^T + \frac{bq_{Ti}^2}{2} - \lambda q_{Ti}ME_i$$

Considering total supply chain profit (Π_i^T) as a proxy for economic activity (or performance)[13] and externalities (TE_i) as a measure of environmental impact, we

[13]Given the scope of our work, using total supply chain profit as a proxy for economic activity does not consider indirect benefits such as improved reputation, access to new markets, and better employee morale that may accompany improvements in environmental performance.

use the taxonomy in Geyer and Jackson (2004) to categorize the outcomes of EPR regulation relative to the no-regulation benchmark. In Figure 2.3, Quadrant I can be classified as a "win-win" for economic and environmental outcomes, respectively. Similarly, Quadrant II is "win-lose", Quadrant III is "lose-win", and Quadrant IV is "lose-lose". For both the integrated and decentralized supply chains, regulation decreases supply chain profit (see Sections 2.3.2 and 2.4.2). From Corollary 2.2 for the integrated supply chain, the virgin material and total quantities under regulation are always lower than the corresponding quantities under no regulation. Therefore, only Quadrant III is possible for the integrated supply chain. However, Corollaries 2.7 and 2.8 for the decentralized supply chain show that the virgin material and total quantities can in fact increase with regulation and therefore both Quadrants III and IV are possible for the decentralized supply chain. While the sharing of program costs within the decentralized supply chain increases supply chain profits (i.e., increases the likelihood of being in Quadrant III), it also increases the virgin material and total quantities (see Table 2.4) and therefore also increases the likelihood of being in Quadrant IV. Thus, the above discussion shows that it is critical for the social planner to recognize both the economic and environmental implications of EPR program design, including the possible sharing of product recovery responsibility, so as to avoid a net negative social welfare impact relative to the no-regulation benchmark. To illustrate the importance of appropriately capturing the interactions between regulatory choices and economic and environmental outcomes, we provide a numerical example below.

2.6.2 Numerical Example

Using a numerical example, we illustrate the impacts of regulation – specifically, the recycling rate under regulation γ_R and the program cost-sharing parameter ψ (Section 2.5.1) – on the economic and environmental components of social welfare for the decentralized supply chain. We select three values (low, medium, and high) of

	$TE_R < TE_N$	$TE_R > TE_N$
$\Pi^T_R > \Pi^T_N$	**I.** Improved economic performance and improved environmental performance	**II.** Improved economic performance and reduced environmental performance
$\Pi^T_R < \Pi^T_N$	**III.** Reduced economic performance and improved environmental performance	**IV.** Reduced economic performance and reduced environmental performance

Figure 2.3: Economic and Environmental Performance

marginal externalities ME_R under the regulatory scenario $\gamma_N^D = 0$ and $\gamma_R^D = \tau$. Table 2.5 includes the parameter values used in the example.

In our example, when externalities are absent or sufficiently small (Figure 2.4a), the primary impact of an increase in the recycling rate is a reduction in supply chain profit and a resulting decrease in social welfare. Note that the effect of program cost sharing is small, but increasing in τ due to the increasing program costs involved. When the marginal externality is at a moderate level (Figure 2.4b), the behavior of social welfare is markedly different; social welfare is non-monotonic in τ and the effect of program cost sharing is more pronounced. When externalities are large (Figure 2.4c), the reduction in externalities due to an increase in the recycling rate dominates the decrease in supply chain profit, resulting in increased social welfare. For large ME_R, program cost sharing (ψ) has a small but positive impact on social welfare.[14]

While the numerical example above is not intended to be exhaustive, it highlights how the social welfare outcomes of EPR programs are intricate and that care should

[14]Our numerical example considers the marginal social costs E^v, E^c, and E^d, collectively through different levels of ME_R. Clearly, separate numeric sensitivity analyses could be performed for each of these marginal costs.

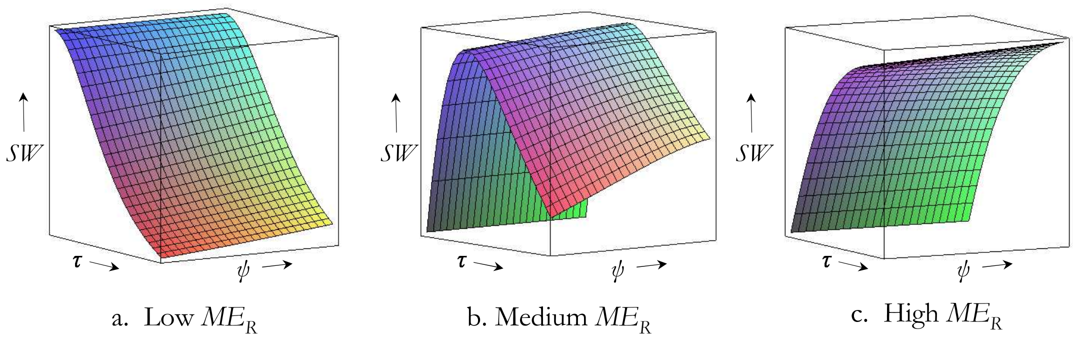

Figure 2.4: Social Welfare as a function of Recycling Rate and Level of Program Cost Sharing
(Scenario: $\gamma_N^D = 0$ and $\gamma_R^D = \tau$)

be taken in designing them in order to ensure a balance between economic and environmental performance. Such a balance is not necessarily guaranteed by sharing responsibility for product recovery due to the fact that while responsibility sharing improves supply chain profit, it also increases virgin material use and the total quantity produced. The results from an analysis such as in our work coupled with estimates of key social cost parameters enabled through the innovative approaches in the fields of environmental economics and industrial ecology (as described earlier), can provide valuable input to social planners in choosing appropriate recovery targets and levels of cost sharing.

2.7 Conclusion

This paper discusses the economic and environmental impacts of Extended Producer Responsibility (EPR) programs that mandate targets for product collection and recycling in supply chains. To address the research questions of interest, we develop and analyze steady-state models of both an integrated and a decentralized two-echelon supply chain. The context for our model is a supplier who provides raw material to a manufacturer; the manufacturer's product is recyclable and the recycled material is a substitute for virgin raw material.

We first examine the impacts of EPR program targets on optimal quantities and profits. While the imposition of regulation reduces supply chain profits for both the integrated and decentralized supply chains, the amount of virgin material used as well as the total quantity produced can increase in the decentralized supply chain with the advent of EPR regulation. A crucial yet common feature of EPR programs is the identification of a single actor (the manufacturer, in our model) within the supply chain as the *producer* who is responsible for ensuring that the mandated targets are met. We explore the important implications of instead sharing responsibility for product recovery between the actors in the supply chain. Although we demonstrate that the sharing of program costs always improves total supply chain profit, such cost sharing is also accompanied with an increase in the amount of virgin material used and the total quantity produced. Also, given the supplier's ability to appropriate the benefits of program cost sharing through the wholesale price charged to the manufacturer, we suggest a contract menu consisting of appropriate combinations of the wholesale price and the level of program cost sharing that can Pareto-improve profits in the supply chain. Recognizing that virgin material extraction, product consumption, and product disposal are associated with societal impacts not entirely internalized through EPR program costs, we construct a holistic measure of social welfare that explicitly considers the externalities of virgin material extraction, product consumption, and disposal, together with supply chain profit and consumer surplus. Using a numerical example, we motivate the importance of appropriately considering these societal impacts in the establishment of collection and recycling targets and cost sharing ratios within supply chains.

Our contribution to the extant literature in operations management that treats the interface between operational decisions and the environment lies in furthering the understanding of the economic and environmental impacts of ever-expanding EPR programs. The analytical results in our work, coupled with numeric assessments of the societal costs of externalities from the fields of environmental economics and industrial ecology, can provide rich input to firms anticipating, lobbying against, or already subject to product recovery regulation, and also to regulators who deliberate on the establishment of (or modifications to) recovery targets and responsibility allocations across supply chains. The possibility for program cost sharing to improve profits for all actors in the supply chain suggests that, rather than shying away from responsibility for program costs altogether, firms in the supply chain may find it in their interest to accept an appropriate level of sharing. From a regulatory standpoint, the Pareto-improvement of profits may suggest an amicable cost-sharing mandate; however, the accompanying societal impacts must be carefully weighed against the economic benefits.

In concluding, we reiterate that mandated sharing of product recovery responsibility, if appropriately implemented, has the potential to reduce the burden of recovery programs through improved supply chain profitability while also improving social welfare. Aside from the benefits to profitability and social welfare, there are the indirect benefits of providing a greater number of participants with a stake in the program's success, encouraging inter-firm cooperation, or strengthening industry-government relationships, that the sharing of product recovery responsibility can help foster.

CHAPTER III

AN EMPIRICAL INVESTIGATION OF ENVIRONMENTAL PERFORMANCE AND THE MARKET VALUE OF THE FIRM

3.1 Introduction

This paper analyzes the shareholder value effects of environmental performance by measuring the stock market reaction (abnormal returns) associated with announcements of environmental performance. We examine the market reaction to two categories of environmental performance. The first category is announcements that provide information about self-reported corporate efforts to avoid, mitigate, or offset the environmental impacts of the firm's products, services, or processes. We refer to such announcements as Corporate Environmental Initiatives (CEIs). We test the market reaction to the broad category of CEIs as well as its subcategories of specific announcement types. The second category is announcements that provide information about recognition granted by third parties specifically for environmental performance. We refer to such announcements as Environmental Awards and Certifications (EACs), and examine the market reactions to both the broad category of EACs as well as its specific subcategories. We also contrast the market reactions to CEIs and EACs.

The issues addressed in this paper are important for a number of reasons. First, Skapinker (2008) highlights the proactive sustainability initiatives of Unilever and Wal-Mart to frame the ongoing debate over whether such initiatives are merely window dressing. Even though Wal-Mart's energy conservation and recycling initiatives and Unilever's forays into low-cost water purification and eco-friendly detergents are well received by the popular press, the question remains as to whether the market perceives the returns on such initiatives to be as attractive as returns on alternative investment opportunities. In other words, can a firm increase shareholder value through improvements in its environmental performance? The controversy continues to receive attention in the press (for example, see Elgin 2007, Thomson 2006). Proponents claim that direct economic benefits from CEIs improve return on investment and market value. Benefits include energy, raw material, and abatement cost reductions, as well as intangible advantages of improved consumer perception, community relations, employee morale, and access to new markets. Skepticism remains, however, due to the perceived high costs of improving environmental performance, and the uncertain and longer-term payoffs from such efforts (Engardio, Capell, Carey, and Hall 2007). By examining the market reaction to environmental performance, we provide evidence for the debate on the potential for environmental initiatives to create value.

Second, academics have studied the relationship between environmental performance and financial performance, both theoretically (Walley and Whitehead 1994, Hart 1995, and Porter and van der Linde 1995) as well as empirically (Ullman 1985, Margolis and Walsh 2003). Friedman (1970) argues that any environmental expenses beyond those required for regulatory compliance are not in the best interest of shareholders and will result in degradation of firm performance and value. However, Barnett and Salomon (2006) suggest that good social performance attracts resources to the firm, including better quality employees and expanded market opportunities. Since proactive approaches to environmental performance require greater intangible skills (e.g., cross-disciplinary activity and problem solving) than do reactive approaches, related efforts create more valuable resources and can be a superior source of competitive advantage (Hart 1995, Russo and Fouts 1997). On the other hand, Walley and Whitehead (1994) propose that instances where environmental efforts can improve firm performance are rare. In analyzing the market reaction to a broad range of environmental initiatives, we shed light on whether such initiatives affect firm value.

Third, although the dominant view today is that good environmental performance translates into improved financial performance, empirical results have been inconclusive and even conflicting. These mixed results highlight the complex nature of the link between environmental and financial performance (Corbett and Klassen 2006). The empirical research methods employing secondary data can be categorized into three types: portfolio studies, regression studies, and event studies (King and Lenox 2001, Guenster, Derwall, Bauer, and Koedijk 2006). Portfolio studies determine whether the return on a portfolio of firms with good environmental performance outperforms the market. Regression analyses are used to establish long-term relationships between environmental performance and accounting-based measures of firm performance. These studies require careful matching of the firms under study with control firms to estimate any departures from "normal" financial performance during the study period. Due to the relatively long time periods over which such studies are conducted, they are sensitive to the host of other possible explanatory factors of firm performance.

On the other hand, event studies (which aim to estimate market value impacts of specific events), use environmental announcements as a proxy for environmental performance. A statistically significant market reaction to announcements of environmental performance would indicate a causal link. Event studies have been used in the literature to determine the impacts of both positive and negative environmental events, e.g., product and process-related initiatives (Gilley, Worrell, Davidson, and El-Jelly 2000), environmental awards and crises (Klassen and McLaughlin 1996), and lawsuits (Karpoff, Lott, and Wehrly 2005). The work of Klassen and McLaughlin (1996), and Gilley et al. (2000) is particularly relevant to our work. Klassen and McLaughlin (1996) document the market reaction to independent, third-party awards for environmental performance. Using a sample of 110 announcements during the period 1986-1991, they find that environmental awards are associated with a statistically significant average market reaction of 0.82%. Gilley et al. (2000) study the market reaction to environmental activities that improve processes and products. Based on a sample of 71 announcements from *The Wall Street Journal* during 1983-1996, they find that process-related announcements result in a statistically significant average market reaction of -0.45% but the market does not react significantly to product-related announcements.

