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GREEN MANAGEMENT AND THE NATURE OF TECHNICAL INNOVATION

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Green Management and the Nature of Technical Innovation

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1. Introduction

Innovation is a key component of a firm's strategy to improve market competitiveness and operational efficiency as well as to respond effectively to changing consumer preferences and regulations. A firm has the choice of undertaking different types of innovations that differ in the extent to which they involve changes in products, processes or practices and lead to gains in efficiency or brand image. We postulate that the extent and nature of innovation undertaken by a firm depends on its management system which not only influences its organizational structure, but also the incentives for making continual improvement in its technical capabilities, the extent of employee involvement in decision making and the internal communication channels for information sharing. We develop an empirical framework to examine the extent to which a management system promotes innovation and how its effect differs across different types of innovations. This understanding will shed light on the channels through which a management system affects a firm's operations and can be used to draw inferences about the strategic factors driving adoption of that management system. The framework developed here can also be used for predicting the effect of adoption of that management system on future adopters of that system and to identify the firms that might experience a higher rate of innovation following its adoption.

We apply this framework to investigate the effect of total quality management (*TQM*), one of the single most influential managerial systems developed in the last twenty five years, on technical innovations that reduce the generation of pollution. *TQM* is an integrated management philosophy that emphasizes customer satisfaction through continuous progress in preventing defects and seeks to achieve gains in efficiency using a systems-wide approach to process management (Powell, 1995). Expansion of the notion of product quality to include the environmental impact of production systems and products and the belief that pollution is equivalent to waste of resources has led firms to apply the systems-based approach of quality management to the management of their environmental impacts.[1] This involves changing the organizational culture of the firm and using quality management tools to encourage prevention of pollution upstream (at source) as a way to increase efficiency rather than controlling pollution after it is generated (DiPeso, 2000; Klassen and MaLaughlin, 1993). Pollution can be reduced at source through a variety of different practices. We examine the types of pollution prevention activities that are more responsive to *TQM* systems, and the implications of such differential response on the channels through which management systems influence technology adoption.

We use a very detailed dataset that catalogues the rate of technical innovation in pollution prevention to reduce toxic releases by a sample of S&P 500 firms over the five year period, 1992-1996. This dataset is a particularly well suited one to demonstrate our approach for a number of reasons. First, it forms a rich five year panel of pollution prevention innovations that firms have undertaken in 43 different categories. Second, during the period of our study a number of firms have chosen to apply *TQM* for environmental management. Third, the description of these practices is sufficiently detailed and allows us to classify these pollution prevention practices based on five attributes. Three of these attributes are technical in nature. Practices are partitioned according to whether they require physical change in equipment, or a change in materials used or if they involves changes in operating procedures. Some practices which could not be given labels that would indicate their technical attributes are simply categorized as "unclassified." This category is likely to include more customized and newly innovated practices that cannot be classified generically. In addition to these, we consider two attributes of strategic value to the firm. These are: visibility to consumers and efficiency-enhancement.

The waste prevention-oriented philosophy of *TQM* suggests an inherent complementarity between *TQM* systems and pollution prevention. One would expect the adoption of all types of pollution prevention practices to be higher among *TQM* firms than among firms that are not practicing *TQM*. However, in the *TQM* philosophy, the tools used for identifying and evaluating opportunities for waste reduction, and the measures for assessing performance may be more conducive to the adoption of some types of practices than others. We use our framework to identify which of the five attributes reinforce the effect of *TQM* on *P2* adoption levels and which ones would detract a *TQM* firm from undertaking specific types of *P2*. Following that, we quantify the impact of *TQM* on pollution prevention practices of each type by estimating the percentage increase in the rate of innovation of that type over the baseline wherein firms are not practicing *TQM*. This analysis can help better understand how *TQM* works in practice, and possibly help infer the strategic motivations that underlie *TQM* adoption and the type of outcomes that *TQM* is designed as an instrument to achieve.

In addition to the role of organizational structure and practice attributes, our analysis recognizes that the net benefits of adopting pollution prevention practices are also likely to be influenced by firm-specific technical and economic factors. These include the suitability/effectiveness of those practices for a firm’s production system (or the inherent propensity of a firm to adopt certain types of pollution prevention practices), the costs of learning about new technologies and the potential for diminishing returns associated with incremental adoption. The costs of learning may be influenced by the “complementary internal expertise” which depends on the prior history of innovation in the firm. The resource based view of the firm suggests that heterogeneity in this expertise across firms lead to differences in the firm's ability to capture the profits associated with a new technology (see survey in Christmann, 2000). We control for unobservable firm-specific features that can affect a firm's inherent propensity to adopt pollution prevention practices by incorporating firm-specific fixed effects. We also include practice-specific fixed effects to control for unobservable factors that might influence the suitability of certain types of practices for a firm's production system.

