# Environmental Management Expenditures:
# Assessing the Financial Returns from Structural and Infrastructural Investments


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April 25, 2009


## Abstract

Customers, regulators, and the public are increasingly demanding that firms minimize the impact of their products and operations on the natural environment within the frame of sustainable development. In response, management research on green operations has continued to evolve to consider a broad range of management decisions, programs and technologies that contribute to greener operations. We argue that, collectively, these infrastructural expenditures on management practices are most likely to form an important strategic resource. Multi-year data drawn from several Canadian government databases provided the basis for assessing the financial implications of increased levels and varying allocations of environmental expenditures, and expanding the range of management tools employed. Overall, environmental management practices, including monitoring, assessments, auditing, administering environmental programs, and environmental training, emerged as a key lever in improving manufacturing performance. Both increasing expenditures of and a greater allocation toward management practices yielded positive financial returns across several specific cost and inventory metrics.



*Key Words:* sustainable development, environmental management practices, pollution prevention, manufacturing operations.

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### 1. Introduction

The question whether investing in environmental management helps or harms firm performance has been a debate that is only slowly beginning to be resolved. If we back up just a couple of decades, from an economic perspective, pollution was viewed as an externality to the firm, which in turn, was borne by society (e.g., Baumol & Oates, 1988). According to this view, as regulations tighten and non-regulatory pressures develop from public and non-governmental organizations, managers must make decisions about how to trade off costs to improve environmental performance against other business opportunities, potentially leading to lower productivity (Grey & Shadbegian, 1993). In contrast, more recently, researchers have put forth arguments that tougher but well-designed environmental regulations (Porter & van der Linde, 1995) and policy incentives (Hahn, 2000) can enhance firm competitiveness by fostering and facilitating innovation and improved efficiency. As a consequence, a tradeoff between business and environmental performance is not necessarily required.

Yet, at least two challenges keep these perspectives from constructing a clear, yet nuanced view of the underlying mechanisms that link environmental expenditures and business performance, and quantifying the expected returns available to managers. The first is the theoretical lens through which the environmental management investment, capabilities, and outcomes are viewed within manufacturing operations and processes. Much attention has been directed at identifying the basic financial costs and benefits of regulations typically designed for a command-and-control regime. Recent economics research has expanded this to include incentive- and trading-based mechanisms that facilitate implementation of lower total cost of compliance within a region or industry (Hahn, 2000). In addition, the nature and form of environmental expenditures has been relatively undifferentiated, with most of the emphasis on structural (i.e., physical) assets that control pollution, and to a lesser but increasing extent, on those that prevent pollution. In contrast, the infrastructural investments (e.g., monitoring and learning-based innovation) are difficult to measure and, as a result, have been given limited attention. Only recently has research begun to examine this important aspect, for example in the area of clean energy (Rivers & Jaccard, 2006).

Several related streams of management research have attempted to differentiate between forms of environmental expenditures or investments, placing them into such categories as pollution prevention, management practices, and pollution control (King & Lenox, 2002; Klassen & Whybark, 1999b; Melnyk, Sroufe, & Calantone, 2003). These tend to be derived primarily from the resource based view (RBV) of the firm (Barney, 2001) and its extension to the natural environment (Hart, 1995). The RBV posits that one pathway to a competitive advantage can be developed through infrastructural investments in new capabilities, those related to stakeholder management (Delmas & Toffel, 2004), as well as structural investments such as greener products (Hart & Christensen, 2002) and end-of-life product recovery (Toffel, 2003), to name several.

Doing so offers the potential for improved profitability (Russo & Fouts, 1997), as costs can be offset by a compensating gain in revenue or contribution margin, or a reduction in other operating costs. However, due to their intrinsic nature, benefits stemming from environmental expenditures that develop integrative capabilities can be difficult to identify and measure (Cebon, 1992), and are easily overlooked (King, 1999). As a result, competitors have difficulty quickly imitating them, generating a potential competitive advantage.

The second challenge has been access to detailed, reliable data that allows for an examination of a rich variety of environmental expenditures. Detailed environmental expenditure data at the firm or plant level, combined with operational and business performance data simply has not been available. To circumvent this shortcoming, researchers have relied on the use of case studies (e.g., Rothenberg, Pil, & Maxwell, 2001), a combination of perceptive and objective measures (e.g., Klassen & Whybark, 1999a; Russo & Fouts, 1997) or the construction of proxy measures (King & Lenox, 2002), all with some inherent limitations for translating investments or expenditures into financial returns and generalizable outcomes.

In this paper we make three empirical contributions to this discussion, while attempting to address some prior shortcomings. First, we apply a theoretically driven typology of environmental expenditures that explicitly breaks apart infrastructural development from classic forms of pollution control and pollution prevention. Second, we identify specific patterns of environmental management tools (i.e., programs) based on their reported use across 10 industries. Finally, after controlling for prior performance, we empirically examine the relationship of environmental expenditures to specific manufacturing performance outcomes, including for raw materials, packaging, labor and energy costs. Also, the implications of environmental expenditures for the level of inventory, i.e., operational leanness, are assessed.

The paper is structured as follows. The following section outlines the underlying theory and hypotheses. Next, a description of the sample and empirical measures are detailed in the methodology section. The fourth section reports the empirical results from an assessment of the linkages between environmental expenditures and manufacturing performance. Finally, a discussion of the findings is presented before concluding with proposals for further research.

## 2. Literature Review

### *2.1. Theoretical Underpinnings: Resource Based View of the Firm*

Recent theoretical developments have moved to ground our growing understanding of environmental management in the resource-based view (RBV) of the firm. Strategic resources are defined as assets and organizational processes that add value, are rare, are difficult to imitate, and have few substitutes (Barney, 2001). These resources can be physical, human, organizational, technological, financial, and reputational (Grant, 1991). The development and control of a firm's specific resources either can be acquired (i.e., tradable resources (Black & Boal, 1994), or can be path dependent, thereby accumulating over time (Dierickx & Cool, 1989). Resources are distinct from capabilities, with the former being basic building blocks such as employee skills and purchasing processes and the latter being bundles of resources brought to bear on value-added tasks (Bowen, Cousins, Lamming, & Faruk, 2001; Hart, 1995).

The theoretical implications for environmental management are multi-faceted. Hart (1995) and Lamming and Hampson (1996) argue that environmentally related strategic resources for manufacturing include continuous improvement, stakeholder management and product stewardship, which encompass product responsibility from cradle to grave. Russo and Fouts (1997) extended this set to include the deployment of physical assets and technology, organizational culture, inter-functional coordination and intangible resources (i.e., appeal to green customer segments and political acumen). In addition, Christmann (2000) found that capabilities for process innovation and implementation are complementary assets. Wu et al. (2008) found that core resources included the top management team's strategic perception and cross-functional cooperation.

These resources can extend beyond the firm to provide multiple points of competitive leverage. Sharma and Vredenburg (1998) extended the set of strategic resources to include stakeholder integration and higher order learning. More recently, identifying, developing and enhancing environmental management in key suppliers has been viewed as a set of strategic resources beyond the traditional organizational boundaries (Carter & Rogers, 2008; Wu et al., 2008). Supply chains that integrate social and environmental resources may be less transparent, and therefore more difficult to replicate, particularly if suppliers have a high degree of asset specificity or relationship based on trust.

In sum, many strategic resources for environmental management focus on knowledge-based capabilities that support a broader environmental strategy. Characterized another way, what have been largely identified as resources are infrastructural in nature, rather than the physical assets required for pollution control, or physical product and process changes for pollution prevention. This dichotomy is well aligned with our classic understanding of operations strategy, where infrastructural decisions are conceptually separated from structural decisions (Hayes & Wheelwright, 1984). Infrastructural elements include planning, organizational structure, labor practices, training, and performance measurement systems.