Our research extends earlier work but also differs from it in several important aspects. First, our approach considers a wide variety of specific CEIs rather than just process and product-related initiatives considered by Gilley et al. (2000). Second, our study of environmental awards builds upon the work of Klassen and McLaughlin (1996) to examine whether, in the time since their study, the increased pervasiveness of and publicity surrounding environmental efforts has affected the market value of firms that receive recognition for such efforts. Third, we expand upon Klassen and McLaughlin's work by testing environmental certifications, which were new to the US market at the time of their study but are prevalent today. The impacts of Environmental Management System (EMS) certifications (such as ISO 14001) on firm performance have mainly been studied using survey data (Delmas 2001, Melnyk, Sroufe, and Calantone 2003). To the best of our knowledge, the literature has not examined the market reaction to EMS certifications. Fourth, by including both CEIs and EACs in our study, we are able to examine the difference between the market reaction to self-disclosed information and to third-party assessments of environmental performance. Finally, we study the market reaction to specific types of CEIs and EACs, many of which have not been examined in the literature.

Our results are based on an analysis of 811 announcements (430 CEI announcements and 381 EAC announcements) that appeared in the daily business press during the period 2004-2006. Although the market does not react significantly to the aggregated CEI and EAC categories, the market does react significantly to certain types of CEI and EAC announcements. Specifically, we find that announcements of: 1) philanthropic gifts for environmental causes, result in statistically significant positive market reaction; 2) pledges or realizations of voluntary emission reductions, result in statistically significant negative market reaction; and 3) attainment of ISO 14001 certification, result in statistically significant positive market reaction. The difference between the market reactions to the aggregate CEI and EAC categories is statistically insignificant. Thus, we find that the market is selective in reacting to announcements of environmental performance with certain types of announcements even valued negatively.

The next section develops our hypotheses. Section 3.3 describes the data collection effort and the sample. Section 3.4 provides a discussion of the event study methodology. Section 3.5 presents the empirical evidence and results. Section 3.6 summarizes the paper and provides directions for future research.

3.2 Hypotheses

We use the framework in Figure 3.1 to develop our hypotheses of the impact of environmental performance on financial performance. In addition to the direct effects of environmental performance on revenue gains and cost reductions, innovation can enhance these effects (Porter and van der Linde 1995). Researchers have proposed different mechanisms for environmental performance to influence revenue gains, cost reductions, and innovation. An examination of these mechanisms illustrates how CEIs can impact firm value.

Revenue growth can be achieved either through improved execution in existing markets or access to new markets. Klassen and McLaughlin (1996) propose that improvement in existing markets can be realized through the reputational benefits

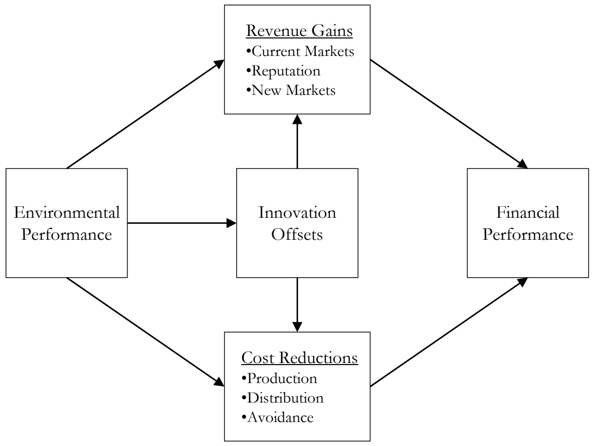

Figure 3.1: Linking Environmental Performance and Financial Performance

of positive environmental performance. They argue that demonstration of reduced environmental impacts of products and processes, and the establishment of an EMS can improve brand reputation. Dowell, Hart, and Yeung (2000) also note that the development and maintenance of stringent environmental management standards can have positive reputational effects. Corbett and Muthulingam (2007) propose that a primary reason for firms to pursue Leadership in Energy and Environmental Design (LEED) certification for building construction is to signal environmental concern to regulators, employees, and the public. Brand recognition and corporate reputation can also be enhanced through "strategic philanthropy" to support environmental causes (Seifert, Morris, and Bartkus 2003). Similarly, other environmentally conscious initiatives, such as alternative energy purchases or investments to reduce emissions below regulatory requirements, can signal a firm's concern for the environment and could have a positive impact on corporate reputation.

Access to new markets can be another important benefit of improved environmental performance. Evolving environmentally conscious markets with their increasing desire for eco-friendly products, can lead to new sales opportunities (Porter and van der Linde 1995). Examples range from high-fashion clothing produced with organic materials (Binkley 2007), to hybrid vehicles and data centers that consume less energy (Bulkeley 2007). In the public sector, US federal agencies, with $350 billion in annual purchases, are mandated to consider environmental criteria in their purchasing decisions (EPA 2008).

In addition to its effects on revenues, environmental performance can impact costs in a variety of ways. Environmental practices reduce the amount of waste, the consumption of various production inputs including energy (Rothenberg, Pil, and Maxwell 2001) and material usage (Sroufe 2003), and the number of components in products (Ashley 1993). Both inbound and outbound logistics benefit from reduced product weights and packaging (Rao and Holt 2005). Pollution prevention may not only reduce disposal and mitigation costs but also avoid the cost of installing and operating pollution control devices (Hart 1995, Hart and Ahuja 1996). Other cost avoidance benefits of effective environmental management include mitigation of risks of losses from crises or regulation (Reinhardt 1999), and preventing expenses associated with lawsuits and legal settlements (Karpoff et al. 2005). Dowell et al. (2000) note that stringent environmental standards can lower the cost to develop, maintain, and enforce policies and procedures, thus allowing easy transfer of accrued knowledge and increasing employee morale and productivity. Similarly, von Paumgartten (2003) argues that LEED-certified buildings can improve worker productivity and retention.

As depicted in Figure 1, both revenue growth and cost reductions can be enhanced by innovation spurred by demands from regulators, consumers, and other stakeholders (Porter and van der Linde 1995). Examples include technologies that improve resource productivity, and new or enhanced eco-friendly product designs. For example, 3M's Pollution Prevention Pays program has helped 3M achieve substantial savings through innovations related to waste reduction, process improvement, energy conservation, and product design. Using case studies from automotive assembly paint shops, Geffen and Rothenberg (2000) discuss how tighter regulations or competitive pressures lead to manufacturer-supplier partnerships and subsequent adoption of innovative technologies that simultaneously improve environmental performance and reduce costs. Klassen and Whybark (1999) discuss examples of investments in pollution prevention leading to innovative manufacturing processes in the furniture industry.

Given the above discussion, our first hypothesis is

Hypothesis 3.1 *The market reacts positively to CEIs.*

The CEI types that have been empirically tested in the event study literature include product and process-related initiatives (Gilley et al. 2000), participation in voluntary environmental programs such as US EPA Climate Leaders (Fisher-Vanden and Thorburn 2008), and voluntary commitments towards pollution abatement (Dasgupta, LaPlante, and Mamingi 2001). As will be discussed later, we classify CEI announcements into seven distinct subcategories. While there is some overlap between the types of CEI announcements in our sample and the types of initiatives previously examined in the literature, there are important types of initiatives that have not been empirically examined before. These include environmental philanthropy, eco-friendly products, and the use or supply of renewable energy. To provide further insight, we provide descriptive results for each CEI subcategory. *A priori*, we expect that the market will react positively to each of the seven CEI subcategories.

CEI announcements represent self-disclosed information by the firm without independent verification of the initiatives. EACs, however, are the result of third-party reviews of environmental performance. In the quality management context, the positive impact of third-party assessments on financial performance is documented by Hendricks and Singhal (1996) for awards and by Corbett, Montes-Sancho, and Kirsch (2005) for ISO 9001 certification. Klassen and McLaughlin (1996) find that announcements of environmental awards lead to a significant positive market reaction. Using surveys, Delmas (2001) finds that the degree and type of stakeholder involvement in ISO 14001 certification affects the firm's resulting competitive advantage. Also using surveys, Melnyk et al. (2003) demonstrate that both financial performance and environmental performance are associated with the level of formality of the firm's EMS, with an ISO 14001 certified EMS correlated with the best overall performance. Thus, our second hypothesis is

Hypothesis 3.2 *The market reacts positively to EACs.*

Due to the differing criteria and standards used by various certification and award granting agencies, the market reaction could be sensitive to the type of certification or award-giver (Hendricks and Singhal 1996, Klassen and McLaughlin 1996). To analyze this, we separate our EAC announcements into two certification subcategories, namely, ISO 14001 and LEED, and three award-givers subcategories, namely, federal, state or local government, and non-government award-givers. We supplement H3.2 by presenting descriptive results for each of the five EAC subcategories.

Finally, we posit that a firm's successful attainment of third-party recognition as reflected in an EAC announcement sends a stronger signal of environmental performance to the market than a CEI announcement. Prior to issuing awards or certifications, third-parties typically examine detailed company information and often conduct onsite reviews. Such objective evidence is likely to be valued more by the market. Given the greater objectivity of third-party awards and certifications, our third hypothesis is

Hypothesis 3.3 *The market reaction to EACs is greater than that for CEIs.*

3.3 Sample and Data Description

To generate our sample, we use a preliminary set of keywords to collect a small set of CEI and EAC announcements from different publications. We read these announcements to identify additional phrases and words that are commonly used in announcements of environmental initiatives, awards, and certifications. Panel A of Table 3.1 presents the keywords that we use in our search. We search the headlines

Table 3.1: Keywords and Sources used in Search for Announcements

Panel A: Keywords Used in Search for Announcements
(conservation or conservational or eco or ecosystem or ecology or ecological or environment or environmental or green or greener or greenest or greening or greened or recycle or recycles or recycling)
Near7
(accomplishment or accomplishments or admire or admiration or admirable or advantage or advantages or analysis or announcement or approve or approves or approval or approvals or award or awards or awarded or best or breakthrough or breakthroughs or celebrate or celebrates or celebration or celebrations or certification certified or consult or consultant or contribute or contributes or contribution or discovery or distinction or donate or donates or donation or donations or effort or efforts or endeavor or endeavors or endowment or example or excellent or excellence or exceptional or exemplary or gift or gifts or grant or grants or granted or great or greatest or honor or honors or honored or idea or ideas or initiative or innovate or innovates or innovation or innovations or innovative or invent or invents or invention or inventions or inventive or involvement or key or lead or leads or leader or leadership or master or mastery or message or messages or model or outstanding or patent or patents or patented or preeminent or preeminence or principle or principles or principled or prize or prizes or program or proactive or proclamation or proclamations or quality or qualities or qualify or qualified or qualification or recognize or recognizes or recognition or recognitions or reputation or research or researcher or respect or respected or reward or rewards rewarded or solution or standard or standards or star or strategy or strategies or strategic or study or success or successes or successful or super or superb or technology or technologies or top or tribute or tributes or tremendous or trust or venture or win or wins or won)

Panel B: Search Sources		
Business Wire	Houston Chronicle	The New York Times
Chicago Tribune	Los Angeles Times	The Wall Street Journal
Denver Post	New York Daily News	USA Today
Dow Jones Business News	Philadelphia Inquirer	Washington Post
Financial Times	PR Newswire (US)	

and lead paragraphs of announcements in the three major business wire services, the ten most widely circulated US daily newspapers, and the leading European business daily during the period 2004-2006. Panel B of Table 3.1 lists the sources that we use in the search. We download all announcements that meet the search criteria in these publications. We read the full text of each announcement and exclude the following types of announcement from our search results:

- Announcements that are environmental in nature but strictly pertain to governmental agencies, NGOs, trade associations, non-profit organizations, non-publicly traded firms, environmental services companies, or individuals.

- Announcements that are very minor in nature. Frooman (1997) recognizes announcements worthy of being studied as those that substantially affect the welfare of identifiable stakeholders. With that in mind, we exclude minor announcements such as sponsorships of local events.

- Duplicate announcements that appear in more than one publication. In such cases, we retain the announcement with the earliest publication date.

- Multiple announcements for the same firm within a span of five trading days. We exclude these announcements since any market reactions for the firm would be confounded among multiple events.

Our final sample consists of 811 announcements (430 CEI and 381 EAC announcements) spanning 355 unique firms. Table 3.2 provides descriptive statistics of our sample. The sample has wide variation in firm characteristics but is weighted toward larger firms. The sample includes firms from 21 unique two-digit and 57 unique three-digit NAICS codes.

Table 3.2: Descriptive Statistics for the Sample of 811 Announcements. Sample Statistics are Based on the Most Recent Fiscal Year Completed Before the Date of the Announcement.

	Market Value ($M)	Total Assets ($M)	Sales ($M)	Net Income ($M)	Employees (000s)	Debt-Equity Ratio	EPS ($)
Mean	41,407.0	77,616.9	38,435.4	2,290.4	108.6	0.356	8.42
Median	13,057.4	15,082.0	11,018.0	493.7	26.0	0.297	1.97
Std Dev	75,308.4	218,439.8	69,262.2	5,374.2	272.8	0.230	171.02
Max	439,013.3	1,884,318.0	345,977.0	39,500.0	1,900.0	2.218	4,753.00
Min	32.2	14.8	4.3	−12,613.0	0.1	0.033	−32.92

To investigate the impacts of specific CEIs, we separate our sample into the following seven subcategories based on announcement content and the CEI types identified in the literature:

- *Environmental Business Strategies*: Acquisitions of environmental-friendly capabilities, joint ventures or alliances, and new corporate environmental policies or standards.