Several studies show that organizational characteristics are important determinants of innovation by firms (see reviews by Hage, 1999; Damanpour, 1991; Sciulli, 1998). A survey of the vast literature on quality management and its key practices suggests that *TQM* has many pro-innovation attributes, such as its emphasis on continuous improvement through the application of scientific information and a non-hierarchical organizational structure that enables the efficient creation and utilization of valuable specific knowledge at all levels of the organization (Sousa and Voss, 2002; Wruck and Jensen, 1998).[2] A few studies have focused specifically on the relationship between *TQM* and innovation. Curkovic et al. (2000) and Khanna et al. (2005) undertake a systematic empirical investigation of the linkage between adoption of pollution prevention techniques and *TQM* and find that there are synergies between the two. While the former study finds that firms with advanced *TQM* systems also have more advanced pollution prevention systems in place as compared to firms just initiating *TQM*, the latter study finds that *TQM* adopters were more likely to choose technically sophisticated pollution prevention practices as compared to non-adopters. However, neither study explores the influence that practice attributes have in the choice of pollution prevention practices selected by *TQM* adopters.[3] Our study contributes to this literature by examining quantitatively whether the organizational structure based on the *TQM* philosophy facilitates adoption of environmentally friendly technologies and the characteristics of the technological changes it fosters.

Our findings demonstrate that *TQM* supports the adoption of practices that involve procedural changes, those which are visible to consumers and those that enhance production efficiency, but not those which involve material or equipment modifications. Further, we find that timing of *TQM* adoption matters. While early *TQM* adopters adopt practices that allow them to gain competitive advantage by enhancing efficiency and improving reputation among consumers, late *TQM* adopters tend to adopt practices that involve physical changes in materials and equipment.

We test the validity and show the usefulness of our framework in assessing the likely effect of introducing *TQM* on the count of pollution prevention practices by constructing out-of-sample forecasts. We find that our model's ability to predict the effect of *TQM* adoption on the adoption counts of pollution prevention practices by different firms is superior to that of a model that variations across different *P2* when deriving two-year ahead forecasts. We also perform simulations in which we calculate the extent to which pollution prevention practices adopted by firms can be attributed to *TQM* and find that in on the average, 12% of the of the count of *P2*s adopted by firms who adopted *TQM* for the first time in 1993, can be attributed to the organizational structure inherent in *TQM*. However, those firms who are projected to adopt *TQM* for the first time in 1997, the first year after our sample, will approximately have 46% fewer *P2*s than they did in 1996, when they were still non *TQM* adopters.

Section 2 of the paper describes the conceptual framework underlying our empirical analysis which is described in detail in Section 3. Data is described in Sections 4, and we present and discuss our results in Section 5, followed by the conclusions in Section 6.

2. CONCEPTUAL FRAMEWORK

2.1. *TQM* and the Adoption of Pollution Prevention Practices.

The *TQM* philosophy has three strategic goals: (i) continuous improvement in quality, (ii) defect (waste) prevention while enhancing value added activities and (iii) meeting or exceeding customer requirements. To achieve these goals, quality management requires management commitment, long range planning, and close relationships with customers that allow anticipation of customer needs sometimes even before customers are aware of them. At the operational level, *TQM* involves the adoption of certain management "tools" or processes. In *TQM* firms, cross functional teams undertake research projects to develop or identify pollution prevention practices, managers do benchmarking visits to other organizations to learn about alternative ways of performing the work, and front-line employees are expected to search continuously for improved and simplified work practices (Hackman and Wageman, 1995). By allocating decision-making authority to problem-solving teams, enabling a high level of employee involvement in quality improvement, facilitating better communication and information sharing among all hierarchical levels in the organization and offering employee training and team-based rewards, total quality management enables the efficient creation and utilization of valuable firm-specific knowledge at all levels of the organization. The management tools described above are driven by identified consumer needs and aim to achieve quality improvements while lowering costs (Cole, 1998).

Growing concerns for environmental quality from consumers, the public, and regulators has led firms to expand their notion of product quality and apply *TQM* to reduce the environmental impact of their production systems and products. This together with the belief that efficiency can be enhanced by minimizing pollution provides a rationale for firms to proactively integrate environmental considerations in product and process design.[1] The upstream prevention focus of quality management, together with the view that pollution is a defect and an indicator of waste in production creates an explicit focus on source-reduction of pollution as opposed to end-of-pipe control (Curkovic et al. 2000). Case studies indicate that quality management tools such as affinity diagrams, Pareto analysis, cause-and-effect diagrams and cost of quality analysis help the teams responsible for environmental management to focus on the causes of their difficult environmental problems (PCEQ, 1993).[4] Moreover, quality management performance measures tend to be more function- or task-specific than traditional measures, thus allowing isolation of the contribution of particular activities to performance. This helps employees understand what actions they can take to improve overall performance (Wruck et al.).[5] This suggests that firms that adopt *TQM* are more likely to be able to identify opportunities for waste reduction and select cost-effective pollution prevention practices. Indications of an inherent complementarity between the concepts of pollution prevention and *TQM* can be found in case studies and surveys of firms which indicate that *TQM* adopters are indeed more likely to adopt pollution prevention practices (Florida, 1996; Atlas, 1997; Klassen and McLaughlin, 1993; see survey in Curkovic et al., 2000).[6]