It is very likely that infrastructural development in environmental management provides the enabling conditions for pollution prevention, while its absence favors pollution control as an outcome. However, despite the appealing theoretical rationale behind investing in stronger infrastructural capabilities, managers balk at the overhead costs that this might add, over and above any ongoing efforts to incorporate elements of pollution control and prevention. Thus, a firm's enacted strategy on environmental management is affected both by the *level* (i.e., extent) of expenditures to develop capabilities, as well as the *form* (i.e., allocation) of that investment across different types of structural and infrastructural areas.

### *2.2. Hypotheses*

For environmental management, the theoretical lens of RBV provides a natural basis for separating physical technologies from the less tangible management practices. However, the management literature has classically separated environmental initiatives as being either prevention or control oriented (King & Lenox, 2002; Klassen & Whybark, 1999b). Collectively, these two views can be synthesized into a simple matrix that explicitly recognizes the dual objectives and outcomes linked to infrastructural changes (Figure 1). For example, training and assessment might be viewed as control-oriented if they focus on how pollutants are to be captured, whereas other aspects of the same activities might target changes in housekeeping and stock rotation to prevent the expiry of otherwise usable raw materials stored in inventory.

**Pollution prevention** is defined as changes to products and processes. As pointed out above, however, the literature has traditionally not been very clear with regards to separating strategic resources from non-strategic ones when investigating the impact of pollution prevention on performance. For example, Klassen and Whybark (1999a) noted that pollution prevention activities depend on organizational and knowledge-based resources, and empirically identified a positive link between pollution prevention and performance. Similarly, King and Lenox (2002) estimated the extent of pollution prevention carried out by firms and found that the degree of implied pollution prevention was associated with better financial performance, as measured by Tobin's q. A lower relative pollution may have been achieved through a host of measures, as explained above, thus, unfortunately, providing no insights regarding causal relationships.

However, as noted earlier, redesigning products and processes may not, in and of themselves, be necessarily strategic resources. Unless patented, product changes can be detected, reverse engineered and imitated, thereby providing limited, short-term competitive advantage. Similarly, manufacturing processes within an industry are often well understood by competitors. For example, equipment suppliers in the printing industry sell more efficient presses across the industry, and buyers advertise to customers the purchase of new equipment in trade journals (giving relatively transparent information about their technical capabilities). Similarly, the petrochemical and chemical industries are extremely capital intensive but use fairly standardized processes. Despite these assertions, based on earlier literature, we expect that pollution prevention expenditures yield positive financial returns in manufacturing operations.

*H1: Expenditures for pollution prevention provide positive financial returns.*

**Pollution control** equipment consists primarily of off-the-shelf technologies that do not fundamentally alter the manufacturing process. Instead, they are appended to the process to capture pollutants, which usually require subsequent disposal, and can be viewed as incremental improvements or innovations. As a result, while implementation might vary to some small degree, pollution control equipment is highly standardized across industries. Moreover, pollution control by its very nature requires additional labor, energy and capital to install and operate beyond what was previously required for basic manufacturing process. However, the outcomes from even this form of technology are not quite so straightforward. The captured pollutants from one manufacturing plant's process can be transferred to and become raw material inputs for another plant's very different processes. Doing so may avoid costs or even generate offsetting revenues. Termed industrial ecosystems, a symbiosis between neighbouring plants is possible (for a detailed historical review, see Desrochers, 2002). However, this is likely the exception, and similar to previous findings (e.g., Grey & Shadbegian, 1997), we hypothesize that pollution control hurts cost and competitiveness.

*H2: Expenditures for pollution control provide negative financial returns.*

The final, and possibly most intriguing, form of environmental initiatives is **management practices**. In many ways, management practices encompass aspects of planning, prevention and control. For planning, tools such as Life-Cycle Analysis (LCA), environmental assessments and green procurement policies establish a data-driven basis for future improvements. Changes in operating procedures, good housekeeping and employee training provide prevention-oriented outcomes. Finally, tighter control can be developed through systems to quantify and monitor environmental performance. Naturally, control can provide feedback or input into future planning cycles.

As such, environmental management practices have many attributes that one might expect in a strategic resource. These practices tend to be based on learning and knowledge-based innovation, and organizational culture, social context, and cross-functional cooperation influence their effectiveness. Beyond the organizational boundaries, these practices connect the firm to its suppliers of materials, components and services, potentially fostering collaboration on specific technical problems, which in turn might result in structural changes to products and processes to improve competitiveness. Finally, initiatives to develop management practices are causally ambiguous and to difficult decipher for competitors because these practices tend to be socially embedded within either the firm or a dyadic relationship between firms. As a result, we hypothesize that management practices improve a firm's competitive advantage.

*H3: Expenditures for environmental management practices provide positive financial returns.*

### *2.3. Measurement Issues in Environmental Research*

Prior research generally has blurred the constructs of environmental strategy (or policy), implementation of environmental changes, and performance (Hart, 1995). Unfortunately, environmental policies do not necessarily translate into action and, ultimately, intended outcomes for many reasons. Thus, the allocation and pattern of expenditures provides a clear window into enacted strategy, separate from other measures of intended or stated policies, particularly in the areas of infrastructural resources. Moreover, tracking financial allocations to environmental management may yield important information that might otherwise be overlooked to enable reflective and corrective actions to align strategy, action and performance.

Much of the research on the financial implications of sustainable manufacturing has explored the relationships between two performance measures, such as environmental performance (e.g., pollutant emissions) and financial performance (e.g., profitability) (Derwall, Guenster, Bauer, & Koedijk, 2005). At the risk of oversimplifying, empirical analysis along these lines tends to gloss over underlying causal mechanisms that explain why such a statistical relationship might exist. Moreover, such studies provide managers with little guidance about what the direct implications of pursuing a collection or pattern of environmental expenditures and investments.

In the following sections, we test our hypotheses using an expanded set of financial metrics for both environmental management and manufacturing performance, as compared to previous research. As noted earlier, this approach has two advantages. First, doing so allows managers to undertake a basic cost-benefit analysis, i.e., return on investment (ROI), similar to other business investments. Second, managers can prioritize among alternative environmental expenditures, knowing that the relative benefits to manufacturing and environmental performance will differ. Historically, the critical limiting factor that has not allowed this to be done on a broad scale basis is the lack of access to detailed multi-year data on environmental expenditures and financial performance, ideally at an intermediate-level of analysis, such as individual manufacturing plants. In contrast, low-level analysis, e.g., with individual projects, limits generalizability, and high-level analysis at the firm level might mask or obscure differences when multiple plants from multiple industries are combined.

## 3. Research Methods

### *3.1. Data sources and sample*

#### *3.1.1. Environmental expenditures*

The set of constructs for environmental management were drawn from the Canadian biennial Survey of Environmental Protection Expenditures (SEPE) (Statistics Canada, 2007). This database is unique in that explicit capital and operating cost data are reported by managers for a variety of environmental expenditure categories, including pollution prevention, pollution control and management practices. Firms are required by federal law to complete the survey, and the data are collected at the establishment level, i.e., the level at which revenues, costs and investments can be explicitly identified, which for many Canadian firms corresponds to site- or plant-level reporting. Moreover, all expenditure categories and environmental tools are clearly defined for the respondents to improve validity and reliability.

Statistics Canada employed a stratified sample based on industry (North American Industrial Classification System, i.e., NAICS) and employment, from which a take-all portion and a take-some portions were identified. While the Canadian sample included both primary (e.g., mining) and manufacturing industries, only manufacturing industries were considered in our study to allow for matching with another independently collected database on manufacturing performance. The take-all strata included the following industries: beverage and tobacco products (NAICS 312); pulp, paper and paperboard mills (322); petroleum and coal products (324); and primary metals (331). The take-some industries included food (311), wood products (321), chemicals (325), non-metallic mineral products (327), fabricated metal products (332), and transportation equipment (336).