- *Environmental Philanthropy*: Substantial gifts for environmental causes, such as natural conservation; the majority of such announcements are cash gifts although some are in kind, such as easements of land.

- *Voluntary Emission Reductions*: Pledges, investments, or achievements related to reducing emissions levels beyond those required by regulation.

- *Eco-Friendly Products*: Introductions of eco-friendly products, environmental enhancements to existing products, or the incorporation of future regulatory requirements into existing products.

- *Renewable Energy*: Supply or purchase of power from alternative energy sources.

- *Recycling*: Recycling of post-consumer waste, recycling intended to reduce raw material consumption, and recycling programs intended to benefit non-profit groups.

- *Miscellaneous*: All remaining CEI announcements, which includes decisions to join environmental groups or councils, energy conservation efforts, development of new eco-friendly technologies, and other corporate programs or initiatives outside of the aforementioned categories.

Panel A of Table 3.3 lists the sample sizes of the seven CEI subcategories. Some examples of CEI announcements include:

- "Caterpillar Sets Aggressive Greenhouse Gas Reduction Target, Goal is Part of EPA's Climate Leaders program", PR Newswire (US), 18 January 2005. Caterpillar pledged to reduce its greenhouse gas emissions by 20% from 2002 levels, by 2010.

- “Liz Claiborne Inc. Adopts prAna Natural Power Initiative”, PR Newswire (US), 3 November 2005. Liz Claiborne Inc. announced that it would purchase only wind power for its New Jersey headquarters.

- “Abitibi-Consolidated Launches its largest Recycling Expansion; Paper Retriever begins collection in seven additional US markets”, PR Newswire (US), 15 November 2005. Abitibi announced expansion of its paper recycling program from 16 to 23 US cities.

Table 3.3: Sample Sizes of Announcement Subcategories

	Sample Size
Panel A: Corporate Environmental Initiatives (CEIs)	430
Environmental Business Strategies	53
Environmental Philanthropy	31
Voluntary Emission Reductions	41
Eco-Friendly Products	62
Renewable Energy	40
Recycling	64
Miscellaneous	139
Panel B: Environmental Awards and Certifications (EACs)	381
ISO 14001 Certifications	51
LEED Certifications	22
Federal Awards	100
State/Local Government Awards	65
Non-Government Awards	143

Our sample also contains 381 EAC announcements. We include RC 14001 certifications within the EAC subcategory of ISO 14001 certifications. Modeled after ISO 14001, RC 14001 is a chemical industry standard developed by Responsible Care® but with additional industry requirements. The awards mentioned in EAC announcements are specifically those given to recognize environmental performance, including pollution prevention, energy conservation, and habitat conservation. Granting agencies include both government and non-government entities. Not included are awards in which environmental performance is just one of multiple criteria for the award (e.g., awards granted to suppliers for excellence in quality, cost, delivery, and environmental performance).

Panel B of Table 3.3 presents the sample sizes for the five EAC subcategories. Examples of EAC announcements include:

- "Smithfield Achieves International 'Gold Standard' for its Environmental Management Practices", PR Newswire (US), 27 April 2005. Smithfield attained ISO 14001 certification for the EMS used at its US-based hog production and processing facilities.

- "Corning's Wilmington, N.C., Optical Fiber Manufacturing Facility To Be Recognized as an Environmental Steward", Business Wire, 2 March 2005. A Corning plant was recognized as an "Environmental Steward" by the North Carolina Department of Environment and Natural Resources for its environmental performance.

3.4 Methodology

We use event study methodology to estimate the market reaction to the announcements of environmental performance. This methodology offers a rigorous approach to estimate market returns associated with specific events, while controlling for market-wide influences on stock prices (see Brown and Warner 1980, 1985, and MacKinlay 1997 for a review of this methodology). The "adjusted" or "abnormal" returns provide an estimate of the percent change in stock price associated with an event. The underpinning of event study methodology is that, in an efficient market, the wealth impact of an event will be reflected immediately in the stock price. Thus, a measure of such impact can be obtained by observing stock prices over a relatively short interval of time.

The first step in executing an event study is determining the event period – the period over which to estimate abnormal returns. Consistent with the approach used in most event studies (e.g., Arora 2001, Hendricks and Singhal 2003, Karpoff et al. 2005), we use a two-day event period consisting of the day of the announcement and the preceding trading day. To translate calendar days into event days, we designate the announcement publication day as Day 0. If the announcement is made on either a non-trading day or after 4:00pm Eastern Time on a trading day, the subsequent trading day is treated as Day 0. All other days in the study are measured relative to Day 0. Thus, the trading day immediately preceding the announcement day is Day −1, while that immediately following the announcement day is Day 1.

Although several competing models have been proposed to estimate abnormal returns, Brown and Warner (1985) show that estimates of the magnitude and statistical significance of abnormal returns are relatively insensitive to the model used. Consistent with most event studies, we use the "market model" to estimate abnormal returns. This model posits a linear relationship between the return on a stock and the market return (i.e., the return on the market portfolio) over a given time period as:

$$R_{it} = \alpha_i + \beta_i R_{mt} + \varepsilon_{it} \qquad (3.1)$$

where R_{it} is the return of stock i on Day t, R_{mt} is the market return on Day t, α_i is the intercept of the relationship for stock i, β_i is the slope of the relationship for stock i with respect to the market return, and ε_{it} is the error term for stock i on Day t. The term $\beta_i R_{mt}$ is the portion of stock i's return attributable to market movements. The error term ε_{it} is the portion of the return that cannot be explained by market movements and therefore captures the effect of firm-specific information. To compute the expected return for each sample firm, we estimate $\hat{\alpha}_i$, $\hat{\beta}_i$, and $\hat{S}^2_{\varepsilon_i}$ (the variance of the error term ε_{it}) using ordinary least squares regression (see equation (3.1)) over the estimation period of 200 trading days. We begin the estimation period from Day −210 and end it on Day −11. We end the estimation period two weeks (10 trading days) prior to the event day in order to shield the estimates from the effects of the announcement and to ensure that any non-stationarities in the estimates are not an issue. In estimating the parameters we require that a firm must have a minimum of 40 stock returns during the estimation period of 200 trading days.

The abnormal return A_{it} for firm i on Day t is computed as the difference between the actual return of firm i and its expected return:

$$A_{it} = R_{it} - (\hat{\alpha}_i + \hat{\beta}_i R_{mt})$$

The mean abnormal return for Day t is given by:

$$\bar{A}_t = \sum_{i=1}^{N} \frac{A_{it}}{N} \tag{3.2}$$

where N is the number of announcements in the sample. To test the statistical significance of the mean abnormal return in equation (3.2), each abnormal return A_{it} is divided by its estimated standard deviation $\hat{S}_{\varepsilon_i}$ to yield a standardized abnormal return. Since the abnormal returns are assumed to be independent across firms, with mean 0 and variance $\hat{S}^2_{\varepsilon_i}$, we know from the central limit theorem that the sum of the N standardized abnormal returns is approximately normal with mean 0 and variance N. Thus, the test statistic TS_t for Day t is calculated as:

$$TS_t = \sum_{i=1}^{N} \frac{A_{it}/\hat{S}_{\varepsilon_i}}{\sqrt{N}}$$

We use a t-test to determine the statistical significance of the mean abnormal return. The cumulative abnormal return (CAR) for a given time period $[t_1, t_2]$ is:

$$\mathrm{CAR}[t_1, t_2] = \sum_{t=t_1}^{t_2} \bar{A}_t$$

The test statistic TS_e for a period spanning multiple days is derived in a manner similar to that for a single day.

$$TS_e = \sum_{i=1}^{N} \frac{(\sum_{t=t_1}^{t_2} A_{it})/\sqrt{\sum_{t=t_1}^{t_2} \hat{S}^2_{\varepsilon_i}}}{\sqrt{N}}$$

To check for the influence of outliers, we supplement the t-tests with two non-parametric tests. We test for the statistical significance of the median abnormal return using the Wilcoxon signed-rank test. We use the generalized sign test to determine if the percent positive abnormal returns during the event period is significantly higher than that during the estimation period. For example, a sample of 50 announcements will have 10,000 abnormal returns during a 200-day estimation period. If 5,100 of these returns are positive, 51.0% positive abnormal returns is established as the null. The percent positive of the 50 abnormal returns during the event period are then compared to the null and a Z-statistic is generated using the normal approximation to the binomial distribution. Note that for all three tests, we report one-tailed p-values since we hypothesize that abnormal returns are positive. We look for consistencies among the three tests to ensure the robustness of our results.

3.5 Results

3.5.1 CEI Announcements

For the full sample of 430 CEI announcements, Panel A of Table 3.4 presents the market reaction for the day preceding the announcement (Day −1), the day of the announcement (Day 0), and the two-day event period (Days −1 and 0). The mean abnormal returns for Days −1, 0, and the two-day event period are all positive (0.03%, 0.09%, and 0.12%, respectively) with the returns for Day 0 and the two-day event period significantly different from zero at the 10% level. The median abnormal return for the two-day event period is 0.03%, but is statistically insignificant (Wilcoxon Signed-Rank Z-statistic is 0.60). Our results also indicate that 51.2% of the abnormal returns for the two-day event period are positive, insignificantly different than the percent positive abnormal returns during the estimation period (Generalized Sign Z-statistic is 1.24). Results for the five-day period preceding the announcements do not indicate statistically significant market reaction either. Thus, the results indicate that the market does not react significantly to the entire category of CEI announcements.

Table 3.4: Event Period Abnormal Returns for the 430 Corporate Environmental Initiative (CEI) Announcements

Panel A: Corporate Environmental Initiatives (CEIs)	Day −1	Day 0	Days −1 and 0
Mean Abnormal Return	0.03%	0.09%	0.12%
t-Statistic	0.44	1.54*	1.40*
Median Abnormal Return	−0.02%	−0.04%	0.03%
Wilcoxon Signed-Rank Z-Statistic	0.67	0.17	0.60
% Abnormal Returns Positive	49.8%	48.4%	51.2%
Generalized Sign Test Z-Statistic	0.66	0.08	1.24

Panel B: CEI Subcategory Results for Event Period (Days −1 and 0)

Subcategory	N	Mean Abnormal Return	t Statistic	Median Abnormal Return	Wilcoxon Signed-Rank Z	% Positive	Generalized Sign Z
Environmental Business Strategies	53	0.72%	2.92***	−0.01%	0.38	49.1%	0.15
Environmental Philanthropy	31	0.45%	1.38*	0.43%	1.57*	64.5%	1.88**
Voluntary Emission Reductions	41	−0.90%	−2.86***	−0.70%	−2.32**	31.7%	−2.13**
Eco-Friendly Products	62	0.05%	0.28	0.05%	0.68	51.6%	0.44
Renewable Energy	40	0.20%	0.79	0.16%	0.93	57.5%	1.25
Recycling	64	0.32%	1.06	0.05%	0.32	51.6%	0.54
Miscellaneous	139	0.05%	0.24	0.07%	0.17	52.5%	1.03

All tests are one-tailed: $^{*}p \leq 0.10$; $^{**}p \leq 0.05$; $^{***}p \leq 0.01$

The lack of market reaction to CEI announcements is intriguing. It is plausible that the market might partially anticipate announcements, based on certain characteristics of the announcing firms. To explore this further, we examine three factors that could cause the market to partially anticipate environmental announcements by a firm, namely, the size of the firm, the frequency of environmental announcements for the firm, and the environmental reputation of the firm.

Firm size has been found to be influential in several event studies (e.g., Hendricks and Singhal 2003, Girotra, Terwiesch, and Ulrich 2007). Typically, smaller firms have stronger market reactions than larger firms due to the greater relative impact of any one event to the firm's revenues or costs. Also, since smaller firms tend to be less closely followed by analysts, their announcements may have more of a surprise element when compared to announcements by larger firms. Thus, environmental announcements would likely result in stronger market reactions for smaller firms. To test for the effect of firm size, we divide our sample into quartiles by total assets. We then compare the market reactions for firms in the lowest quartile (total assets less than $2 billion; median total assets are $647 million) with those for firms in the highest quartile (total assets greater than $30 billion; median total assets are $60.8 billion).

Additionally, it is reasonable to assume that the "new information" content in an announcement for a firm with relatively infrequent environmental performance announcements would generally be greater than that for a firm with more frequent environmental performance announcements. Thus, we expect that firms with a lower announcement frequency would have stronger market reactions to their announcements than firms with a higher frequency. We measure announcement frequency as the number of announcements per firm during our three-year study period. We test for the effect of announcement frequency by comparing the market reactions associated with announcements for firms that have an average of less than or equal to one announcement per year to those for firms with an average of more than one announcement per year.