Pollution can be prevented in a variety of different ways. These practices may not only vary in their effectiveness in reducing pollution in a firm but also in other attributes that could be important for a firm because they affect the economic benefits and costs of adoption for that firm. Moreover, the choice of practices can be expected to depend on the organizational structure within the firm (i.e. whether or not it is guided by total quality principles) that influences the identification and evaluation of that practice, the technical capabilities of the firm and firm-

[1] Studies examining the relationship between TQM and innovative approaches to environmentally conscious manufacturing find that TQM goals and methods align well with those of environmental management and promote

specific and practice-specific features that determine the suitability of that practice to the firm's production system as well as the firm's inherent propensity to adopt such practices.

Given the discussion above, one would expect the adoption of all types of pollution prevention practices to be higher among *TQM* firms than among other firms. However, the *TQM* philosophy, the tools used for identifying and evaluating opportunities for waste reduction, and the measures for assessing performance may be more conducive to the adoption of some types of practices than others. The list of pollution prevention practices used in our analysis is included in Table 1. We distinguish five key attributes that characterize these practices. Three of these are mutually exclusive functional (or technical) attributes (multi-functional and/or hard to categorize practices form a fourth and omitted category). The other two are economic (or strategic) attributes. We describe all these attributes in detail below.

We partition practices into four groups depending on whether they are likely to require physical modifications to equipment; changes in raw materials; changes in operating procedures for employees; or involve hard to categorize/multiple changes. Practices requiring *Equipment* modifications include changes in container design, cleaning devices, rinse and spray equipment and overflow alarm systems. Practices requiring *Material* modifications involve substitutions of raw materials, new solvents, coating materials or process catalysts. Practices, such as improved maintenance scheduling, improved storage and stacking procedures, better labeling procedures, which involve changes in the way that operations are organized and managed, are classified as *Procedural* modifications. Practices that are hard to categorize form the fourth group, henceforth denoted as *Unclassified* practices; this forms the omitted category in the econometric analysis.

Procedural changes require specific and detailed knowledge about work processes that is likely to reside with employees on the factory floor rather than with upper management

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environmental excellence (Klassen and McLaughlin, 1993).

(Hackman and Wageman, 1995; Wruck and Jensen, 2000). *TQM* emphasizes cross-functional teamwork, allocation of decision-making authorities to employees and improved flow of information among employees; it is therefore more likely to promote “grass-roots” efforts at waste reduction using the full spectrum of information and expertise to bear on decisions about system wide problems. On the other hand, practices that involve technical changes in equipment and materials may be relatively easy to identify even by firms that are not practicing *TQM*. Such modifications may be more process-specific rather than firm-specific and their benefits may be more standard knowledge among firms. Their adoption may thus be less responsive to specific knowledge/training of a firm’s employees or a firm’s management system. We, therefore, expect that the likelihood of adoption, by *TQM* firms, of pollution prevention practices that require procedural changes would be higher than that of adopting practices that require physical or material modifications. In other words, practices with *Equipment* or *Material* modifications attribute are expected to get a smaller (if any) boost from *TQM* systems while those with a *Procedural* modification attribute is expected to get a larger stimulus from *TQM*. For the fourth *Unclassified* practices, the definitions in the dataset do not provide enough information to allow us to discern their attributes. This category is likely to consist of practices that do not belong to standard categories or approaches of preventing pollution, are individually tailored to a firm’s production operations and are possibly multi-functional.

In addition to these technical considerations, the adoption of a practice may be influenced by its other attributes that affect the economic benefits of adoption. One such attribute of a practice is its visibility to *Consumers*. A second such attribute is the ability of that pollution prevention practice to lead to improvements in production efficiency, reduction in costs and savings in time and resource use, enabling firms to gain a competitive advantage. We consider such practices to be production *Efficiency-Enhancing*.