The take-all and take-some portions of the sample were determined by Statistics Canada based on a number of factors found in each industry, such as the average level of environmental protection expenditures per employee being greater than $1,000, and the number of small and medium-sized establishments (SMEs) within each industry.[1,2] A total of 1,210 establishments responded, yielding a response rate of 76.4%. However, because this database was subsequently matched with others for manufacturing performance, and depending on the set of variables needed, the number of observations available for analysis was substantially less.

In addition to covering business expenditures on environmental protection, SEPE also reported on the adoption of environmental management and pollution prevention *tools*. Tools were reported as a series of yes/no dichotomous items, including such aspects as adopting ISO 14000 and using a green procurement policy. Thus, two broad sets of measures were available: *expenditures*, stated in financial value; and *tools*, i.e., indicated the presence or absence of one or more specific environmental activities, procedures and techniques. While the measures were

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1 The take-some sample was stratified by ranking establishments within each NAICS industry by total employment. If there were 50 or more establishments in a NAICS category, the top 15% of establishments were selected to be surveyed. If there were between 15-49 establishments, the top 20% were selected. Where the total number of establishments fell below 15, all establishments were selected. The sample selected the largest establishments in order to maximize the employment covered while minimizing the number of establishments surveyed.

2 These firms received a long-form questionnaire. All other manufacturing industries were also sampled, but received a short-form questionnaire that reported only an aggregate measure of environmental expenditures. Thus, establishments using the short-form could not be utilized for detailed analysis.

self-reported, the official nature and importance of the survey were expected to yield highly reliable and valid data.

Overall, Canadian industry reported $6.8 billion in expenditures to protect the environment in 2004, virtually unchanged from 2002 (Statistics Canada, 2007). Across this two-year period, businesses reported allocating more financial resources toward pollution prevention and less toward end-of-pipe pollution abatement and control projects. Finally, analysis by Statistics Canada showed no correlation between environmental expenditures per employee and establishment size.

#### 3.1.2. *Manufacturing performance*

Manufacturing performance and contribution margin were extracted from the Annual Survey of Manufactures and Logging (ASML) (Statistics Canada, 2004), which is collected independently from SEPE. This survey is intended to cover all establishments primarily engaged in manufacturing and logging activities, as well as the sales offices and warehouses that support these establishments. Among other variables, this survey captured revenue, salaries and wages, costs of materials and supplies used, costs of utilities (e.g., energy and water), and the value of inventories. While Statistics Canada estimates population-level statistics for manufacturing annually for ASML, only about one-third of establishments in the 21 NAICS manufacturing codes respond in any given year to the detailed survey, with specific line-item detailed data on manufacturing revenue, costs and inventories. (For the remaining establishments, imputation is used to reduce the survey burden, i.e., only basic data, such as total revenue or inventory levels, are drawn from other sources such as tax records. However, while imputation is reasonable at an aggregate industry level, validity is questionable for individual establishments.)

Given that data for environmental expenditures and practices were available from SEPE for 2004, ASML data were used for the three-year period that bracketed these data, 2003-05 (the most recent year available at the time). Data from 2004 were used to scale the expenditure data, and 2003 allowed us to control for prior performance, thereby permitting an assessment of causality (Greene, 1997). Given the highly sensitive nature of the establishment-level data, and assurances to businesses that the data will remain confidential, both researchers were required to undergo national security checks, work with anonymous data (i.e., all identifying information such as addresses was removed), and conduct all analysis on-site in Ottawa with no access to external resources. Statistics Canada personnel used unique random establishment-level codes to link the respondents across four databases, i.e., SEPE (2004) and ASML (2003-05), which yielded a total of 530 observations.

### *3.2. Definitions of measures*

#### *3.2.1. Environmental expenditures*

Based on prior research (Klassen & Whybark, 1999a), and consistent with Statistics Canada definitions (Statistics Canada, 2007, p. 38), environmental expenditures were assigned to specific categories: pollution prevention, pollution control, and management practices. Pollution prevention captured costs related to developing a new or significantly modified production process that prevents or reduces pollutants, waste, leaks or spills; conserves energy or water; or improves on-site recirculation, recovery, reuse and recycling of materials. In addition, environmentally related changes to product design are included. Pollution control included costs for separately identifiable processes that abate pollutants emitted, treat waste and process sewage. Site reclamation and decommissioning also were to be included here, as these represent pollution control expenditures deferred from prior periods. Overall, these two categories can be both understood as structural expenditures or "hardware". A third, infrastructural category ("software"), termed management practices, encompasses management tools, methods and programs. Management practice expenditures encompass costs associated monitoring, assessments and auditing, and other environmental expenditures. Such practices as life-cycle analysis (LCA) and ISO 14001 also are included.

Establishments can vary both the *level* of investment to each category (scaled by establishment size), as well as the *allocation* between the three categories. The allocation within the overall environmental expenditures that provides some indication of the establishment's proactivity or reactivity on environmental issues (Klassen & Whybark, 1999b). Thus, two sets of related expenditure indicators were constructed: level of expenditure scaled by manufacturing costs, and allocation, with each expenditures in each category scaled by total environmental expenditures (i.e., fraction or proportion). More specifically, the level of each category of expenditures is:

$$\text{level of expenditures}_i = \text{category expenditures}_i \,/\, \text{manufacturing cost} \quad (1)$$

where

*i* = pollution prevention, pollution control and management practices (all costs stated in C$)

manufacturing cost = total direct and indirect costs, including: raw materials, packaging, energy, labour (both direct and subcontracted), energy, transportation, warehousing and shipping, rental and leasing, repair and maintenance, professional and business service fees, management fees and other service fees paid to head office, telecom, and office supplies.

In contrast, the relative allocation between the three categories is given by:

$$\text{allocation of expenditures}_i = \text{category expenditures}_i \,/\, \text{total environmental expenditures} \quad (2)$$

where:

total environmental expenditures = pollution prevention + pollution control + management practices

#### *3.2.2. Environmental tools (variety)*

SEPE includes two multi-part questions on management and pollution prevention tools, i.e., specific activities, procedures and techniques that contribute to environmental management. Both questions were presented as a list of items to which respondents provided a dichotomous yes/no response about a particular activity being used in that establishment. The particular items are listed in Tables 1 and 2, and because of their dichotomous nature provide a measure of the range (i.e., variety) of activities and techniques being used within each tool domain.

Naturally, managers can choose to apply the activities and techniques in each domain with varying levels of commitment and diligence, and their use is not likely to be independent of all others. Item response theory (IRT) was employed to provide a methodological basis for exploratory factor analysis using a two-step procedure: first, estimating a matrix of tetrachoric correlations, and second, conducting an exploratory factor analysis using principle components analysis (Parry & McArdle, 1991; Uebersax, 2000). This methodology makes the reasonable assumption that there was an underlying continuous scale that reflects the varying degrees of use, e.g., for ISO 14001, two establishments that are certified can exhibit differing levels of commitment and effort toward reducing solid waste.

Based on the eight items management activities, two factors were identified[3]. The estimated loadings for several items that fell below a basic cut-off threshold of 0.4, leaving three items for the factor labeled *internal tools*, and two items for the factor labeled, *supply chain tools* (Table 1). A similar analysis on the pollution prevention activities domain only yielded a single factor, which accounted for 57% of the explained variance. Thus, all seven items were aggregated into a single measure of *pollution prevention tools* (Table 2). A summated scale for each factor was used in subsequent analysis. It is interesting to note the relative levels of

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[3] Although a number of graphical and numerical criteria can be used, multiple approaches generally pointed to a two-factor solution, e.g., scree plot and eigenvalues > 1. Overall variance explained was 68%, n = 999.

adoption reported, with the average use of pollution prevention tools being 3.3 (out of seven), internal tools being 1.52 (out of three), and supply chain tools being 0.18 (out of two) (Table 3).