Market reaction could also depend upon the firm's environmental reputation. The announcement of an environmental initiative by a firm not known to be a strong environmental performer will be more of a surprise to the market than that by a firm with a superior environmental reputation. We capture a firm's environmental reputation as the indicator of whether the firm was included in the Dow Jones World Sustainability Index (DJSI World) at the time of the announcement. Launched in 1999, the DJSI World uses weights for economic, environmental, and social criteria to annually determine the top performers among the world's 3,000 largest publicly traded firms (Dow Jones 2008). To test for the effect of environmental reputation, we compare the market reactions for the two announcement groups corresponding to firms either listed or not listed in the DJSI World as of the announcement day.

For each of the above three factors, we test for differences in means and medians between the respective announcement groups using t-tests and Mann-Whitney Z-tests. In each case, the differences are in the theorized directions but insignificant. For example, small firms have a mean (median) abnormal return of 0.04% (0.09%) compared to 0.00% (−0.01%) for large firms. The mean (median) difference in abnormal returns is 0.04% (0.10%) but is insignificantly different from zero. The results suggest that the market does not react significantly to CEI announcements as an entire category, despite controlling for firm size, announcement frequency, and environmental reputation.

However, it is plausible that the market reaction could differ by CEI subcategory. The market might react positively, negatively, or not at all to some subcategories. By aggregating CEI announcements of different types, the average reaction could well be insignificantly different from zero. We therefore provide descriptive results for each of the seven CEI subcategories. Panel B of Table 3.4 presents these results for the two-day event period (Days −1 and 0).

In the subcategory of environmental business strategies, the mean abnormal return during the two-day event period is 0.72%, significant at the 1% level. However, the median return of −0.01% is insignificantly different from zero. Only 49.1% of the abnormal returns are positive, which is insignificantly higher than the percent positive abnormal returns during the estimation period. Thus, the evidence suggests that the market does not react to announcements in the environmental business strategies subcategory.

The mean (median) abnormal return for environmental philanthropy is 0.45% (0.43%), statistically significant at the 10% (10%) level. In addition, 64.5% of the abnormal returns are positive, which is significantly higher (at the 5% level) than the percent positive abnormal returns during the estimation period. This could be because such philanthropic actions generate customer goodwill and enhance corporate reputation, thus contributing to future profitability growth. Our results are supported by Wang, Choi, and Li (2008), who document that financial performance is increasing in low-to-moderate levels of philanthropy.

Perhaps our most surprising result is for announcements of voluntary emission reductions. The mean (median) abnormal return is −0.90% (−0.70%), statistically significant at the 1% (5%) level. The 31.7% positive returns are also significantly lower (at the 5% level) than the percent positive during the estimation period. Thus, announcements of voluntary emission reductions are viewed negatively by the market. This finding has some support in the literature. In addition to the theoretical arguments of Friedman (1970) discussed earlier, Hart and Ahuja (1996) suggest that while initial emission reductions may also improve financial performance, subsequent reductions are more likely to result from costly pollution control. Fisher-Vanden and Thorburn (2008) find that membership in the EPA Climate Leaders program yields a negative abnormal return of −0.90%; the negative abnormal returns are even stronger when specific pledges are made for GHG reductions. The Climate Leaders program is referred to in 12 of the 41 announcements in our voluntary emissions reductions subcategory; the remainder of the announcements within the subcategory relate to other air emissions or hazardous waste reductions.

The market reactions for the remaining CEI subcategories – eco-friendly products, renewable energy, recycling, and miscellaneous – are statistically insignificant.

3.5.1.1 Consideration of Multiple Inferences and Statistical Significance

Given that our analysis draws multiple inferences from the CEI announcement data, we consider whether the statistical significance of each result is reduced. The objective of adjusting the statistical significance for multiple inferences is to reduce the probability of false positives (i.e., Type I errors). Our first protection against spurious conclusions is the use of both parametric and non-parametric statistical tests – t-test, Wilcoxon signed-rank test, and generalized sign test – for each result. We look for consistency among the tests to ensure robustness.

As an alternative to consistency among multiple tests, numerous methods have been devised to directly adjust statistical significance for multiple inferences. The methods vary in both their power and their specificity. One such technique – the Sidak method – is derived from the theorem that the joint probability of independent events is the product of their individual probabilities. The adjusted p-value is determined as:

$$\hat{p} = 1 - (1 - p)^k$$

where k is the number of multiple inferences drawn from the data. In our analysis, each CEI data point is used to infer two estimates: one for the overall CEI category, and one for the specific CEI subcategory. Thus, $k = 2$. Table 3.5 presents the CEI subcategory unadjusted and adjusted p-values for which we report significant results, namely, environmental business strategies, environmental philanthropy, and voluntary emission reductions.

Table 3.5: Unadjusted (Adjusted) p-values for selected Corporate Environmental Initiative (CEI) Subcategories

Subcategory	Mean Abnormal Return	p ($\hat{p}$)	Median Abnormal Return	p ($\hat{p}$)	% Positive	p ($\hat{p}$)
Env. Business Strategies	0.72%	0.003 (0.005)	−0.01%	0.353 (0.582)	49.1%	0.442 (0.689)
Env. Philanthropy	0.45%	0.089 (0.170)	0.43%	0.059 (0.115)	64.5%	0.030 (0.059)
Vol. Emission Reductions	−0.90%	0.003 (0.006)	−0.70%	0.011 (0.021)	31.7%	0.017 (0.033)

Adjustments to p-values are made using the Sidak Method. All tests are one-tailed.

Comparing the results in Table 3.5 with those in Table 3.4, we see that the significance levels remain unchanged for the environmental business strategies and voluntary emission reductions subcategories. However, in the environmental philanthropy subcategory, the significance level for the mean and median abnormal returns decreases from the 0.10 level to greater than 0.10, and the significance level of the % positive abnormal returns decreases from the 0.05 level to 0.10. Thus, statistical support for the environmental philanthropy subcategory is weakened.

3.5.2 EAC Announcements

Panel A of Table 3.6 presents the results for the full sample of 381 EAC announcements. The mean abnormal return for Days −1, 0, and the two-day event period are all negative (−0.09%, −0.03%, and −0.12%, respectively) but statistically insignificant. Similarly, the median abnormal returns are negative but statistically insignificant, and the percent positive abnormal returns are insignificantly different than the percent positive abnormal returns during the estimation period. Results for the five-day period preceding the announcements do not indicate significant market reaction either. Thus, the evidence suggests that the market does not react significantly to the entire category of EAC announcements.

Table 3.6: Event Period Abnormal Returns for the 381 Environmental Award and Certification (EAC) Announcements

Panel A: Environmental Awards and Certifications (EACs)	Day −1	Day 0	Days −1 and 0
Mean Abnormal Return	−0.09%	−0.03%	−0.12%
t-Statistic	−0.62	−0.76	−0.98
Median Abnormal Return	−0.03%	−0.01%	−0.10%
Wilcoxon Signed-Rank Z-Statistic	−0.08	−0.42	−0.36
% Abnormal Returns Positive	48.8%	49.6%	46.7%
Generalized Sign Test Z-Statistic	0.29	0.60	−0.53

Panel B: EAC Subcategory Results for Event Period (Days −1 and 0)

Subcategory	N	Mean Abnormal Return	t Statistic	Median Abnormal Return	Wilcoxon Signed-Rank Z	% Positive	Generalized Sign Z
ISO 14001 Certifications	51	0.33%	0.78	0.65%	2.10**	58.8%	1.64*
LEED Certifications	22	0.01%	0.58	0.34%	0.30	63.6%	1.48*
Federal Awards	100	−0.12%	−0.35	−0.09%	−0.09	45.0%	−0.57
State/Local Government Awards	65	−0.29%	−0.72	−0.04%	−1.00	47.7%	−0.14
Non-Government Awards	143	−0.22%	−1.51*	−0.18%	−1.10	40.6%	−1.85**

All tests are one-tailed: $^{*}p \leq 0.10$; $^{**}p \leq 0.05$; $^{***}p \leq 0.01$

As with CEI announcements, we determine whether firm size, announcement frequency, and environmental reputation influence the market reaction to EAC announcements. For each of the three factors, we divide our sample of EAC announcements into respective groups and test for differences in means (medians) using t-tests (Mann-Whitney Z-tests). The resulting changes in market reactions are statistically insignificant. As an example, small firms have a mean (median) abnormal return of 0.16% (0.10%) compared to the mean (median) abnormal return of 0.03% (−0.02%) for large firms. The mean (median) difference in abnormal returns is 0.13% (0.12%) but is insignificantly different from zero. The results indicate that the market does not react significantly to EAC announcements as an entire category, despite controlling for firm size, announcement frequency, and environmental reputation.

However, as with CEIs, it is plausible that the market may not perceive all subcategories of EACs to be value creating. We therefore provide descriptive results for each of the five EAC subcategories. Panel B of Table 3.6 presents the results for the two-day event period. There are several interesting results that we highlight.

First, the market reacts positively to announcements of ISO 14001 certification. The mean (median) abnormal return during the two-day event period is 0.33% (0.65%); the median abnormal return is statistically significant at the 5% level. 58.8% of the abnormal returns are positive, significantly higher (at the 10% level) than the percent positive during the estimation period. The literature offers some support for the positive impact of ISO 14001 in particular and EMSs in general on firm performance, using survey data (Delmas 2001, Melnyk et al. 2003). To our knowledge, we are the first to provide empirical evidence of the impact of ISO 14001 certification on the market value of the firm.

Second, although 63.6% of the abnormal returns for LEED certifications are positive and significantly higher (at the 10% level) than the percent positive during the estimation period, the mean (median) abnormal return is 0.01% (0.34%) and is statistically insignificant. Thus, despite the benefits of LEED certification cited in the literature (e.g., von Paumgartten 2003, Corbett and Muthulingam 2007), the market reaction is insignificant.

Third, average market reactions for awards granted by both federal and state/local governments are statistically insignificant. Our findings are different from those reported by Klassen and McLaughlin (1996). Using announcements during the period 1985-1991, they find a significant abnormal return of 0.82% for environmental awards and no significant differences across award-giver types (whether national/international or state/local). A possible explanation for our results is that the growing importance of environmental management in general is such that the market may now expect the level of performance required by awards; i.e., awards do not convey significant new information to the market. The lack of market reaction to environmental awards may also be due to the increasing frequency of such awards over time. As an example, the US EPA/DOE Energy Star Program has grown from one award in 1993 to 92 awards in 2007 (Energy Star 2008).

Interestingly, non-government awards result in a −0.22% mean abnormal return, significant at the 10% level. 40.6% of the abnormal returns are positive, significantly lower (at the 5% level) than the percent positive during the estimation period. Thus, the market actually views the winning of non-government awards negatively. This could be because the market may perceive the efforts in seeking such awards as unnecessarily expensive relative to the value they provide.

3.5.2.1 Consideration of Multiple Inferences and Statistical Significance

As with CEIs, we consider whether the statistical significance of our EAC results are reduced due to multiple inferences. Using the same procedure as with CEIs, Table 3.7 presents the EAC subcategory unadjusted and adjusted p-values for which we report significant results, namely, ISO 14001 certifications, and non-government awards.

Table 3.7: Unadjusted (Adjusted) p-values for selected Environmental Awards and Certifications (EAC) Subcategories

Subcategory	Mean Abnormal Return	p ($\hat{p}$)	Median Abnormal Return	p ($\hat{p}$)	% Positive	p ($\hat{p}$)
ISO 14001 Certifications	0.33%	0.221 (0.393)	0.65%	0.018 (0.036)	58.8%	0.050 (0.098)
Non-Government Awards	-0.22%	0.067 (0.129)	-0.18%	0.136 (0.254)	40.6%	0.032 (0.063)

Adjustments to p-values are made using the Sidak Method. All tests are one-tailed.

Comparing the results in Table 3.7 with those in Table 3.6, we see that the significance levels remain unchanged for the ISO 14001 certification subcategory. However, in the non-government awards subcategory, the significance level for median abnormal returns decreases from the 0.10 level to greater than 0.10, and the significance level of the % positive abnormal returns decreases from the 0.05 level to 0.10. Thus, statistical support for the non-government awards subcategory is weakened.

3.5.3 Self-Disclosed Information vs. Third-Party Assessments

To determine whether the market values self-disclosed information about environmental performance differently than third-party assessments, we test for the difference in the overall market reactions to CEIs and EACs. Using a one-tailed test, we find that the means (medians) are insignificantly different from each other (t-statistic is -1.44; Mann-Whitney Z-statistic is -1.14). Thus, the market does not react differently to the two categories. A possible explanation for this result is that our sample consists of relatively large firms (median total assets are $15.1 billion), and recent studies have shown that self-disclosed environmental information increasingly reflects actual environmental performance particularly for large firms (Patten 2002, Al-Tuwaijri, Christensen, and Hughes 2004).