Practices that could be visible to *Consumers* are those that involve changing the raw materials used or that lead to modifications in the specifications or composition of the product could affect the functionality of the product, its appearance or its disposal after use. Firms may include such information in product labels or advertisements to make consumers aware of the environmental friendliness of that product. Such practices can allow firms to appeal to environmentally conscious consumers and charge price premiums and increase market share. *TQM* emphasizes customer and quality improvements to meet or exceed customer expectations; some of which may be latent or unarticulated, such as those generated by increasing environmental concerns. Firms that adopt *TQM* firms are likely to be more outwardly focused and to have closer relationships with customers which would enable them to identify the practices that customers' value. They are also more likely to have the tools, such as life-cycle analysis, to evaluate the environmental impacts of alternative product specifications, raw materials and disposal options, from "cradle to grave." We, therefore, expect that *TQM* adopters are more likely to adopt practices with the *Consumers* attribute. If this is the case, the results would reveal the extent to which *TQM* is being implemented to increase the appeal of a firm's products to environmentally conscious consumers.

Pollution prevention practices that could enhance production-efficiency include improved recordkeeping, inventory control, installation of overflow alarms or automatic shut-off valves and better inspection, and monitoring and labeling procedures. Wruck et al. (1998) find that although *TQM* is grounded in a concern for product quality, it reaches beyond these issues to emphasize efficiency throughout the organization on issues that may have little or no direct relation to product quality, such as equipment maintenance. So while *TQM* programs use the rhetoric of quality to accomplish change many practices may actually be efficiency-improvement initiatives that necessitate major reorganization and restructuring. We, therefore, expect that practices with the production *Efficiency-Enhancing* attribute, would get a significant boost in likelihood of adoption by *TQM* firms. Empirical evidence of this would provide support for the contention that "lean and green," go hand in hand as firms seek to more become more productive by pursuing strategies that enhance business and environmental performance (Florida, 1996). This would suggest that *TQM* adopters consider pollution prevention as part of the broader corporate effort to improve quality and implement leaner management systems.

2.2. Fixed Effects and Other Time Varying Factors

While the focus of this work is the identification of within-firm differential effects of *TQM* on the adoption of pollution prevention practices, we also control for the effects of other factors on adoption rates. Ideally, we would adopt a purely treatment effects count data model which would include a exhaustive set of firm-cross-practice fixed effects which would control for the baseline propensity of firms to adopt a particular pollution prevention practice. We depart from this ideal estimation strategy in that we use firm fixed effects and practice fixed effects rather than an exhaustive set of firm-cross-practice fixed effects. Including an exhaustive set of firm-cross-practice fixed effects is not feasible for our data as most firms have zero adoption rates for most practices. Instead, we use firm dummies to account for unobserved firm-specific characteristics such as technological knowledge and capacity or inherent propensity of the firm to undertake pollution prevention activities, and we use *P2* dummies to control for the uniqueness and appropriateness of each type of *P2* activity.

In this paper, we also control for secular changes in adoption rates through year fixed effects. Additionally, there are some potentially important time varying firm specific factors relevant for the adoption of pollution prevention techniques that we take into consideration. A firm's adoption decision may be affected by the availability of complementary technical resources within the firm. Previous experience with technologies which embody constituent elements of the same technological paradigm can lower the costs of learning and enable firms to realize a competitive advantage through incremental adoption earlier than competitors (Nelson and Winter, 1982). A possible measure of cumulative experience in year *t*, is the cumulative number of pollution prevention techniques that have been adopted between 1991 (when firms first began reporting this information to the TRI) and year *t-1*. We expect that cumulative adoption will be associated with a firm's incremental adoption in year *t* in two ways. First, it is an indicator of the experience that firms have had with pollution prevention techniques which might lower their current costs of incremental adoption. Second, a firm could experience diminishing returns to pollution prevention, thus *ceteris paribus,* higher level of cumulative adoption would lead to lower level of incremental adoption. The effect of cumulative pollution prevention is therefore ambiguous.

Since learning is likely to arise most strongly from recent experiences with pollution prevention practices of the same type, while diminishing returns are more likely to depend on the cumulative history of adoption of all types of pollution prevention practices, we identify the learning effect by including the count of pollution prevention practices adopted in year *t-1* as an explanatory variable. The lagged count of pollution prevention practices would also account for any other semi-transient factors that affect the adoption of pollution prevention practices, such as managerial interest and staff technical capabilities. Finally, we control for the number of opportunities a firm has to undertake pollution prevention practices. These opportunities are expected to be higher for firms that emit a higher number of chemicals and that have a larger number of emitting facilities.