#### 3.2.3. Manufacturing (financial) performance

Manufacturing performance and profitability was assessed using three general groups of measures: specific manufacturing costs (i.e., efficiency), gross margin (i.e., market return), and inventory levels (i.e., leanness, also related to efficiency). Direct costs for raw materials, packaging, labour (both direct and subcontracted employees), and energy provide key performance measures that are typically under the control of manufacturing managers. Each cost category was scaled by total manufacturing cost (1).[4] Thus, raw materials, packaging, labor and energy costs were estimated as:

$$\text{cost performance}_j = \text{expense}_j \,/\, \text{manufacturing cost} \qquad (3)$$

where
$j$ = raw materials, packaging, labor and energy costs

Gross margin, a measure of profitability, was expressed as the difference between manufacturing revenue and manufacturing costs, scaled by revenue. However, because an adjustment is necessary for any change in inventory levels (to appropriately match expenses and revenue), the total Cost of Goods Sold was used in (4) and replaced manufacturing cost as the divisor in (1) for estimating this model only.

$$\text{gross margin} = (\text{manufacturing revenue - Cost of Goods Sold}) \,/\text{manufacturing revenue} \qquad (4)$$

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[4] Alternative formulations were considered whereby total manufacturing costs were replaced with a narrower measure (i.e., sum of raw materials, packaging, labor, and energy), and a broader measure Cost of Goods Sold, as defined by Statistics Canada (i.e., including R&D, licensing payments, etc., and then adjusting for annual change in inventory levels). The results for the significant variables in these additional models did not vary notably from those reported here.

Finally, four inventory metrics were assessed, each again scaled by total manufacturing cost: total inventory, raw materials, work-in-process, and finished goods. For each, the inventory level was estimated based on averaging the beginning and end of year levels.

$$\text{inventory performance}_k = \text{average inventory}_k \,/\, \text{manufacturing cost} \quad (5)$$

where
$k$ = total; raw materials; work-in-process; and finished goods

## 4. Empirical Results

Four critical areas of manufacturing costs were investigated: raw materials, packaging, labour, and energy costs, which represent, on average, 53.9%, 2.6%, 25.2%, and 8.3% of manufacturing costs in 2005, respectively. On average, inventory values were 6.3%, 2.1%, and 5.3% of manufacturing costs, for raw materials, work-in-process and finished goods, respectively. The average reported gross margin was -3.1%, after accounting for inventory adjustments; unlike the other performance measures, the standard deviation was quite large, at 49%.

In general, each empirical model was structured to include prior performance (2003), a set of control variables (2004), and measures of environmental expenditures and tools (2004). The control variables included: size (i.e., small [0,99], medium [100,499], and large [500,…] as defined by Statistics Canada); industry (3-digit NAICS); research and development and depreciation expenses (each scaled by revenue); and revenue change. Three steps were taken to clean the data and estimate the reported models. First, establishments that reported revenue growth over the two-year period (2003-05) exceeding three standard deviations were excluded. In practice, this excluded firms that grew by more than about 100% (i.e., doubling revenue), which could correspond to a major new capacity investment being brought on-line. For these establishments, a comparison with prior performance is questionable. After observations with missing variables were removed, 450 observations remained.

Second, each model initially was estimated using OLS regression.[5] A small number of outliers or high leverage points were removed, and the model was then re-estimated.[6] Finally, to examine the importance of establishment size on the main effects, two groups of interaction terms were tested sequentially: size and expenditure allocation; and size and usage of tools. The interactions, as a group, contributed little to the explanatory power of any model, with the exception of energy performance, which is presented later.

### *4.1. Manufacturing costs and contribution margin*

Raw material costs as a fraction of the manufacturing costs was significantly related to the level of management practice expenditures (Table 4, Model 4.1). The estimated coefficient, $B = -3.32$ ($p < 0.05$) can be directly interpreted as the two-year return on investment; thus, for every incremental dollar spent on management practices, raw material costs decreased by an average of $3.32 over a two-year period for this sample. While one must be cautious about extrapolating this finding outside the range of spending on management practices captured in this sample – where the average expenditure on management practices was only 0.23% of manufacturing costs – the return is very attractive.

Moreover, it also is interesting to note that as the allocation toward management practices increased (with a corresponding decrease in the allocation of pollution prevention and pollution

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5 Recall that the allocation to the three categories in (2) are, by definition, linearly dependent. Thus, the model was estimated including: a) initially allocation to pollution prevention and management practices; and b) then, re-estimated with allocation to pollution control. Model (a) is reported in full, and the single parameter estimate for allocation to pollution control from (b) is reported separately.

6 Because of the limited time onsite at Statistics Canada (Ottawa), two automated criteria were used to filter outliers: standardized residual > 4; and leverage value > 0.2. Combined, these criteria generally reduced the sample size by 2-3%.

control expenditures), raw material costs increased ($B = 0.0585$, $p < .01$). While this may appear to be small, if this were converted to financial terms, we must account for the average allocation toward management practices relative to manufacturing cost. Thus, if $1 was shifted to management practices from the combination of pollution prevention and control, raw material costs increased $3.54.[7] The implications is that any increased spending on management practices cannot come at the expense of reduced spending of other environmental expenditures, or net costs for raw materials changes little. Instead, increases in management practices must be net incremental expenditures toward environmental management.

As reported in Model 4.2, none of the environmental variables were significantly related to packaging costs ($p < 0.05$). It should be noted that this model was formulated slightly differently, as prior costs (2003) correlated very highly with current year costs (2005), at approximately 0.85, a level at which first-differencing is appropriate for the dependent variable, i.e., ($cost_{2005} – cost_{2003}$) (Wooldridge, 2006, p. 398). A contributing factor is likely that packaging costs account for only 2.6% of manufacturing costs, and detecting a statistically significant effect is difficult might be given the sample size. As a result, it may not be appropriate to conclude that no relationship between environmental management and packaging costs exists, either positive or negative, but rather that such a relationship could not be detected with this data.

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[7] Comparison on an equivalent basis requires that the regression parameter estimate, B, be converted to equivalent units. The units for the dependent variable, raw material costs, are: Y ≡ [$ / $manufacturing cost].
The units for the independent variable, allocation toward management practices, are:
$X_1$ ≡ [$ / $environmental expenditures].
Thus, the units of the estimated linear parameter in Table 4 for the allocation variables are:
$B_1$ ≡ [$environmental expenditures / $manufacturing cost].
Because on average, environmental expenditures = 1.65% of manufacturing cost,
$B_1$’ = ($environmental expenditures / $manufacturing cost) * ($manufacturing cost / 0.0165 $environmental expenditures) = 60.6 B
Thus, a change in the allocation of $1 toward management practices = $B_1$’*$B_1$ = 60.6 * 0.0585 = $3.54.

For labor, the allocation of environmental expenditures to management practices was significantly related to lower costs (Model 4.3; $B = -0.0510$, $p < 0.01$). The estimated coefficient translates into a reduction in labor costs of $3.09 for every $1 shifted (re-allocated) from a combination of pollution prevention and pollution control to management practices. Thus, increased attention to training, auditing and other practices provided a positive return by reducing labor costs, which might occur through reduced waste material handling, less rework, and other labor intensive activities.

A contrasting effect was observed for pollution control. As the proportion of environmental expenditures allocated to pollution control increased, labour costs increased significantly. The estimated coefficient, 0.0348 ($p < 0.01$), translates into increased labour costs of $2.09 for every extra $1 shifted away from pollution prevention and management practices.