3.6 Summary

This paper analyzes the shareholder value effects of environmental performance by measuring the market reaction associated with announcements of environmental performance. We examine the market reaction to two categories of environmental performance. The first category includes 430 announcements of Corporate Environmental Initiatives (CEIs) that provide information about self-reported corporate efforts to avoid, mitigate, or offset the environmental impacts of the firm's products, services, or processes. The second category includes 381 announcements of Environmental Awards and Certifications (EACs) that provide information about recognition granted by third parties specifically for environmental performance. Although we find that the market does not react to announcements in the aggregate categories of CEIs and EACs, we do find significant market reactions for certain announcement types. Specifically, announcements of philanthropic gifts for environmental causes result in a statistically significant mean (median) abnormal return of 0.45% (0.43%); announcements of voluntary emission reductions result in a statistically significant mean (median) abnormal return of −0.90% (−0.70%); and announcements of ISO 14001 certification result in a statistically significant median abnormal return of 0.65%. In addition, the difference between the overall market reactions to the CEI and EAC categories is statistically insignificant.

The above findings translate into a number of insights. First, the market is selective in reacting to environmental efforts. Second, when the market does react, it does not do so uniformly; certain environmental efforts are even viewed negatively by the market. Third, the market reaction to environmental awards is quite different since the time of the work by Klassen and McLaughlin (1996) that found significant and positive market reaction to environmental awards. A key implication for managers seeking to improve market value through environmental efforts is to be selective and not rush to implement the variety of environmental activities touted by various stakeholders. Additionally, since budgets for environmental efforts are typically limited, it is important that potentially value-improving efforts be identified and pursued. Furthermore, a business case behind such efforts must be rationalized and communicated.

Avenues for future research include studies of the long-term relationship between environmental and market performance. While we observe that the market's reaction to awards is quite different than that reported in the literature a decade ago, statistical evidence across time will inform managers as to the changing nature of the market's assessment of environmental efforts, and will also provide valuable input for awarding and certifying agencies to tailor commendations to specific attributes that create value. Another interesting direction is to use alternative measures of firm performance. If CEI or EAC announcements truly affect shareholder value, measures such as return on assets or return on sales would be impacted as well. A study focusing on the effects of environmental initiatives on accounting-based measures will help in further understanding the link between environmental performance and firm performance. A limitation of our study is that self-reported announcements of environmental efforts do not imply that the corresponding environmental objectives will indeed be realized. Although challenging, a treatment of the possibility of window dressing or that of ineffectiveness of demonstrated efforts, will allow for interesting additional insights into the continuing debate.

CHAPTER IV

THE EFFECT OF PRODUCT DEVELOPMENT RESTRUCTURING ON SHAREHOLDER VALUE

4.1 Introduction

Product development is a potential source of competitive advantage for many firms and continues to be a subject of research and interest by academics and practitioners (see reviews by Brown and Eisenhardt 1995, and Shane and Ulrich 2004). To improve product development effectiveness, firms have focused on improving their product development process, rationalizing their product portfolios, and realigning their organizational structure (Krishnan and Ulrich 2001). The literature has used analytical and empirical methods to study many strategies for improving product development such as component sharing, supplier integration, portfolio selection, testing sequence, and team structure. These strategies are generally applied at a product or platform level. At a firm level, many companies have restructured their product development function, which often involves reorganization, realignment, refocusing, or streamlining of the product development organization.

This paper examines the effect of product development restructuring (hereafter referred to as PDR) on shareholder value. We research two issues. First, we use the event study methodology to estimate the overall magnitude of the stock market reaction to a sample of PDR announcements made by publicly traded firms. Second, we examine how certain characteristics of the firm and the nature of the PDR influence the stock market reaction. In particular, we develop and test hypotheses that relate the stock market reaction to the announcing firm's prior financial performance, primary restructuring objective, R&D expenditures, and size.

The research presented in this paper is important for a number of reasons. First, the product development literature has presented many strategies for improving the effectiveness of product development. These include component sharing (Fisher et al. 1999, Krishnan and Gupta 2001), integration with suppliers (Clark 1989, Takeishi 2001), portfolio balance and selection (Ali et al. 1993, Chao and Kavadias 2008), organization and team structure (Zajac et al. 1991, Sosa et al. 2004), and others. The study of these strategies is typically from an analytical perspective, and evidence of their adoption, use, and impacts is often anecdotal. By empirically examining PDR, we supplement this literature by studying several aspects of product development including the types of restructuring actions taken, the objectives behind restructuring, and the effect of PDR on shareholder value.

Second, our paper adds to the literature concerned with the impacts of the product development process. Although this literature is extensive, research on how the performance of the product development process affects financial performance is relatively sparse (Brown and Eisenhardt 1995). Exceptions include Terwiesch et al. (1998), who find that product development effectiveness is an important determinant of profitability for dominant firms in the electronics industry, and Hertenstein et al. (2005) who find that firms with high design effectiveness exhibit improved financial performance. Chan et al. (1990) and Eberhart et al. (2004), among others, find that increases in R&D expenditures, a subset of product development expenses, result in improved financial performance. The negative financial impacts from a lack of product development effectiveness have been demonstrated by Girotra et al. (2007) in their study of the stock market reactions to drug failures during late-stage testing, and by Hendricks and Singhal (1997, 2008) who find that product introduction delays reduce both stock prices and return on assets (ROA). We augment this literature by examining the link between PDR and shareholder value.

Finally, we supplement the organizational restructuring literature. Bowman and

Singh (1993) categorize restructuring as three types: 1) financial restructuring; 2) portfolio restructuring; and 3) organizational restructuring. Financial restructuring involves changes in a firm's capital structure by altering levels of debt, equity, and other forms of claims. Portfolio restructuring comprises changes in a firm's configuration usually through acquisitions, divestitures, or spinoffs. Organizational restructuring involves changes in a firm's organizational structure. Such organizational changes include the formation of new units, redefinition of intra-organizational boundaries, realignment of management responsibilities, and adjustments in unit size or scope. As discussed in Bowman et al. (1999), the literature on financial restructuring and portfolio restructuring is extensive, but studies on organizational restructuring are less common and have found mixed results. They suggest that, relative to the effects of financial and portfolio restructuring, the impacts of organizational restructuring are more contingent on the circumstances that initiate the restructuring. We augment the organizational restructuring literature in three ways. First, we present empirical evidence regarding varied types of restructuring including reorganizations, changes in decision structure, establishment of new units, consolidations, layoffs, and reductions in scope. Second, we examine how the characteristics of the initiating firm and the objective of the restructuring moderate the stock market reaction. Third, we study organizational restructuring in the specific context of product development.

Our results are based on an analysis of 114 PDR announcements during the period 2001-2007. We find that PDR announcements are associated with an economically and statistically significant stock market reaction. Over a two-day period (the day of the announcement and the day before the announcement), the mean (median) stock market reaction is 1.60% (0.72%). The percentage of firms that experience a positive market reaction is 58.8%. The stock market reacts more positively to PDR by firms that financially underperform their industry group than to PDR by outperformers. The firm's primary PDR objective is not a significant determinant of the stock market reaction. However, the interaction between the firm's prior financial performance and its PDR objective is significant. PDR by financial underperformers is more positively valued if the primary objective of the PDR is to cut costs. We also find that the market reaction to PDR is positively correlated with the firm's R&D intensity, and negatively correlated with firm size.

The next section develops our hypotheses. Section 4.3 describes the sample collection. Section 4.4 presents a discussion of the event study methodology used to estimate the stock market reaction. Section 4.5 presents the results. Section 4.6 summarizes the paper.

4.2 Hypotheses

Firms undertake PDR to improve the effectiveness of their product development activity. The improved product development effectiveness from restructuring can increase revenues and reduce costs. Revenues can be increased by better producing the right products at the right time, which can lead to improved market share and higher prices. Restructuring can reduce costs by boosting the efficiency and productivity of the product development activity. Restructuring can also help to avoid the frequency of product delays and failures, which can lead to improved profitability. To illustrate some of the mechanisms by which PDR can improve shareholder value, we offer three examples of PDR that differ in their actions and objectives, and examine how those actions and objectives can lead to increased revenues or reduced costs.

In our first example, Cordis, a medical device maker and subsidiary of Johnson & Johnson, created the new post of Chief Technology Officer in 2006 to lead the company's technology development efforts. Through this restructuring, Cordis sought to *improve the decision structure*, *strengthen management support* for product development, and thereby increase the potential for development of breakthrough technologies (Kamp 2006). If successful, the results would be improved products (with the potential for increased market share and premium pricing) and, therefore, increased revenues for the firm. The organizational attributes that are targeted by the Cordis restructuring, decision structure and management support, can improve product development effectiveness (Brown and Eisenhardt 1995). Rothwell et al. (1974) find that the appointment of an executive champion is associated with successful products. Zirger and Maidique (1990), Cooper and Kleinschmidt (1994), and Swink (2000), among others, find that management support is key to product development success.

Our second PDR example is an announcement by Guilford Pharmaceuticals in 2002 that it would reduce its workforce of 280 by 20-25% in order to *reduce expenses* and *focus its resources* on its most advanced product development programs (PR Newswire 2002). Not only will the reduction in labor costs increase profitability and shareholder value, but the increase in organizational focus can also create value. By improving focus, managers can avoid the excessive complexity due to broad product mix, catering to different market segments, and the need to develop different technologies (Skinner 1974, 1996). In the case of product development, increased focus can lead to reduced proliferation in development projects, better allocation of limited resources to the remaining projects, and improved productivity of the product development process (Wheelwright and Clark 1992). The value of corporate focus has been examined in the literature. Comment and Jarrell (1995) find a significantly positive relationship between increases in corporate focus and financial performance. John and Ofek (1995), Daley et al. (1997), and Desai and Jain (1999) find that sale or spinoff of unrelated assets results in greater shareholder value creation than that of related assets.

Our final PDR example is the restructuring by Hewlett-Packard of its development laboratories in 2007. In this case, Hewlett-Packard reduced the number of projects and increased the resources on each remaining project to *ensure each project* *had adequate resources* to commercialize them and to also *shift more resources to innovative technologies* (Mullins 2007). Wheelwright and Clark (1992) advocate such strategies as a way to improve product development focus and achieve the benefits of focus discussed above. Furthermore, firms need to strike the appropriate balance of projects in product development portfolios subject to resource constraints (Shane and Ulrich 2004). If firms are too biased toward their existing markets, they may fail to recognize shifts in markets or technologies (Christensen and Bower 1996). By devoting the appropriate resources to either incremental or radical innovation, firms can optimize their product success, revenues, and profits (Chao and Kavadias 2008).

PDR can also create value by better aligning product development with corporate strategy and capabilities (Leonard-Barton 1992), fostering cross-functionality in product development (Pinto et al. 1993, Keller 2001), and improving the fit between organizational structure and product architecture (Sosa et al. 2004).

Based on the above discussion, we expect that PDR will have a positive effect on a firm's stock price. Our first hypothesis, stated in alternate form, is:

Hypothesis 4.1 *PDR announcements will have a positive stock market reaction.*

Our next hypothesis concerns how the market reaction to PDR is influenced by the firm's prior financial performance. There are at least three reasons why we expect prior financial performance influences the market reaction, namely, the relative benefits from restructuring, investor expectations, and the motivation required to successfully implement restructuring. First, the relative benefits of PDR for good and poor financial performers can be considered in light of competing hypotheses that are presented by Iqbal and Shetty (1995). The "potential benefit" hypothesis proposes that since poor performing firms have more to gain from improvement efforts than good performers, such efforts will be valued more positively by the market than those by good performers. Conversely, the "financial distress" hypothesis posits that restructuring by poor performers might be seen as further confirmation of financial difficulties and indicative of continued poor business prospects, and so leads to negative market reaction. The empirical evidence in support of these two hypotheses is mixed. For example: Iqbal and Shetty (1995) find that layoffs by financially weak firms are more positively valued than those by financially healthy firms; Khurana and Lippincott (2000) find that the market reaction to restructuring in "loss" firms is more positively valued than that in "profit" firms; and Brickley and VanDrunen (1990) find that internal reorganizations are generally valued positively even though most firms undertaking restructuring for cost/efficiency reasons experienced poor prior financial performance. On the other hand, Blackwell et al. (1990) find that the market reaction to plant closings is more negative for poor performing firms, and Worrell et al. (1991) find that layoffs in financially distressed firms are valued more negatively.

Second, since restructuring is a strategy to improve the financial performance of the firm, it is reasonable to assume that investors at least partially expect such announcements from firms with poor prior financial performance. Thus, we would expect that when PDR by a poor financial performer is announced, it will be interpreted as confirmation of investors' expectations and will be positively valued by the market. On the other hand, investors are less likely to expect PDR announcements by good financial performers. Such announcements might signal either that the firm is taking proactive efforts to improve performance, or that it is likely to face unknown future problems or poor future business prospects. Since PDR announcements by good performers are less expected by investors and the motivations behind them are more uncertain, market reaction to them can be mixed.

Third, the firm's financial performance can impact the motivation required to successfully implement restructuring. The challenges in implementing organizational changes such as restructuring are well documented in the literature (e.g., see survey by Armenakis and Bedeian 1999). Bowman and Singh (1993) argue that although restructuring is intended to enhance performance, the changes it induces can be disruptive to operations, employees, and corporate relationships, can cause loss of competencies, and might actually make the situation worse. Kotter (1995) suggests that poor business results can increase the probability of successful restructuring because the need for change is more apparent, and consequently the urgency and motivation required for successful restructuring implementations is more readily found in poor performers. Although financial distress can generate the required motivation and urgency to restructure, it also limits the resources that may be needed to restructure. From this perspective, financially healthy firms may fare better in implementing restructuring since they are more likely to have adequate implementation resources.