3. Econometric Framework

3.1. Specification and Estimation

We consider a general framework that relates the count of adoption of pollution prevention practices with the presence of *TQM* and the level of other time varying firm characteristics. The expected number of pollution prevention practices of type *j* adopted by firm *i* in year *t*, $P2_{ijt}$, is a period is given by

$$E[P2_{ijt}] = \exp\{\alpha_j TQM_{it} + \beta \log[TOTP2_{it-1}] + \gamma \log[CUMP2_{it-1}] + \delta \log[CHEM_{it}] + w_t + e_{ij}\} \quad (1)$$

where the variables and the parameters are defined as follows.[2] The indicator variable TQM_{it} takes the value of 1 if firm *i* applied *TQM* to the environmental aspects of its production by year *t*. The effect of TQM_{it} on the adoption rate of pollution prevention practices of type *j*, α_j, is the parameter vector of primary interest in our study. The variable $TOTP2_{it-1}$ is the total number of pollution prevention activities of all types adopted by firm *i* in the preceding year, and it proxies for slowly evolving (or transient) unobserved factors that affect the adoption of pollution prevention techniques. These would include effects of learning (which arise from experience with all types of pollution prevention practices but which are expected to decay over time), changes in managerial interest in pollution prevention (which is expected to revert to some steady state over time), transient changes in firm expertise through staff turnover, and other

[2] The description of the source data and the construction of the variables are deferred to the next section.

factors. We would expect the parameter β to be positive but smaller than 1, reflecting the non-permanence of the above factors. The variable $CUMP2_{it-1}$ is the cumulative number of pollution prevention techniques of any type adopted by firm *i* before the start of year *t*, and it reflects the possible presence of diminishing returns to pollution prevention: the more techniques have been introduced by a firm, the fewer remaining pollution prevention opportunities may be left to exploit. For single facility firms, the variable $CHEM_{it}$ is the number of chemicals a firm uses in period *t*, while for multi-facility firms $CHEM_{it}$ aggregates this number over all facilities of that firm. The log specification for these variables allows the model parameters to be interpreted as elasticities. Finally, w_t and e_{ij} are year and firm cross practice fixed effects, respectively.

The primary parameters of interest, α_j, are assumed to relate to characteristics of pollution prevention practices *j* through the linear equation

$$\alpha_j = \alpha + \alpha_e EQUIP_j + \alpha_m MAT_j + \alpha_p PROC_j + \alpha_f EFF_j + \alpha_c CONS_j \qquad (2)$$

where $EQUIP_j$, MAT_j, and $PROC_j$ are mutually exclusive dummy variables that indicate whether practice *j* has *Equipment*, *Material* or *Procedural* attributes. EFF_j is a dummy variable that indicates whether practice *j* is *Efficiency-enhancing*, while $CONS_j$ indicates whether practice *j* is *Visible* to the consumers of the product. If *TQM* affects the adoption rate of all types of practices equally, then the parameters α_e through α_c would all be zero and the effect of *TQM* on pollution prevention would not be systematically related to the composition of pollution prevention practices employed by firms. However, if the effect of *TQM* on pollution prevention practices is not uniform for reasons discussed in the conceptual framework, then α_j will be statistically significantly different from α and α_j will vary across practices.

We now turn to the estimation of equation (1). We make no assumptions on the distribution of $P2_{ijt}$ other than that each realization is conditionally independent of each other. Thus, we not only relax the Poisson assumption of equality of mean and variance, but we also relax the weaker assumption of proportionality of mean and variance. We also assume that all independent variables are exogenous, i.e., independent of the equation disturbance term. Our estimation and inference follow the Quasi-Maximum Likelihood (QML) estimation approach: while point estimates are obtained from Poisson regression which is the QML estimator (see Wooldridge 1997 and references therein), standard errors are obtained from the Huber-White robust covariance matrix constructed from the regression residuals.[3]

Estimation of the model specification given in equation (1) is complicated by a number of factors. First, though $CHEM_{it}$ is always positive, $CUMP2_{it}$ and $TOTP2_{it-1}$ are occasionally zero (albeit very rarely: $CUMP2_{it}$ is zero in 2.63%of the sample, while $TOTP2_{it-1}$ is zero in only 8.50% of the sample). To prevent the loss of any observations, we add 1 to these two variables prior to taking the log, a rather small change in the transformation given the scale of the variables. For robustness, we have also re-estimated the model using these two variables in levels rather than in logs, though in this latter specification the model parameters can no longer be interpreted as elasticities. Second, estimation of the firm cross practice fixed effects e_{ij} is not possible using the above statistical framework as the typical firm has zero innovations for most of the practices over our 5 year period (and has only a single innovation for some of the remaining practices). Therefore, we assume that e_{ij} has the additive structure $e_{ij} = u_i + v_j$, which

[3] Implementation is through STATA 9. The robust standard errors are similar to those obtained under the assumption that the variance of P2 is proportional to its mean, using the (normalized) Pearson residuals. However, Maximum Likelihood Poisson standard errors are smaller than either of the above by a factor of 2, consistent with the presence of substantial over-dispersion in the P2 count.

prevents the loss of any observations (and the information they contain), albeit by imposing a parametric assumption.