In addition, the use of a greater variety of the internal tools, including ISO 14000 certification, an environmental management system, and a pollution prevention plan, yielded lower labor costs as well. Each additional program yielded a reduction in labor costs of 0.80% of manufacturing costs. Unfortunately, unlike the environmental expenditure variables, it is impossible to estimate the financial investment required to adopt each new tool.

Environmental expenditures had no significant direct effect on the overall gross margin (Model 4.4). However, recall that unlike all of the other performance models, for Model 4.4 higher is better, and the use of a greater variety of internal tools was significantly related to greater gross profits ($B = 0.0251$, $p < 0.05$). The effect is quite large, as each new program translated into an additional gross margin of 2.51%. Thus, we again see some evidence that expanding internal systems to actively manage the environment has positive benefits, which support evidence of others regarding ISO 14001 (Delmas, 2001; King & Lenox, 2001).

Finally, as with packaging, a first difference model was estimated for energy costs, as the correlation exceeded 0.9 between the two years (Table 5). In addition, this was the one model in which a group of interaction terms added significantly to the explanatory power of the model ($\Delta R^2 = 0.036$, $p < 0.01$). First, expenditures for pollution prevention were significantly related to reduced energy costs (B = -0.247, $p < 0.05$). This must be interpreted as a modest two-year return on investment, with every incremental dollar in pollution prevention yielding $0.25 over that period. However, given that energy costs were rising dramatically during this time, it is very likely that managers would see this level of return as acceptable.

Second, the allocation to management practices also was significantly related to lower energy costs; however, it is important to interpret this in light of the significant interaction effects. The relationship was only supported for small establishments (Model 5.1, B = -0.0585, $p < 0.01$),[8] for which the magnitude of this coefficient indicates that a $1 shift to management practices yielded a return of $3.55 in lower energy costs for small establishments. Finally, the opposite effect was observed when a related model with the allocation to pollution control replaced the combination of pollution prevention and management practices. Here, small establishments had significantly higher energy costs (B = 0.0185, $p < 0.05$) as the allocation to pollution control increased, equivalent to increased energy costs of $1.12. While large establishments had significantly lower energy costs than small establishments as the allocation to pollution control increased, the overall effect for large establishments was not significant (B =

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[8] For medium and large establishments, the linear term, -0.0535, must be added to their respective interaction terms, i.e., 0.0516 and 0.0629, for medium and large establishments, respectively. The resulting sums, -0.0069 and 0.0044, are not significantly different from zero. Thus, the outcome was significantly different for small establishment, relative to their larger peers.

0.0185 – 0.0408 = -0.0223).

### *4.2. Inventory values*

Four inventory valuation models were estimated using methods similar to that for manufacturing cost performance. Reduced inventory valuations imply lower costs through reduced working capital, smaller warehousing space, reduced storage and handling costs, and fewer obsolete and spoiled materials and products. While these combined costs of inventory vary dramatically from industry to industry (and establishment to establishment) and stage in the manufacturing process, a rule-of-thumb is to consider annual costs to be roughly 25% of the value of the inventory (Ritzman, Krajewski, Malhotra, & Klassen, 2007).

For total inventory, the allocation to management practices was statistically significant (Models 6.1, $B = -0.0242$, $p < 0.05$). This finding indicates that the overall level of inventory decreased as management put increasing emphasis on management practices, while shifting expenditures away from a combination of pollution prevention and control. For every dollar shifted, on average, establishments lowered total inventory value by \$1.47, which if assessed at 25%, yielded an annual reduction in costs of \$0.37. When disaggregated into the three specific forms of inventory (i.e., raw materials, work-in-process and finished goods), it is clear that the reduction in raw materials inventory was the primary contributor (Model 6.2, $B = -0.0162$, $p < 0.05$). In contrast, increasing allocation to pollution control was significantly related to higher levels of inventory ($p = 0.06$ and 0.04, for Models 6.1 and 6.2, respectively). The parameter estimates for the other two forms of inventory were not significant (Models 6.3 and 6.4).

Finally, unexpectedly, as more green supply chain tools were introduced, the level of finished goods inventory increased (Model 6.4, $B = 0.0090$, $p < 0.05$). The overall effect is modest, with the adoption of one additional tool adding 0.9% to the value of finished goods inventory, relative to manufacturing costs. Recall that these tools included green procurement and product certification. Both tools might increase variability in the supply chain, with green procurement potentially requiring different suppliers and tighter material specifications, and green certification requiring the additional of new SKUs into inventory. As a result, managers might have increased finished goods inventory to accommodate the new sources of variability and maintain customer service.

## 5. Discussion

### *5.1. Linking patterns of expenditures to performance*

Can investing in environmental management form a strategic resource and provide the basis for a competitive advantage? Or in other words, is there a business case to be made for spending more on environmental expenditures? Based on the empirical analysis reported earlier, one facet of these questions can be answered by identifying the means by which expenditures are used to improve capabilities, rather than the aggregate level of expenditures alone. While this is not an entirely new insight, as others have clearly identified linkages between pollution prevention and profitability (King & Lenox, 2002) and improved manufacturing performance (Klassen & Whybark, 1999a), it does specifically explore the financial costs and benefits. In doing so, we are able to move beyond the less direct measures of earlier research. Most importantly, it contributes to the understanding how management practices might form a strategic resource that improves competitiveness.

Three critical levers for environmental management were examined: expenditure levels (for three structural and infrastructural categories, relative to manufacturing costs), expenditure allocations (proportion between three categories), and the variety of tools adopted (three factors).

After controlling for prior performance, by far the most important lever turned out to be management practices. Increasing expenditures for management practices, as a percentage of manufacturing cost, were linked with lower raw material costs. Also notable, shifting the allocation of environmental expenditures away from a combination of pollution prevention and control (structure) and toward management practices (infrastructure) yielded significant benefits across a range of metrics: labor and energy costs; and total and raw materials inventory levels.

The one exception was raw material costs, where an increased the allocation of environmental expenditures to management practices hurt raw material costs. However, increasing the level of management practices balanced this outcome. Thus, we have clear financial evidence that expenditures, or more precisely, investments in infrastructure for environmental management – in the form of environmental monitoring, assessments, audits, training, information programs, and coordination – allowed managers and employees to manage the manufacturing system more efficiently.

As such, this study provides some evidence for the nature of how management practices might be a strategic resource. As emphasis is shifted from pollution prevention and pollution control to management practices, improved planning, prevention and control contributed to reduced process-related costs for raw material, labor and energy costs. This is further supported by the findings related to the pollution prevention tools and internal tools. Expanding the range of internal tools used, not pollution prevention tools, also tended to generate labor savings and higher margins. Thus, strong support was found for H3.

The hypotheses for pollution prevention and pollution control also found limited support in the expected directions. The level of pollution prevention expenditures was linked with reductions in energy costs only (H2). In contrast, as environmental expenditures were increasingly allocated to pollution control, only labor and energy costs increased (H3). Other cost areas and inventory levels revealed no consistent pattern.

Finally, one unexpected result emerged. It was surprising that, as the allocation of environmental expenditures shifted away from management practices to pollution control, raw materials costs decreased – the opposite of what was expected. Several reasons might be explain this. First, it must be recognized that this performance metric captures the costs, not quantities of raw materials. Thus, firms with a greater emphasis on management practices, relative to pollution control, might opt to purchase more expensive materials to eliminate pollutants. A simple example can be offered from the furniture industry. Water-based finishes tend to cost somewhat more than organic solvent-based finishes, but reduce the need for fume-capture pollution control equipment. Thus, a greater emphasis on pollution control might generate lower raw materials costs (as in Model 4.1), but simultaneously higher energy costs (as in Model 5.1).