The above discussion indicates that although we expect prior financial performance to influence the market reaction to PDR, the direction of the reaction is unclear given the competing theories and empirical evidence. Our hypothesis is:

Hypothesis 4.2 *The market reaction to PDR is dependent on the announcing firm's prior financial performance.*

Next, we consider the influence of PDR objectives on the market reaction to PDR. PDR objectives are varied and include goals such as increasing focus, reducing time-to-market, addressing product development failures, exploiting new market opportunities, and boosting productivity. As we discussed in the development of H4.1, achieving these objectives helps to increase revenues, reduce costs, or both. We expect that the market reaction to PDR is influenced by whether the PDR objective is aimed primarily at increasing revenues or cutting costs. Ertimur et al. (2003) find that the market generally reacts more favorably to unanticipated revenue increases than it does to unanticipated cost reductions. They attribute this mainly to the more persistent nature of revenue increases versus the more transitory nature of many cost reductions; i.e., sales increases tend to be longer-lasting while cost savings are often one-time events.

Empirical evidence indicates that the market reaction to restructuring aimed at cost cutting is less than that to restructuring intended to increase revenues. For example, Brickley and VanDrunen (1990) divide their sample of internal reorganizations into "expansion" and "increase efficiency/cut costs" categories, and find that the market reacts positively to both categories but that reorganizations intended to cut costs are less positively valued. Similarly, Chan et al. (1995) find that the market reacts positively to business relocations motivated by expansions but that relocations to achieve cost savings are positively valued only if they do not indicate a reduction in capacity. Lin and Rozeff (1993) find that the stock market reacts negatively to cost cutting events (layoffs, closings, and pay cuts).

Based on the above discussion, our hypothesis is:

Hypothesis 4.3 *The market reacts more positively to PDR that is primarily intended to increase revenues than to PDR primarily intended to cut costs.*

We also examine how the market reaction to PDR is affected by the firm's R&D spending. It is reasonable to expect that firms with greater R&D expenditures are more dependent on product development and are impacted to a greater degree by PDR than firms with less R&D expenditures. Given our conjecture that the stock market reacts positively to PDR, firms more dependent on product development will experience a more positive market reaction to PDR. To normalize the R&D spending measure for firm size, we use R&D intensity (R&D expenses divided by total sales) as our indicator.

Our logic that PDR has greater effect in firms with high R&D intensity is paralleled by findings in the literature that increases in R&D spending have greater impacts in firms with already-high levels of R&D spending. For example, Chan et al. (1990) find that R&D spending increases result in more positive market reactions if the firm has higher R&D intensity than the industry average. Similarly, Eberhart et al. (2004) find that R&D spending increases result in positive market reactions and abnormal profit margins, especially for high-tech firms.

Our hypothesis regarding the firm's R&D expenditures is:

Hypothesis 4.4 *The market reacts more positively to PDR by firms with higher R&D intensity than to PDR by firms with lower R&D intensity.*

Our final hypothesis is that the firm's size will influence the market reaction to PDR. There at least three reasons for this. First, the impact of any single event on a small firm's future financial performance is proportionately greater than that for a large firm. The profitability of small firms is more closely tied to individual products under development, products that will more likely be directly impacted by any PDR announcement. Second, firm size can be a proxy for diversification; large firms tend to be more diversified than small firms. Since product development is typically organized by business segment, the impact of PDR in a more focused firm is likely more positive than that of PDR in a more diversified firm. Third, smaller firms tend to be less closely followed by analysts and investors; announcements by smaller firms have more of a surprise element when compared to announcements by larger firms. Given our hypothesis that PDR is positively valued by the market, our hypothesis on firm size is:

Hypothesis 4.5 *The market reacts more positively to PDR by small firms than to PDR by large firms.*

4.3 Sample and Data Description

To generate our sample, we identify a preliminary set of keywords to collect a small set of PDR announcements from *The Wall Street Journal*. We read these announcements to identify additional phrases and words that are commonly used in PDR announcements. Through an iterative process of testing keywords for search results, we develop the final list of keywords that we use in our search (see Table 4.1).

Table 4.1: Keywords used in Search for Announcements

(application design* or application develop* or application discover* or application innovat* or component design* or component develop* or component discover* or component innovat* or content design* or content develop* or content discover* or content innovat* or design develop* or development staff or drug design* or drug develop* or drug discover* or drug innovat* or engineering design* or engineering develop* or engineering discover* or engineering innovat* or engineering staff or labs or laboratory or laboratories or network design* or network develop* or network discover* or network innovat* or NPD or pharmaceutical design or pharmaceutical develop* or pharmaceutical discover* or pharmaceutical innovat* or process design* or process develop* or process discover* or process innovat* or product design* or product develop* or product discover* or product innovat* or PD or R&D or research* or software design* or software develop* or software discover* or software innovat* or technology design* or technology develop* or technology discover* or technology innovat* or vehicle design* or vehicle develop* or vehicle discover* or vehicle innovate*)
Near10
(acqui* or add* or align* or bolster* or boost* or build* or collaborat* or construct* or creat* or discover* or effort* or emphasi* or establish* or expan* or form* or grow* or improv* or increas* or innovat* or invest* or launch* or pact* or open* or rais* or renew* or resource* or reviv* or set* or spend* or alter* or chang* or clos* or concentrat* or contract* or consolidat* or cost* or cut* or decreas* or downsiz* or focus* or layoff* or mov* or organiz* or overhaul* or outsourc* or pare* or realign* or reduc* or refocus* or reform* or reorganiz* or restructur* or retrench* or revamp* or review* or slash* or split* or streamlin* or structur* or subcontract* or trim*)

We search the headlines and lead paragraphs of announcements in the *Dow Jones News Service* and *The Wall Street Journal* during the six-year period 2002-2007. We download announcements that meet the search criteria in these two publications. The announcements are then sorted through multiple screens to obtain a suitable sample. First, each announcement is scanned for relevance to PDR. Unavoidable byproducts of such a broad-based search are announcements that have no relevance to the desired topic (e.g., announcements about the expanding market share of the Blackberry firm Research in Motion, announcements regarding investment research policies, etc.). Second, we read the full text of each of the remaining announcements and exclude duplicate announcements that appear in more than one publication. In such cases, we retain the announcement with the earliest publication date. Third, information from the remaining announcements is graded for its focus on PDR. We retain only those announcements that are primarily concerned with restructuring of product development. Also, given that our research interests are internal restructuring, we exclude announcements of development collaborations or joint ventures with other firms.

Our final sample consists of 114 announcements. Table 4.2 presents descriptive statistics of our sample; the information in the table is based on the most recent fiscal year completed prior to the PDR announcement and is collected from the Compustat Industrial Annual database. The mean (median) observation in the sample represents a firm with \$21.8B (\$1.1B) in total assets, \$14.1B (\$574M) in sales, and 35,500 (2,600) employees. Our sample includes firms from 16 unique two-digit and 31 unique three-digit SIC codes. 46 announcements are from the pharmaceuticals industry (SIC code 283), and 15 announcements are from the software industry (SIC code 737).

Table 4.2: Descriptive Statistics for the Sample of 114 PDR Announcements; Sample Statistics are Based on the Most Recent Fiscal Year Completed Before the Date of the Announcement using data obtained from Compustat

	Market Value ($M)	Total Assets ($M)	Sales ($M)	Net Income ($M)	Employees (000s)	Debt-Equity Ratio	EPS ($)
Mean	27,219.5	21,808.5	14,080.4	232.6	35.5	0.363	−0.11
Median	1,350.4	1,072.6	573.9	−4.2	2.6	0.058	−0.02
Std Dev	55,479.7	54,609.6	31,109.5	9,940.4	66.6	1.241	1.93
Max	266,036.4	323,969.0	173,353.0	19,337.0	365.0	9.858	5.06
Min	7.5	9.8	0.0	−98,696.0	0.0	0.000	−10.01

PDR encompasses a variety of actions, including establishment of new units, merging or splitting of units, changes in decision structures, consolidations, layoffs, closures, etc. Many PDR announcements in our sample indicate multiple actions. Table 4.3 presents the distribution of restructuring actions that we find in our sample. We classify each announcement by its "primary action" (the action either mentioned first in the headline or lead paragraph or most frequently in the announcement) but we also capture other actions discussed in the announcement (labeled in Table 4.3 as "secondary action"). For the 114 announcements in our sample, nine different actions are captured as either primary or secondary content or both. The most frequent PDR

Table 4.3: Distribution of PDR Actions in the Sample of 114 PDR Announcements

PDR Action	Primary Action	Secondary Action
Layoff	28	28
Consolidate	15	4
Divest	15	2
Reduce Scope	14	15
Merge or Split Units	10	1
Establish New Units	10	0
Change Decision Structure	9	5
Close	7	1
Other	6	3
Totals	114	59

action is Layoff. Layoffs are the primary action in 28 announcements (25% of the sample) and are the secondary action in an additional 28 announcements. Consolidate and Divest are the primary actions in 15 announcements each, and Reduce Scope is featured in 14 announcements. Together, these four primary actions comprise 63.2% of our sample.

Some examples of the announcements in our sample include:

- "Boston Scientific Announces Plan to Reallocate CRM Research and Development Resources", *Dow Jones Newswires*, 8 January 2007. Boston Scientific cuts 500 to 600 jobs, mainly from its cardiac-rhythm-management R&D unit in Minnesota. By downsizing, Boston Scientific's objective is to reduce costs and focus more on a select number of development projects that better meet customer needs. The primary action in this announcement is Layoff.

- "Sony President Narrows R&D to Focus on Promising Areas", *The Wall Street Journal*, 24 June 2005. Sony Corp. halts its R&D efforts in certain sectors to concentrate its resources on those areas with the most promising commercial applications, including video equipment, mobile phones, and flat-panel televisions.

The primary action in this announcement is Reduce Scope.

- "Flextronics International Ltd: Three Indian Software Firms to be Consolidated into Unit", *The Wall Street Journal*, 13 December 2004. Flextronics combines three software development subsidiaries – Hughes Software, FutureSoft, and DeccaNet Designs – into a single entity. Flextronics' objective is to increase internal product design and engineering capabilities. The primary action in this announcement is Merge or Split Units.

- "DuPont Co.: Maxygen Plant-Sciences Unit to be Bought for $64M", *The Wall Street Journal*, 4 June 2004. Maxygen sells its wholly owned Verdia, Inc. subsidiary to DuPont. Through this divestiture, Maxygen's objective is to increase focus on its human therapeutics business. The primary action in this announcement is Divest.

4.4 Methodology

We use event study methodology to estimate the market reaction to the announcements of PDR. This methodology offers a rigorous approach to estimate "abnormal" returns associated with specific events by controlling for market-wide influences on stock prices (see Brown and Warner 1980, 1985, and MacKinlay 1997 for a review of this methodology). The abnormal returns provide an estimate of the percent change in stock price associated with an event. The underpinning of event study methodology is that, in an efficient market, the wealth impact of an event will be reflected immediately in the stock price.

The first step in executing an event study is determining the event period – the period over which to estimate abnormal returns. Consistent with the approach used in many event studies (MacKinlay 1997), we use a two-day event period consisting of the day of the announcement and the preceding trading day to include the possibility that the stock market acquired information before the actual announcement. To translate calendar days into event days, we designate the day of the announcement as Day 0. If the announcement is made on either a non-trading day or after 4:00pm Eastern Time on a trading day, the subsequent trading day is treated as Day 0. All other days in the study are measured relative to Day 0. Thus, the trading day immediately preceding the announcement day is Day −1, while that immediately following the announcement day is Day 1.

Although several competing models have been proposed to estimate abnormal returns, Brown and Warner (1985) show that estimates of the magnitude and statistical significance of abnormal returns are relatively insensitive to the model used. Consistent with most event studies, we use the "market model" to estimate abnormal returns.[1] This model posits a linear relationship between the return on a stock and the market return (i.e., the return on the market portfolio) over a given time period as:

$$R_{it} = \alpha_i + \beta_i R_{mt} + \varepsilon_{it} \tag{4.1}$$

where R_{it} is the return of stock i on Day t, R_{mt} is the market return on Day t, α_i is the intercept of the relationship for stock i, β_i is the slope of the relationship for stock i with respect to the market return, and ε_{it} is the error term for stock i on Day t. The term $\beta_i R_{mt}$ is the portion of stock i's return attributable to market movements. The error term ε_{it} is the portion of the return that cannot be explained by market movements and therefore captures the effect of firm-specific information. To compute the expected return for each sample firm, we estimate $\hat{\alpha}_i$, $\hat{\beta}_i$, and $\hat{S}^2_{\varepsilon_i}$ (the variance of the error term ε_{it}) using ordinary least squares regression (see equation (4.1)) over the estimation period of 200 trading days. We begin the estimation period from Day −210 and end it on Day −11. We end the estimation period two weeks (10 trading days) prior to the event day in order to shield the estimates from the effects of the

[1] All analyses were also conducted using the "market-adjusted model" and "mean-adjusted model"; the results were not appreciably different and are not reported here.

announcement and to ensure that any non-stationarities in the estimates are not an issue. In estimating the parameters we require that a firm must have a minimum of 40 stock returns during the estimation period of 200 trading days.