The parameter vector α_j is interpreted structurally. That is, we posit that if a firm were to apply *TQM* to environmental management, the effect on the rate of adoption of pollution prevention activities would be given by the values of the parameters α_j. It is possible that the estimated values of α_j could differ from the true structural effect of *TQM* due to endogeneity of TQM_{it}, i.e. if TQM_{it} is correlated with the equation disturbance term. Given the presence of firm and year fixed effects, and the inclusion of $TOTP2_{it-1}$ as an independent variable, such correlation must be with the idiosyncratic disturbance term that is non-permanent and takes place at the time of *TQM* adoption. For example, a "green" manager arrives at the firm and ramps up both the pollution prevention innovation and applies *TQM* to the environmental operations of the firm. The arrival of the "green" manager is a permanent shock that is (positively) correlated with the application of *TQM* to environmental issues. Under this example, the estimates of α_j will be upwardly biased estimates of the true structural parameters. Though we cannot directly eliminate the possibility of such endogeneity, we emphasize that its source cannot arise from the correlation of permanent firm characteristics with the application of *TQM* (given the incorporation of firm fixed effects) or the correlation of economy wide shocks with the application of *TQM* (given the incorporation of year fixed effects) or the presence of slow build-up of firm level factors that simultaneously lead to increases in pollution prevention innovation and to the application of *TQM* (given the incorporation of $TOTP2_{it-1}$ in the regression). We thus posit that the likelihood that such endogeneity would lead to substantial bias is remote, an assumption made by the bulk of the panel data literature using short panels with fixed effects.

3.2. Counterfactual Simulations and Policy Analysis

In this section we describe our use of the model to quantify the impact of applying *TQM* to pollution prevention on the firm-level adoption rate of pollution prevention practices. Given that *TQM* has a differential impact on the adoption rate of different types of pollution prevention practices, and given that firms have different "baseline" rates of employing each of these pollution prevention types, the *TQM* treatment effect will vary by firm, and by type of *P2*. We distinguish between two types of simulations. The first involves the prediction of the likely effect of *TQM* on the adoption of pollution prevention techniques one and 2 years hence by firms that have yet to employ *TQM* at the end of our sample period, 1996. The second type of simulation is retrospective and evaluates the extent to which *TQM* increased the adoption rate of pollution prevention practices by early *TQM*-adopting firms.

3.2.1. Effect of TQM on the Untreated

We first describe the prospective use of our framework, i.e., the use of framework to evaluate the extent to which the adoption of *TQM* by firms that have yet to adopt it would lead to increases in the number of pollution prevention practices adopted by these firms. In particular, we suppose that all of the remaining firms in 1996 that have yet to apply *TQM* in to pollution prevention do so in 1997 and 1998, the immediate two years following the end of our sample. We generate two forecasts: one assumes that the year fixed effects grows at the same rate as it did from 1995 to 1996 and the other assumes that the year fixed effect stays constant at its 1996 value, i.e., with and without secular change. We also assume that the firms in question do not change the number of chemicals they process in each of their facilities. We then use the estimates of obtained by the model given by equations (1) and (2), to generate the one and two year ahead forecasts of the number of adopted pollution prevention techniques by these firms. The one-year ahead predictions are obtained by the equation

$$E[P2^{f}_{ij1997}] = E[P2_{ij1996}]\exp\left\{\alpha_j + \beta\,\Delta\log[TOTP2_{i1995}] + \gamma\,\Delta\log[CUMP2_{i1995}] + \Delta w_{96}\right\} \qquad (3a)$$

where $\Delta x_t = x_{t+1} - x_t$. All the terms on the right hand side of the above equation are known (i.e., there are data or estimated parameters). We use the actual value of $P2_{ijt}$ in 1996 for its expectation $E[P2_{ijt}]$.

We also construct the two year-ahead predictions, i.e., the predictions of the number of pollution prevention techniques adopted the second year after the application of *TQM* on pollution prevention. These predictions are obtained from the equation

$$E[P2^{f}_{ij1998}] = E[P2^{f}_{ij1997}]\exp\left\{\alpha_j + \beta\,\Delta\log[TOTP2^{f}_{i1996}] + \gamma\,\Delta\log[CUMP2^{f}_{i1996}] + \Delta w_{97}\right\} \qquad (3b)$$

Where $E[P2^{f}_{ij1997}]$ is derived by summing up for each firm *i* the count of *P2* from all 43 categories derived from (3a). Observe that unlike in the one year ahead predictions, we no longer take the values of all the variables in the expressions on the right hand side of the above equation (3b) as known. Rather, we use the firm-level one year ahead predictions from (3a), $TOTP2^{f}_{i1997}$, to compute $\Delta\log[TOTP2^{f}_{i1996}]$ and $\Delta\log[CUMP2^{f}_{i1996}]$ using the formula below:

$$\Delta\log[TOTP2^{f}_{i1996}] = \log[TOTP2^{f}_{i1997}] - \log[TOTP2_{i1996}]$$

$$\Delta\log[CUMP2^{f}_{i1996}] = \log[CUMP2_{i1996} + TOTP2^{f}_{i1997}] - \log[CUMP2_{i1996}]$$