What cannot be easily answered with the available data is how strategic resources from management practices might feed-forward to develop proprietary or other competitive advantages in pollution prevention (or even pollution control) over the longer term. While research by others using panel data constructed over longer time periods (but with more aggregated measures) has demonstrated that waste reduction is key (King & Lenox, 2002), it was not clear if these improvements were gained through management practices or pollution prevention. Moreover, if this richer question could be answered, we might be able to move closer to identifying whether there is something akin to an optimal allocation of expenditures, either in total level, or across the three forms of initiatives.

### *5.2. Variety of environment tools*

Not surprisingly, the use of environmental tools by manufacturing did not occur randomly; managers tended to adopt sets of related practices. Management practices aligned around two general factors: those focused on internal systems and others oriented toward the external supply chain. Internal systems included a basic environmental management system, registration for one or more ISO 14000 standards, and some type of pollution prevention plan. Overall, the adoption level of these tools was modest across 10 industries a diverse of establishments; in contrast, environmental tools related to the external supply chain have received far less attention by Canadian manufacturers. Supply chain practices included obtaining some type of environmental certification for a product, or using environmental criteria in purchasing decisions (i.e., green procurement). While usage might be expected to increase with time, they still lag far behind internal tools.

Given the difference in use, it requires little speculation to assume that manufacturing establishments first adopt environmental tools that clean up their own operations before imposing such standards on others. In one sense this is good news, as manufacturers lead by example. And these results also partly allay concerns that environmental responsibility is simply being outsourced to suppliers through green procurement policies. However, by not working to develop both internal and supply chain tools simultaneously, manufacturers may be overlooking significant competitive opportunities related to greening the supply chain (Bowen et al., 2001), particularly for smaller suppliers (Lee & Klassen, 2008).

Unfortunately, the relationships between specific sets (i.e., factors) of tools and manufacturing performance outcomes were generally less consistent in their directional outcomes. While internal tools tended to result in lower labor costs and higher gross margins, both good, there was also some evidence that finished goods inventory levels increased as more supply chain tools were used. Thus, the effects of applying multiple environmental management tools can be beneficial—the development of environmental management systems, ISO 14001 and pollution prevention plans exhibited quantifiable benefits—but the evidence here was not clear across all dimensions.

Finally, applying more pollution prevention tools, such as product reformulation, process modifications and on-site recycling, did not produce clear-cut benefits. This result was found despite earlier evidence from other studies that waste reduction is profitable (King & Lenox, 2002). In essence, this outcome further buttresses the discussion in Section 5.1 that management practices in conjunction with structural activities, not physical changes that reduce pollution prevention alone, are capable of improving competitiveness.

### *5.3. Limitations*

Several limitations to the analysis should be noted. First, the SEPE database specifically narrowed the definition of environmental protection expenditures to "all operating expenses, capital and repair expenditures that are incurred in order to anticipate or comply with Canadian or international environmental regulations, conventions or voluntary agreements" (Statistics Canada, 2007). The means to achieve these regulations, conventions or voluntary agreements encompassed multiple options, allowing for the development and implementation of different management strategies. However, general expenditures or other competitive initiatives that might more broadly reduce environmental impact, such as energy efficiency, were explicitly excluded. Thus, this analysis likely under-estimated both environmental expenditures and related manufacturing benefits, providing a conservative test.

Second, this analysis focused on a relatively short period of investment, namely two years. This was done to minimize the loss of observations, as well as other extraneous and potentially confounding events, such as ownership changes, new environmental regulations or economic shocks. Implications for the longer term need further study, possibly with extended panel data. Third, because data were collated by matching four separate surveys occurring over three years, it is unlikely that the responses are systematically biased (Statistics Canada also performed extensive data quality checking); however, it cannot be explicitly ruled out. Finally, the 10 manufacturing industries sampled tended to have greater environmental expenditures, and may not accurately represent others that currently spend little on environmental management (either because they resist higher expenditures, or alternatively have no need for them).

## 6. Conclusions

In this paper we linked environmental expenditures with business performance through the lens of the (Natural) Resource Based View of the firm (Barney, 2001; Hart, 1995). Most importantly, this literature suggest that infrastructural investments in environmental management practices may be a potential strategic resource because of the difficulty that competitors are likely to experience when attempting to identify, dissect, and finally copy these initiatives. Thus, we predicted that increased investments in strategic environmental resources would yield a competitive advantage, as operationalized through positive financial returns.

In contrast, we argued that, conceptually, investments in pollution prevention and pollution control are structural, non-strategic resources and, thus, likely to offer minimal short-term competitive advantage. Nevertheless, based on the findings of previous literature, we proposed that both pollution prevention and management practices would have a positive effect on financial performance, and pollution control would have a negative effect. These hypotheses were tested using data drawn from four surveys reported to Statistics Canada during 2003 to 2005 and were able to largely verify our hypotheses.

This study made three important contributions to the literature. First, from a theoretical perspective, it summarized possible causal factors linking environmental initiatives to changes in financial performance of manufacturing, and then linked those factors to the theoretically driven typology of environmental expenditures. In doing so, we hope to have further clarified the definitions and uses of those environmental expenditure categories.

Second, we identified specific patterns of environmental tools based on their reported use across 10 industries. Those patterns emerged from a list of environmental management routines commonly carried out at the plant level. Of the three environmental practices – pollution prevention, internal systems and supply chain management – supply chain practices were used the fewest by Canadian manufacturers. As such, they may be missing out on significant opportunities; supply chain practices are largely infrastructural and may serve as strategic resources, and by extension, might potentially improve a firm's competitive advantage. Unfortunately, given that the environmental tools were measured using basic dichotomous responses, the coarse resolution of these scales likely hampered the clear identification of consistent implications of using different sets of tools for manufacturing performance.

Finally, we empirically examined the relationship of environmental expenditures to business performance outcomes for raw materials, packaging, labor and energy costs. In addition, the implications of environmental expenditures for the value of inventories held were assessed. Through this investigation we were able to verify the importance of infrastructural expenditures (management practices) for improving the financial performance of manufacturing.

Indeed, these findings also bolster the need to more precisely measure how pollution prevention is achieved.

This study was constructed such that the difference in performance was measured given a two-year time lag (i.e., 2005 versus 2003), with expenditures being measured during the intervening year (2004) to infer causality. Given the oft-complex nature of environmental expenditures, the potential lag between initiation and outcomes, and the cumulative nature of strategic resources, constructing an extended set of panel data might yield additional insights. For example, performance could be measured in 2003, 2005 and 2007, with environmental expenditures reported during the even-numbered, intervening years. Doing so may allow for the separation of short- and long-term effects of expenditures on business performance. Second, the use of dichotomous responses in the construction of the environmental practice factors likely blurred any related outcomes. The use of a 5- or 7-point Likert scale would have been helpful.

Overall, this study provides a critical snapshot of the effect of different types of environmental expenditures on business performance using predominantly objective data. While the results apply to all manufacturing industries in other countries, it does provide a stepping-stone in building a more nuanced understanding of the causal linkages between environmental expenditures and business outcomes. As a next step, it would be interesting to replicate this study in a different country with a longer history of environmental activities (e.g., the USA, or a Western European country) or investigate the impact of environmental expenditures on environmental performance.

**Acknowledgments**

The authors would like to thank both Industry Canada and Statistics Canada for their financial and methodological support. In particular, Michael Bordt, Assistant Director of Environment Accounts and Statistics, provided invaluable assistance. The research and analysis are based on data from Statistics Canada and the opinions expressed do not represent the views of Statistics Canada.