The abnormal return A_{it} for firm i on Day t is computed as the difference between the actual return of firm i and its expected return:

$$A_{it} = R_{it} - (\hat{\alpha}_i + \hat{\beta}_i R_{mt})$$

The mean abnormal return for Day t is given by:

$$\bar{A}_t = \sum_{i=1}^{N} \frac{A_{it}}{N} \tag{4.2}$$

where N is the number of announcements in the sample. To test the statistical significance of the mean abnormal return in equation (4.2), each abnormal return A_{it} is divided by its estimated standard deviation $\hat{S}_{\varepsilon_i}$ to yield a standardized abnormal return. Since the abnormal returns are assumed to be independent across firms, we know from the central limit theorem that the sum of the N standardized abnormal returns is approximately normal with mean 0 and variance N. Thus, the test statistic TS_t for Day t is calculated as:

$$TS_t = \sum_{i=1}^{N} \frac{A_{it}/\hat{S}_{\varepsilon_i}}{\sqrt{N}}$$

We use a t-test to determine the statistical significance of the mean abnormal return. The cumulative abnormal return (CAR) for a given time period $[t_1, t_2]$ is:

$$\text{CAR}[t_1, t_2] = \sum_{t=t_1}^{t_2} \bar{A}_t$$

The test statistic TS_e for a period spanning multiple days is derived in a manner similar to that for a single day.

$$TS_e = \sum_{i=1}^{N} \frac{(\sum_{t=t_1}^{t_2} A_{it})/\sqrt{\sum_{t=t_1}^{t_2} \hat{S}_{\varepsilon_i}^2}}{\sqrt{N}}$$

To check for the influence of outliers, we supplement the t-tests with two nonparametric tests. We test for the statistical significance of the median abnormal return using the Wilcoxon signed-rank test. We use the binomial sign test to determine if the percent positive of the abnormal returns during the event period is significantly higher than the null of 50%. The percent of positive abnormal returns during the event period is compared to the null and a Z-statistic is generated using the normal approximation to the binomial distribution. Unless otherwise noted, we report one-tailed p-values for all three tests since we hypothesize that abnormal returns for PDR are positive. We look for consistencies among the three tests to ensure the robustness of our results.

4.5 Results

For the full sample of 114 PDR announcements, Panel A of Table 4.4 presents the market reaction for the day preceding the announcement (Day -1), the day of the announcement (Day 0), and the two-day event period (Days -1 and 0). The mean abnormal returns for Days -1, 0, and the two-day event period are all positive (0.73%, 0.87%, and 1.60%, respectively) and significantly different from zero at the 1% level. The median abnormal returns for Days -1, 0, and the two-day event period are also positive (0.57%, 0.01%, and 0.72%, respectively) with the returns for Day -1 and the two-day event period significantly different from zero at the 5% level. Similarly, the percent positive abnormal returns for Days -1, 0, and the two-day event period are 60.53%, 50.88%, and 58.77%, respectively, but only the percent positive returns for Day -1 and the two-day event period are significantly different from 50% at the 5% level. To test if our results are driven by outliers, we trim our data at 2.5% in each tail. Panel B of Table 4.4 presents the results using the trimmed sample. These results are consistent with those for the full sample. Overall, the results indicate that the stock market reacts positively to PDR. Given the consistency of results for both the full and trimmed samples, we report results using only the full sample for our remaining analyses (except where noted). [2]

Table 4.4: Event Period Abnormal Returns for the PDR Announcements

Panel A: Full Sample (N = 114)			
	Day −1	Day 0	Days −1 and 0
Mean Abnormal Return	0.73%	0.87%	1.60%
t-Statistic	2.94***	3.19***	4.33***
Median Abnormal Return	0.57%	0.01%	0.72%
Wilcoxon Signed-Rank Z-Statistic	1.92**	0.20	1.85**
% Abnormal Returns Positive	60.53%	50.88%	58.77%
Binomial Sign Test Z-Statistic	2.25**	0.19	1.87**

Panel B: Trimmed Sample (N = 109)			
	Day −1	Day 0	Days −1 and 0
Mean Abnormal Return	0.56%	0.31%	0.87%
t-Statistic	2.81***	1.69**	3.18***
Median Abnormal Return	0.58%	0.01%	0.71%
Wilcoxon Signed-Rank Z-Statistic	2.15**	0.04	1.80**
% Abnormal Returns Positive	61.47%	50.46%	58.72%
Binomial Sign Test Z-Statistic	2.39**	0.10	1.82**

All tests are one-tailed: $^{*}p \leq 0.10$; $^{**}p \leq 0.05$; $^{***}p \leq 0.01$

To put our results in perspective with previous findings in the literature, we consider the study of internal reorganizations by Brickley and VanDrunen (1990). They find an overall two-day abnormal return of 0.32% due to internal reorganizations, compared to our finding of 1.60%. They attribute the small magnitude of their result to the fact that the reorganizations they consider are limited to the unit- rather than the firm-level, and so have a reduced impact on firm performance. In comparison, our finding is for a functional area, product development, rather than a unit or subsidiary. Other studies in the literature tend to focus on only one specific restructuring action and generally find negative market reactions. For example, Blackwell et al. (1990) find a −0.55% market reaction to plant closings, and Worrell et al. (1991) find a −0.41% market reaction to layoffs.

[2] The results using the trimmed sample with 109 observations are not substantively different from those obtained using the full sample.

To investigate the effect of the firm's prior financial performance on the market reaction to PDR, we compute the firm's prior financial performance as its return on equity (ROE) relative to the average of its industry medians in Year −1 and Year −2 prior to the PDR announcement, where the firm's industry is defined as firms with the same three-digit SIC code as the sample firm. We measure ROE as:

$$ROE = (Net\ Income - Preferred\ Dividends)/Common\ Equity$$

We consider "outperformers" ("underperformers") as those firms whose average ROE in Years −1 and −2 is higher (lower) than the average of their industry group. We exclude seven firms that had negative equity in either Year −1 or Year −2. Thus, our sample for prior financial performance is reduced to 107 announcements.

Panel A of Table 4.5 presents the results for the two-day event period. Our sample is divided between 57 outperformers and 50 underperformers. Although the mean abnormal return for the outperformers is 0.22% and is significantly different from zero at the 5% level, the median abnormal return is 0.25% and is insignificant. The underperformers have a mean abnormal return of 3.96%, significant at the 1% level, and a median abnormal return of 1.78%, significant at the 5% level. The difference in means (medians) between the outperformers and underperformers is −3.74% (−1.53%) and is significant at the 5% (10%) level. The evidence indicates that the market reaction to PDR is dependent on the firm's prior financial performance, and that PDR is more positively valued in underperformers than in outperformers.

Next, we investigate the impact of the firm's primary PDR objective on market reaction. Our sample is divided into 65 announcements primarily aimed at cutting costs and 49 announcements primarily intended to increase revenues. Cost cutting announcements are generally targeted at reducing labor, facilities, or other product development expenses. Referring to Table 4.3, the cost cutting announcements are those in the PDR action categories of Layoff, Consolidate, Reduce Scope, and Close. In addition, some of the Other announcements are classified as cost cutting based

Table 4.5: Two-Day Event Period Cumulative Abnormal Returns for the Sample of 114 PDR Announcements, conditioned on the Firm's Prior Financial Performance and PDR Objective

Panel A: Prior Financial Performance

	Good [a]	Poor [a]	Difference [b]
N [c]	57	50	
Mean Abnormal Return	0.22%	3.96%	−3.74%
t-Statistic	1.79**	4.72***	−2.04**
Median Abnormal Return	0.25%	1.78%	−1.53%
Z-Statistic [d]	0.71	2.21**	−1.75*

Panel B: PDR Objective [a]

	Cut Costs	Gain Revenues	Difference
N	65	49	
Mean Abnormal Return	2.01%	1.06%	0.95%
t-Statistic	4.69***	3.93***	0.58
Median Abnormal Return	0.71%	0.73%	−0.02%
Z-Statistic [d]	1.16	1.58*	−0.03

Panel C: Two-Way ANOVA of Prior Financial Performance and PDR Objective

	SS	df [b]	MS	F	p
Prior Financial Performance	372.88	1	372.88	4.702	0.032
PDR Objective	88.35	1	88.35	1.114	0.294
Interaction	157.43	1	157.43	1.985	0.162
Error	8,167.76	103	79.30		
Total	8,786.42	106			

Panel D: Two-Way Rank ANOVA of Prior Financial Performance and PDR Objective

	SS	df [b]	MS	F	p
Prior Financial Performance	2,985.6	1	2,985.6	3.213	0.076
PDR Objective	44.1	1	44.1	0.047	0.828
Interaction	3,350.7	1	3,350.7	3.606	0.060
Error	95,697.6	103	929.1		
Total	102,078.0	106			

[a] Tests are one-tailed: $*p \leq 0.10$; $**p \leq 0.05$; $***p \leq 0.01$

[b] Tests are two-tailed: $*p \leq 0.10$; $**p \leq 0.05$; $***p \leq 0.01$

[c] Sample size is reduced to 107 observations due to 7 firms with negative equity in either Year −1 or Year −2.

[d] Z-statistics are obtained using Wilcoxon Signed-Rank tests for individual segments and a Mann-Whitney U test for differences between segments.

on announcement content. Revenue increasing announcements include asset sales, entry into new markets, or efforts to improve performance in existing markets. Again referring to Table 4.3, revenue generation announcements include the PDR action categories of Divest, Merge or Split Units, Establish New Units, Change Decision Structure, and the remaining portion of the Other announcements. Panel B of Table 4.5 presents the results by objective category for the two-day event period. Cost

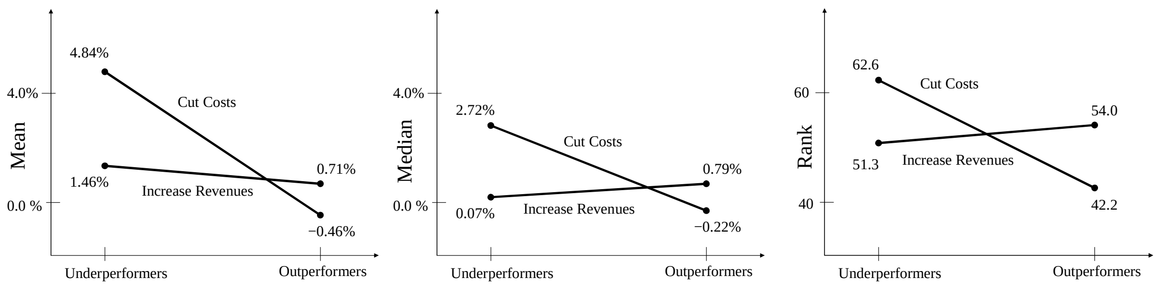

Figure 4.1: Interaction of the Firm's Prior Financial Performance and PDR Objective on Mean, Median, and Ranked Two-Day Event Period Cumulative Abnormal Returns for the Sample of 107 PDR Announcements

cutting PDR has a mean abnormal return of 2.01%, significant at the 1% level, and a median abnormal return of 0.71%, insignificantly different from zero. PDR aimed at revenue generation has a mean abnormal return of 1.06%, significantly different from zero at the 1% level, and a median abnormal return of 0.73%, significant at the 10% level. The differences in means and medians (0.95% and −0.02%, respectively) are not directionally consistent and are insignificant. We can conclude that the market reaction for PDR aimed at revenue generation is not greater than that for cost cutting PDR. In fact, it appears that the market reaction is more positive when the PDR is intended to cut costs.

The market reactions to PDR based on the firms' prior financial performance and its PDR objectives leads us to examine the interaction between the two factors. Figure 4.1 presents plots of the mean, median, and ranked abnormal returns due to PDR dependent on both the firm's prior financial performance and its primary PDR objective. The general pattern of the mean, median, and rank plots is consistent and indicates an interaction. For PDR primarily intended to increase revenues, the market reaction is positive but relatively insensitive to the firm's prior financial performance. For underperformers, the mean (median) market reaction to revenue increasing PDR is 1.46% (0.07%). For outperformers, the mean (median) reaction to revenue increasing PDR is 0.71% (0.79%). However, for PDR intended to cut costs, the market reaction is heavily moderated by the firm's prior financial performance. For underperforming firms, the mean (median) market reaction to cost cutting PDR is 4.84% (2.72%). For outperforming firms, the mean (median) reaction to cost cutting PDR is −0.46% (−0.22%). Panel C of Table 4.5 presents the results of a two-way ANOVA of the mean abnormal returns that indicates the interaction effect is greater than the PDR objective main effect but is insignificant. Panel D of Table 4.5 presents the results of a two-way ANOVA on abnormal return ranks; it indicates that the interaction effect is significant at the 10% level. The existence of the interaction at least partially explains the contradictions we find when examining the main effects of the two factors. If we only consider outperformers, the market reaction is as theorized in H4.3; i.e., PDR aimed at revenue generation is more positively valued than PDR intended to cut costs. However, when underperformers are considered, the market reacts more positively to cost cutting.