In both on and two-year ahead predictions, we make two assumptions on the year fixed effects: one we assume that it is constant at the 1996 level such that $\Delta w_{96} = 0$ or that it grows at the same rate as the 1996 level such that $\Delta w_{95} = \Delta w_{96} = \Delta w_{97}$. We first compute the effect of *TQM* adoption for each type of *P2* to illustrate the variability of the responsiveness of different activities to *TQM*. We then compute the mean count of *Total P2* activities for each firm after summing up the *P2*s over all 43 categories. In computing the effect of *TQM* adoption for each of the firms that have yet to apply it to pollution prevention, we can describe the possible impact of *TQM* adoption of firms that have chosen to delay or postpone *TQM* until 1997.

3.2.2. Effect of TQM on the Treated

As an illustration of a retrospective simulation, we consider the firms that introduced *TQM* tools on pollution prevention for the first time in each year, starting from the second year of our sample. For these firms, we compute the contribution of *TQM* on the adoption of pollution prevention practices for the 1993, 1994, 1995 and 1996 among first-time adopters in each year. Thus, for the year 1993, the forecasted number of adopted pollution prevention practices is given by

$$E[P2^{f}_{ij1993}] = E[P2_{ij1992}]\exp\left\{\beta\,\Delta\log[TOTP2_{i1991}] + \gamma\,\Delta\log[CUMP2_{i1991}] + \Delta w_{1992}\right\} \quad (4a)$$

By aggregating over all practices, *j*, we obtain the counter-factual firm level number of pollution-prevention practices had the firm not adopted *TQM* in 1993, $\log[TOTP2^{f}_{i1993}]$. The corresponding estimates for first time adopters in 1994, 1995 and 1996 can be computed as follows:

$$E[P2^{f}_{ij1994}] = E[P2_{ij1993}]\exp\left\{\beta\,\Delta\log[TOTP2_{i1992}] + \gamma\,\Delta\log[CUMP2_{i1992}] + \Delta w_{1993}\right\} \quad (4b)$$

$$E[P2^{f}_{ij1995}] = E[P2_{ij1994}]\exp\left\{\beta\,\Delta\log[TOTP2_{i1993}] + \gamma\,\Delta\log[CUMP2_{i1993}] + \Delta w_{1994}\right\} \quad (4c)$$

$$E[P2^{f}_{ij1996}] = E[P2_{ij1995}]\exp\left\{\beta\,\Delta\log[TOTP2_{i1994}] + \gamma\,\Delta\log[CUMP2_{i1994}] + \Delta w_{1995}\right\} \quad (4d)$$

These simulations would allow us to describe the how much of the *P2*s adopted by the first-time *TQM* adopters, both early and late in our sample, can be attributed to the management structure. We then compare this with the effect of *TQM* adoption among the non-adopters (the untreated) until 1996, the "very late adopters" and discuss insights on the potential different effect of *TQM* on early and late adopters.

4. DATA DESCRIPTION AND VARIABLE CONSTRUCTION

The sample in this study consists of S&P 500 firms which responded to the IRRC survey on the adoption of corporate environmental management practices and whose facilities reported to the Toxics Release Inventory (TRI) over the period 1992-96. TRI was established under Section 313 of the Emergency Planning and Community Right to Know Act (EPCRA) in 1986. It requires all manufacturing facilities operating under SIC codes 20-39, with 10 or more employees, and which produce or use toxic chemicals above threshold levels to submit a report of their annual releases to the USEPA. Since 1991, reporting of all *P2* activities adopted in that year to reduce the TRI chemicals is mandatory under the National Pollution Prevention Act of 1990. Each facility of a firm is required to report their adoption of any of 43 different pollution prevention activities for each toxic chemical mandated in the TRI in a given year[7]. These activities can be classified into 8 broad categories: (1) changes in operating practices (2) materials and inventory control (3) spill and leak prevention (4) raw material modifications (5) equipment and process modifications (6) rinsing and draining equipment design and maintenance (7) cleaning and finishing practices and (8) product modifications. Table 1 contains the different types of *P2s* under each broad category.

Our dependent variable is the count of new pollution prevention techniques of each of these 43 specific types adopted by a firm during a year. Since pollution prevention is popularly referred to as *P2*, we call this variable *New Specific P2*. We aggregated the number of such practices adopted in a year across chemicals for each facility and then across all facilities belonging to a parent company to obtain *New Specific P2* at the firm-level for that year. To match the facility level TRI data with the parent company level IRRC information on *TQM* adoption, we constructed unique parent company identifiers for each facility in the TRI database.[8] Chemicals which have been added or deleted over the period 1991-1996 were dropped due to changes in the reporting requirements by the USEPA. This ensures that the change in *P2* activities in our sample over time is not due to differences in the chemicals that were required to be reported. Since all S&P 500 companies that reported to the TRI did not respond to the survey by the IRRC, observations with missing data were deleted. Our final sample consists of a five year unbalanced panel of 168 parent companies for a total of 34,400 observations[9].