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*Figure 1: Classifying environmental initiatives*

| | | Form of change | |
|---|---|---|---|
| | | ***structural*** | ***infrastructural*** |
| **Means of reduction** | ***prevention*** | product and process changes that reduce pollutants | management practices, (e.g., monitoring, assessing, training) |
| | ***control*** | processes to capture pollutants or remediate problems | |

*Table 1: Factor loadings for management tools scales*

| **Activities** | **Internal tools** | **Supply chain tools** |
|---|---|---|
| 1. Environmental management system | **0.51** | -0.04 |
| 2. ISO 14000 | **0.43** | -0.10 |
| 3. Pollution prevention plan | **0.42** | -0.02 |
| 4. Report on environmental performance | 0.37 | 0.10 |
| 5. Environmental voluntary agreement | 0.34 | 0.01 |
| 6. Design for Environment (DfE) | 0.32 | 0.09 |
| 7. Goods certified | -0.06 | **0.77** |
| 8. Green procurement | 0.09 | **0.61** |

N = 999
Principle components analysis of tetrachoric matrix, followed with varimax rotation.

*Table 2: Items for pollution prevention tools scale*

1. Product design or reformulation
2. Equipment or process modifications (integrated)
3. Recirculation, on-site recycling or reuse or recovery of materials or substances
4. Materials or feedstock substitution, solvent reduction, elimination or substitution
5. Improved inventory management or purchasing techniques
6. Prevention of leaks and spills
7. Good operating practices or pollution prevention training

*Table 3: Correlation matrix*

| | mean | sd | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Control variables* | | | | | | | | | | | | |
| 1. R&D | 0.0018 | 0.0104 | | | | | | | | | | |
| 2. depreciation | 0.0497 | 0.0625 | 0.06 | | | | | | | | | |
| 3. revenue growth | 0.0878 | 0.3405 | -0.04 | -0.19 | | | | | | | | |
| *Level of expenditures* | | | | | | | | | | | | |
| 4. pollution prevention | 0.0053 | 0.0210 | -0.04 | -0.02 | -0.02 | | | | | | | |
| 5. pollution control | 0.0090 | 0.0167 | 0.05 | 0.12 | 0.03 | 0.46 | | | | | | |
| 6. management practices | 0.0023 | 0.0105 | 0.03 | -0.02 | 0.03 | 0.51 | 0.47 | | | | | |
| *Allocation of expenditures* | | | | | | | | | | | | |
| 7. pollution prevention | 0.211 | 0.267 | 0.02 | 0.02 | 0.04 | 0.37 | -0.08 | 0.01 | | | | |
| 8. management practices | 0.206 | 0.249 | 0.06 | 0.01 | -0.02 | -0.11 | -0.20 | 0.10 | -0.22 | | | |
| *Environmental tools* | | | | | | | | | | | | |
| 9. pollution prevention tools | 3.293 | 1.945 | 0.06 | 0.06 | 0.00 | 0.10 | 0.16 | 0.04 | 0.12 | -0.05 | | |
| 10. internal tools | 1.516 | 1.125 | 0.01 | 0.18 | 0.00 | 0.12 | 0.23 | 0.11 | 0.07 | 0.08 | 0.41 | |
| 11. supply chain tools | 0.182 | 0.445 | -0.02 | 0.11 | 0.03 | 0.07 | 0.03 | 0.02 | 0.06 | 0.02 | 0.17 | 0.26 |

n = 450. Coefficients greater than 0.09 and 0.12 are statistically significant, at p = 0.05 and 0.01, respectively.

## Table 4: Manufacturing Cost Performance

| Independent Variables | 4.1 Raw materials | | | 4.2 Packaging | | | 4.3 Labour | | | 4.4 Gross margin | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***B*** | ***std err*** | | ***B*** | ***std err*** | | ***B*** | ***std err*** | | ***B*** | ***std err*** | |
| *Control variables* | | | | | | | | | | | | |
| prior performance (2003) | 0.7837 | (0.024) | ** | __[b] | | | 0.7228 | (0.026) | ** | 0.8159 | (0.037) | ** |
| medium-size establishment | -0.0061 | (0.012) | | -0.0011 | (0.002) | | 0.0081 | (0.009) | | -0.0274 | (0.031) | |
| large-size establishment | -0.0072 | (0.016) | | -0.0020 | (0.003) | | 0.0216 | (0.012) | | -0.0292 | (0.041) | |
| NAICS 312 | -0.0171 | (0.026) | | -0.0087 | (0.006) | | -0.0190 | (0.019) | | 0.1414 | (0.067) | * |
| 321 | -0.0156 | (0.016) | | 0.0040 | (0.003) | | 0.0227 | (0.012) | | 0.0067 | (0.042) | |
| 322 | -0.0286 | (0.018) | | 0.0052 | (0.003) | | 0.0137 | (0.013) | | 0.0350 | (0.046) | |
| 324 | 0.0261 | (0.028) | | 0.0059 | (0.005) | | 0.0003 | (0.020) | | -0.2140 | (0.071) | ** |
| 325 | 0.0048 | (0.018) | | 0.0030 | (0.003) | | 0.0088 | (0.013) | | -0.0022 | (0.047) | |
| 327 | -0.0670 | (0.021) | ** | 0.0019 | (0.004) | | 0.0514 | (0.015) | ** | 0.0099 | (0.053) | |
| 331 | 0.0070 | (0.018) | | 0.0048 | (0.003) | | 0.0339 | (0.014) | ** | -0.0210 | (0.048) | |
| 332 | -0.0160 | (0.019) | | 0.0009 | (0.004) | | 0.0389 | (0.015) | ** | -0.0006 | (0.050) | |
| 336 | 0.0238 | (0.022) | | 0.0077 | (0.004) | | 0.0103 | (0.017) | | 0.0492 | (0.057) | |
| R&D | -1.5925 | (0.750) | * | 0.0176 | (0.143) | | 0.8278 | (0.559) | | -3.4925 | (1.945) | |
| depreciation | -0.1493 | (0.095) | | 0.0041 | (0.017) | | 0.0276 | (0.069) | | -1.1748 | (0.246) | ** |
| revenue growth | 0.0805 | (0.013) | ** | -0.0004 | (0.002) | | -0.0954 | (0.009) | ** | 0.2435 | (0.032) | ** |
| *Level of expenditures* | | | | | | | | | | | | |
| pollution prevention | -0.2097 | (0.372) | | -0.0167 | (0.071) | | 0.1682 | (0.277) | | -0.7363 | (1.032) | |
| pollution control | 0.0661 | (0.368) | | -0.0639 | (0.069) | | -0.3778 | (0.273) | | 0.2000 | (1.064) | |
| management practices | -3.3223 | (1.645) | * | 0.3345 | (0.307) | | 2.0482 | (1.199) | | 4.1616 | (5.006) | |
| *Allocation of expenditures* | | | | | | | | | | | | |
| pollution prevention | 0.0120 | (0.019) | | 0.0030 | (0.004) | | -0.0234 | (0.014) | | 0.0457 | (0.049) | |
| management practices | 0.0585 | (0.019) | ** | 0.0018 | (0.004) | | -0.0510 | (0.014) | ** | -0.0721 | (0.049) | |
| *Environmental tools* | | | | | | | | | | | | |
| pollution prevention tools | -0.0017 | (0.002) | | -0.0001 | (0.000) | | 0.0005 | (0.002) | | 0.0042 | (0.006) | |
| internal tools | 0.0046 | (0.004) | | 0.0004 | (0.001) | | -0.0080 | (0.003) | ** | 0.0251 | (0.011) | * |
| supply chain | 0.0062 | (0.010) | | 0.0001 | (0.002) | | -0.0024 | (0.007) | | -0.0044 | (0.025) | |
| *Constant* | 0.1398 | (0.024) | ** | -0.0063 | (0.003) | | 0.0635 | (0.014) | ** | -0.0141 | (0.047) | |
| *Allocation* - pollution control[a] | -0.0348 | (0.015) | * | -0.0024 | (0.003) | | 0.0346 | (0.011) | ** | 0.0121 | (0.039) | |
| $R^2$ | 0.824 | | | 0.042 | | | 0.760 | | | 0.608 | | |
| N | 439 | | | 436 | | | 440 | | | 442 | | |

Notes:

* p < 0.05; ** p < 0.01

[a]Replaced pollution prevention and management practices with pollution control (linear combination).