Next, to determine whether the firm's R&D expenditures influence the market reaction to PDR, we segregate our sample into firms that have greater and lesser R&D intensity than the sample median (18.4%). Panel A of Table 4.6 presents the results by R&D intensity category for the two-day event period. The mean (median) abnormal return for the high R&D intensity group is 3.58% (1.62%) and is significantly different from zero at the 1% (5%) level. The mean (median) abnormal return for the low R&D intensity group is −0.38% (0.25%) and is significant at the 10% level (insignificant). The differences in means and medians are 3.96% and 1.37%, respectively, and both are significant at the 5% level. The results suggest that PDR is more positively valued for firms with greater R&D expenses.

Last, we consider the effect of firm size on the market reaction to PDR. To test

Table 4.6: Two-Day Event Period Cumulative Abnormal Returns for the Sample of 114 PDR Announcements, conditioned on the Firm's R&D Intensity and Size

Panel A: R&D Intensity [a]			
	High	Low	Difference
N	57	57	
Mean Abnormal Return	3.68%	−0.38%	3.96%
t-Statistic	4.62***	1.51*	2.25**
Median Abnormal Return	1.62%	0.25%	1.37%
Z-Statistic [b]	2.00**	0.56	1.83**

Panel B: Size [a]			
	Small	Large	Difference
N	57	57	
Mean Abnormal Return	2.84%	0.36%	2.48%
t-Statistic	4.13***	1.99**	1.39*
Median Abnormal Return	1.20%	0.71%	0.49%
Z-Statistic [b]	1.38*	1.50*	0.38

[a] All tests are one-tailed: $^{*}p \leq 0.10$; $^{**}p \leq 0.05$; $^{***}p \leq 0.01$

[b] Z-statistics are obtained using Wilcoxon Signed-Rank tests for individual segments and a Mann-Whitney U test for differences between segments.

for the influence of firm size, we segregate our sample by total assets and test the market reaction to PDR by firms with total assets less than or greater than the sample median ($1.07B). Panel B of Table 4.6 presents the results by firm size category for the two-day event period. The mean abnormal return for the small firms is 2.84%, significantly different from zero at the 1% level. The median abnormal return of 1.20% is significant at the 10% level. PDR for large firms has a mean abnormal return of 0.36%, significant at the 5% level, and a median abnormal return of 0.71%, significant at the 10% level. The difference in means (medians) is 2.48% (0.49%) and is significantly different from zero at the 10% level (insignificant). The results suggest that the market reaction to PDR is more positive for small firms than it is for large firms.

4.5.1 Multivariate Analysis

To further test our hypotheses, we develop two regression models to explain the two-day market reaction. Model 1 includes our four hypothesized factors – the firm's prior financial performance (PFP), PDR objective (OBJ), R&D intensity (RDI), and size (LTA) – as well as the interaction between prior financial performance and PDR objective ($PFP \cdot OBJ$) as independent variables, the market reaction for the two-day event period as the dependent variable (AR_i), and an error term (ε_i). PFP is defined as in our earlier testing as the firm's average ROE relative to its industry group in Years −1 and −2. To capture the firm's PDR objective, we define the dummy variable OBJ with value 1 if the objective is revenue increasing, and value 0 if the objective is cost cutting. RDI is also calculated as in our earlier testing as the firm's R&D expenses divided by total sales in Year −1. LTA is defined as the natural logarithm of the firm's total assets in Year −1. Model 1 is shown in Equation 4.3:

$$AR_i = \beta_0 + \beta_1 PFP + \beta_2 OBJ + \beta_3 PFP \cdot OBJ + \beta_4 RDI + \beta_5 LTA + \varepsilon_i \qquad (4.3)$$

Since effective product development can be more critical in highly competitive industries, we also test for its effect. As in Hendricks and Singhal (1997), we use the Herfindahl index (HID) for the firm's industry group as a proxy for the degree of competition. Because the index is a measure of concentration, it is inversely related to the competitiveness of the industry. We compute the industry Herfindahl index by using the sales data of all firms in Compustat with the same three-digit SIC code as that of the announcing firm. Model 2 is shown in Equation 4.4:

$$\begin{aligned} AR_i &= \beta_0 + \beta_1 PFP + \beta_2 OBJ + \beta_3 PFP \cdot OBJ + \beta_4 RDI \\ &\quad + \beta_5 LTA + \beta_6 HID + \varepsilon_i \qquad (4.4) \end{aligned}$$

Table 4.7 presents the parameter estimates (t-values in parentheses) for Models 1 and 2. Because of the sensitivity of regression to outlying values, we use the trimmed sample of 109 announcements for our multivariate analysis. We exclude five firms that had negative equity in either Year −1 or Year −2. Thus, the sample size for our regression analyses is 104 observations. The F-values for Models 1 and 2 are 1.671 and 1.390, respectively. The signs of the coefficients for the hypothesized variables are as found in our earlier analyses; i.e., market reaction is greater for financial underperformers, cost cutting PDR, high R&D intensity, and small firms. If we compare Models 1 and 2, we see that the model fit is not improved by adding our industry competitiveness control variable HID. In fact, the model significance is decreased. Given the lack of significance for HID and the poorer model fit, we conclude that industry competitiveness is not unduly influencing our results.

Table 4.7: Parameter Estimates (t-values) from Regression Results for Predicting Two-Day Event Period Cumulative Abnormal Returns for the Trimmed Sample of 109 PDR Announcements

	Variable	Predicted Sign	Model 1 [a] (Eq. 4.3)	Model 2 [a] (Eq. 4.4)
Intercept	β_0	?	0.5207 (0.321)	0.4782 (0.292)
Prior Financial Performance	PFP	?	−0.9939 (−0.767)	−1.0076 (−0.773)
PDR Objective	OBJ	+	−0.3629 (−0.376)	−0.3739 (−0.385)
$PFP \cdot OBJ$ Interaction	$PFP \cdot OBJ$	?	2.7183 (1.108)	2.7608 (1.092)
R&D Intensity	RDI	+	0.1247 (2.325)**	0.1253 (2.322)**
Size	LTA	−	−0.0086 (−0.043)	−0.0158 (−0.077)
Industry Competitiveness	HID	?		0.8958 (0.257)
N [b]			104	104
Model F-value			1.671	1.390
R^2			7.86%	7.92%
Adjusted R^2			3.15%	2.22%

[a] $^*p \leq 0.10$; $^{**}p \leq 0.05$; $^{***}p \leq 0.01$

[b] We exclude five firms with negative equity in either Year −1 or Year −2 from our trimmed sample of 109 announcements.

4.5.2 Descriptive Results

The literature has typically examined restructuring by specific actions; therefore, we include an analysis of PDR segmented by primary action for comparison purposes. Table 4.8 presents descriptive statistics for each of the PDR actions in our sample with more than 10 observations. The greatest market reaction is for Layoff (N = 28); the mean (median) abnormal return is 5.02% (1.34%), significant at the 1% (10%) level. Also significant is Reduce Scope (N = 14) with a mean (median) market reaction of 3.02% (3.79%), significant at the 5% (5%) level, and Divest (N = 15) with a mean (median) market reaction of 1.92% (1.90%), significant at the 1% (5%) level. Only Consolidate has a negative market reaction, although it is insignificantly different from zero.

Table 4.8: Two-Day Event Period Cumulative Abnormal Returns for the Sample of 114 PDR Announcements, categorized for all PDR Primary Actions with $N > 10$

	Layoff	Consolidate	Divest	Reduce Scope
N	28	15	15	14
Mean Abnormal Return	5.02%	−1.46%	1.92%	3.02%
t-statistic	4.03***	−0.53	2.68***	2.45**
Median Abnormal Return	1.34%	−0.94%	1.90%	3.79%
Z-statistic	1.47*	−0.58	1.69**	1.65**

All tests are one tailed: $^{*}p \leq 0.10$; $^{**}p \leq 0.05$; $^{***}p \leq 0.01$

Given that the power of our descriptive analysis segmented by primary action is low due to small sample sizes, and that category definitions are not always precise or generally accepted in the literature, it is challenging to contrast our results with previous empirical findings. Therefore, we only discuss comparisons for the Layoff category; it has the largest number of observations in our sample (N = 28) and its definition is commonly understood. Compared to the positive results in our sample of PDR layoffs, Capelle-Blancard and Couderc (2007) find that abnormal returns for layoffs are generally negative regardless of time period or geographic region. Their results are based on a review of 41 event studies of layoffs from 1970-2001. For example, Iqbal and Shetty (1995) find a -0.3% two-day abnormal return associated with layoff announcements, and Chen et al. (2001) find a -1.2% two-day abnormal return. Caves and Krepps (1993) find that the average three-day abnormal return for layoffs is -1.65%. As explained by Lin and Rozeff (1993), the negative market reaction to layoffs is generally attributed to the decreased demand that is signaled by such events.

4.6 Summary

Effectiveness of the firm's product development function can be a key factor in building shareholder value. Managers often attempt to improve product development effectiveness by restructuring but the subsequent impacts to shareholder value have not been systematically studied. This paper analyzes the shareholder value effects of product development restructuring (PDR) by measuring the market reaction associated with announcements of PDR. We examine the stock market reaction to our overall sample of 114 PDR announcements. We also segment our sample to examine the effects of several factors on the market reaction to PDR. The factors tested are the announcing firm's prior financial performance, restructuring objective, R&D expenditures, and size. We find that the market does significantly react to PDR announcements with a mean (median) abnormal return of 1.60% (0.72%); 58.8% of firms experience a positive market reaction. We also find that the market reacts more positively to PDR by financial underperformers than it does to PDR by outperformers. Regardless of whether the primary objective of the PDR is to cut costs or to increase revenues, the market reaction to PDR is not significantly different. However, for these two factors – the firm's prior financial performance and its PDR objective – we find a significant interaction. In addition, we find that the market reaction to PDR by firms with higher R&D intensity is more positive than it is to PDR by firms with lower R&D intensity. Last, we find that PDR by small firms results in a more positive market reaction than PDR by large firms.

From the above findings, we have a number of interesting insights. First, PDR, on average, increases shareholder value. Given that product development accounts for only a portion of the firm's activity (the median R&D intensity in our sample is 18.4%), the fact that the average market reaction equals 1.60% is not only statistically significant but also economically significant. In addition, our finding that the average market reaction to PDR increases to 3.58% for firms more with greater R&D expenses further confirms the value created by PDR.

Second, the greater positive market reaction for PDR by financial underperformers adds evidence to the restructuring literature regarding the impact of the firm's prior financial performance on market reaction to restructuring. In particular, it lends support to the potential benefit hypothesis of Iqbal and Shetty (1995); i.e., poor performing firms have more to gain from restructuring than good performers. Perhaps more importantly, our finding does not support the financial distress hypothesis of Iqbal and Shetty (1995); i.e., PDR is not seen as indicative of poor business prospects. We note that, even though the market reaction to PDR by underperformers is more positive, PDR by financial outperformers is also valued positively by the market. Given the other reasons we outlined in developing our hypothesis (H4.2), our finding might also indicate that investor expectations about poor performing firms' likelihood to restructure is an important consideration, and that the firm's financial difficulties might help provide the necessary urgency and motivation to successfully restructure.

Third, contrary to our hypothesis (H4.3), we find that the market reaction to PDR does not differ significantly dependent on the primary PDR objective (whether aimed at cutting costs or increasing revenues). The market reaction indicates that PDR creates shareholder value regardless of its stated objective. Although the firm's PDR objective has an insignificant main effect, it does significantly moderate the effect of the firm's prior financial performance on market reaction to PDR. For financial underperformers, PDR aimed at cost cutting is more positively valued than PDR aimed at increasing revenues. Conversely, for financial outperformers, the market reaction to PDR aimed at increasing revenues is more positive than it is for PDR aimed at cost cutting. Logically, the three considerations influencing the impact of the firm's prior financial performance on the market reaction to PDR (outlined in our development of H4.2) are all strengthened in favor of financial underperformers when the PDR objective is cost cutting, and in favor of financial outperformers when the PDR objective is revenue gains.

Finally, the market reaction to PDR is consistently positive regardless of the segmentation criteria – prior financial performance, PDR objective, R&D expenses, and size – that we use. These results are in contrast to much of the literature that finds generally negative or mixed market reactions to organizational restructuring. We conjecture that this disparity is due to the unique characteristics of product development (e.g., its proprietary nature, uncertainty in results due to technological and market challenges, consumption of significant firm resources) versus those of other operational assets, and that investors consider PDR to be a signal of renewed focus on this critical function.

Avenues for future work include a better understanding of the market reactions to specific PDR actions and how they differ from the more general restructuring context. For example, further work on the similarities and differences in the role of layoffs in PDR versus layoffs in general is fruitful grounds for future research. By gathering data on firms' financial performance and product successes or failures subsequent to PDR layoffs, we may be able to better tease out the relationships between PDR layoffs and market reaction. Similarly, studying the relationship between product development effectiveness and PDR is a topic worth further review. Do product development effectiveness measures such as time-to-market, R&D productivity, and percent of sales from new products demonstrably improve after PDR? Another interesting avenue is the use of alternative measures of firm performance rather than market reaction. If PDR affects shareholder value, measures such as ROE, return on assets (ROA), or return on sales (ROS) would also be impacted. A study focusing on the effects of PDR on accounting-based measures will help in further understanding the link between product development activity and firm performance.

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