[b]Because 2005 performance was very highly correlated with 2003, a "difference" model was employed.

## Table 5: Manufacturing Cost Performance (continued)

| Independent Variables | 5.1 Energy | | |
|---|---|---|---|
| | ***B*** | ***std err*** | |
| *Control variables* | | | |
| prior performance (2003) | __[b] | | |
| medium-size establishment | -0.0082 | (0.005) | |
| large-size establishment | -0.0126 | (0.007) | * |
| NAICS 312 | 0.0047 | (0.007) | |
| 321 | 0.0000 | (0.004) | |
| 322 | 0.0054 | (0.005) | |
| 324 | 0.0043 | (0.008) | |
| 325 | 0.0038 | (0.005) | |
| 327 | 0.0038 | (0.006) | |
| 331 | -0.0048 | (0.005) | |
| 332 | 0.0011 | (0.005) | |
| 336 | -0.0029 | (0.006) | |
| R&D | -0.0912 | (0.219) | |
| depreciation | -0.0057 | (0.003) | |
| revenue growth | 0.0093 | (0.025) | |
| *Level of expenditures* | | | |
| pollution prevention | -0.2473 | (0.117) | * |
| pollution control | 0.0809 | (0.102) | |
| management practices | -0.1507 | (0.446) | |
| *Allocation of expenditures* | | | |
| pollution prevention | 0.0077 | (0.011) | |
| management practices | -0.0535 | (0.013) | ** |
| *Environmental tools* | | | |
| pollution prevention tools | 0.0007 | (0.001) | |
| internal tools | -0.0012 | (0.001) | |
| supply chain | -0.0011 | (0.003) | |
| *Interactions with allocation* | | | |
| medium * pollution prev'n | -0.0040 | (0.012) | |
| large * pollution prev'n | 0.0082 | (0.020) | |
| medium * management practices | 0.0516 | (0.014) | ** |
| large * management practices | 0.0629 | (0.019) | ** |
| *Constant* | 0.0099 | (0.006) | |
| | | | |
| *Allocation* - pollution control[a] | 0.0185 | (0.009) | * |
| medium * pollution control | -0.0181 | (0.010) | |
| large * pollution control | -0.0408 | (0.014) | ** |
| | | | |
| $R^2$ | 0.089 | | |
| N | 437 | | |

## Table 6: Manufacturing Inventory Performance

| Independent Variables | 6.1 Total inventory | | | 6.2 Raw materials | | | 6.3 WIP | | | 6.4 Finished goods | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***B*** | ***std err*** | | ***B*** | ***std err*** | | ***B*** | ***std err*** | | ***B*** | ***std err*** | |
| *Control variables* | | | | | | | | | | | | |
| prior inventory (2005) | 0.8062 | (0.026) | ** | 0.6343 | (0.033) | ** | 0.8164 | (0.033) | ** | 0.7717 | (0.027) | ** |
| medium-size establishment | 0.0120 | (0.008) | | 0.0062 | (0.005) | | 0.0030 | (0.003) | | 0.0079 | (0.005) | |
| large-size establishment | 0.0131 | (0.010) | | 0.0036 | (0.007) | | 0.0087 | (0.003) | ** | 0.0030 | (0.006) | |
| NAICS 312 | 0.0101 | (0.019) | | 0.0192 | (0.011) | | -0.0012 | (0.006) | | 0.0056 | (0.011) | |
| 321 | 0.0110 | (0.010) | | 0.0164 | (0.007) | * | 0.0082 | (0.003) | * | -0.0057 | (0.006) | |
| 322 | 0.0152 | (0.011) | | 0.0088 | (0.008) | | 0.0039 | (0.004) | | 0.0065 | (0.007) | |
| 324 | 0.0131 | (0.018) | | 0.0098 | (0.012) | | 0.0069 | (0.006) | | -0.0027 | (0.011) | |
| 325 | 0.0306 | (0.012) | ** | 0.0107 | (0.008) | | 0.0086 | (0.004) | * | 0.0181 | (0.007) | ** |
| 327 | 0.0235 | (0.013) | | 0.0121 | (0.009) | | 0.0073 | (0.004) | | 0.0127 | (0.008) | |
| 331 | 0.0318 | (0.012) | ** | 0.0225 | (0.008) | ** | 0.0122 | (0.004) | ** | 0.0032 | (0.007) | |
| 332 | 0.0143 | (0.012) | | 0.0085 | (0.008) | | 0.0037 | (0.004) | | 0.0025 | (0.008) | |
| 336 | 0.0061 | (0.014) | | 0.0012 | (0.010) | | 0.0038 | (0.005) | | -0.0115 | (0.009) | |
| R&D | -0.1387 | (0.485) | | -0.0336 | (0.348) | | 0.2500 | (0.157) | | -0.7509 | (0.298) | ** |
| depreciation | -0.0609 | (0.059) | | 0.0069 | (0.044) | | -0.0072 | (0.019) | | -0.0546 | (0.039) | |
| revenue growth | -0.0257 | (0.008) | ** | -0.0181 | (0.005) | ** | -0.0038 | (0.003) | | -0.0018 | (0.005) | |
| *Level of expenditures* | | | | | | | | | | | | |
| pollution prevention | 0.1953 | (0.239) | | 0.0959 | (0.162) | | 0.0450 | (0.078) | | 0.0678 | (0.147) | |
| pollution control | -0.3284 | (0.232) | | -0.2267 | (0.157) | | -0.0484 | (0.076) | | 0.0244 | (0.142) | |
| management practices | 0.9520 | (1.037) | | 0.9246 | (0.707) | | -0.3339 | (0.336) | | 0.6238 | (0.635) | |
| *Allocation of expenditures* | | | | | | | | | | | | |
| pollution prevention | -0.0125 | (0.012) | | -0.0101 | (0.008) | | -0.0031 | (0.004) | | -0.0032 | (0.007) | |
| management practices | -0.0242 | (0.012) | * | -0.0162 | (0.008) | * | 0.0023 | (0.004) | | -0.0046 | (0.007) | |
| *Environmental tools* | | | | | | | | | | | | |
| pollution prevention tools | 0.0017 | (0.002) | | 0.0018 | (0.001) | | -0.0003 | (0.000) | | 0.0005 | (0.001) | |
| internal tools | -0.0039 | (0.003) | | -0.0011 | (0.002) | | -0.0004 | (0.001) | | -0.0010 | (0.002) | |
| supply chain | 0.0045 | (0.006) | | -0.0047 | (0.004) | | -0.0007 | (0.002) | | 0.0090 | (0.004) | * |
| *Constant* | 0.0049 | (0.012) | | 0.0044 | (0.008) | | -0.0020 | (0.004) | | 0.0012 | (0.007) | |
| *Allocation* - pollution control[a] | 0.0183 | (0.010) | | 0.0131 | (0.006) | * | 0.0004 | (0.003) | | 0.0039 | (0.006) | |
| $R^2$ | 0.732 | | | 0.545 | | | 0.657 | | | 0.706 | | |
| N | 438 | | | 439 | | | 438 | | | 442 | | |

Notes:
* p < 0.05; ** p < 0.01

[a]Replaced pollution prevention and management practices with pollution control (linear combination).