We construct *Cumulative P2* as the cumulative number of pollution prevention techniques of all types that have been adopted between 1991 (when firms first began reporting this information to the TRI) and year *t-1*. We also constructed the count of all types of *P2s* adopted in the previous year and labeled this as *Lagged P2*. To capture appropriateness of specific *P2s* we also constructed 43 *P2* dummy variables. We control for the number of pollution reduction opportunities a firms has by including the *Number of Chemicals* emitted. This variable is the count of chemicals reported by the firm which is obtained by summing up the chemicals reported by each facility over all facilites of that firm. This controls for the possibility that firms emitting a larger number of chemicals or having a larger number of facilities may adopt more pollution prevention practices simply because they have more opportunities.

To develop the attributes for the *New Specific P2s*, the authors started with brainstorming and developed a list of all possible attributes of these practices. In addition to the five attributes described above, the expanded list included others such as visibility to stakeholders and regulators, practices requiring decision making at the upper vs. lower managerial levels, technological sophistication, and practices that will alter the production process. The characterization of the *New Specific P2s* according to different attributes was done by each of the authors separately. Characterizations of *New Specific P2s* by three other experts in the field of business and environmental strategy were also solicited. We then looked at the correlations among the attributes and found that some were very closely related to each other while for some attributes our confidence on classifying them based on information available in the TRI on that practice was not high. We therefore narrowed the list to five attributes by dropping those for which agreement in assigning them to the pollution prevention practices was relatively low and merging together those with high correlations with each other.[10] The final classification was arrived at through a process of discussion by the authors. It is also important to note, that we kept the "Other" types of *Specific P2s* under each category (19, 29, 39, 49, 58, 71, 78 and 89) because these account for a significant count of *P2s* in each category (See Table 1). We classify them based on the set of attributes that the rest of the *P2s* in that same category possess. If all of *P2s* in a category had a particular attribute, the "Other" *P2s* were assigned the same attribute. Otherwise, due to lack of definitive information on the kind of practices included in "Other", we assume that it does not possess that attribute, and assign it a value of "0".

Correlation between these five attributes is low. Positive correlation of 0.42 is observed between *Procedural* and *Efficiency-Enhancing* attributes and of 0.35 between *Visibility* and

Materials attributes. Both *Equipment* and *Material* are negatively correlated with *Procedural*, with coefficients of -0.36 and -0.43, respectively.

5. RESULTS AND DISCUSSION

5.1. Summary Statistics

The summary statistics in Table 1 show that highest adoption rates for both *TQM* and non-*TQM* adopters are for practice 13 (maintenance scheduling and record-keeping procedures), practice 52 (modification of equipment, lay-out or piping), practice 42 (substitution of raw materials), and practices 19 and 58 (others). Generally, the rate of adoption among *TQM* adopters is higher than that among non-adopters[11]. These practices differ considerably in their attributes. Among the three most widely adopted *P2s*, only activity 52 is characterized by a single attribute, *Equipment*, while the other two activities, 13 and 42, are characterized by two of the remaining four different attributes. Practice 13 involves *Procedural* and *Efficiency-Enhancing* attributes while practice 42 is *Visible* to consumers and involves *Material Modifications*. The annual rates of change from 1992 to 1996 vary widely across different categories of *P2*s. Category 75 increases at an average rate of 112%, the highest among all P2s, while category 61 has the highest average percent reduction of 38%. The average rate of change among the 43 types of *P2* is -6%. For Total *P2*, the average annual rate of change from 1992 to 1996 is -0.12%.

5.2. Estimation of Count Models

We estimate different models that explain the count of each of the 43 different *P2* practices adopted, using count data models, while adjusting the standard errors to incorporate the possibility that the adoption of different types of *P2* by the same firm may not be independent. The estimates in Tables 2 to 4 show that in all models, the firm-specific dummies and the *P2*-specific dummies are always jointly significant, indicating that there are indeed unobservable firm and *P2* effects that need to be accounted for. We use the heteroscedasticity-robust Huber-White sandwich variance estimators to account for non-spherical disturbances.

Tables 2 through 4 contain the regression results for the different models analyzed. Table 2 presents Models I-V. Model I examines the effects of the three technical attributes on adoption by *TQM* firms.[12] Model II is an extension of Model I which includes the log of *Lagged P2* and the log of *Cumulative P2*. Model III and IV, correspond to Models I and II except that in addition to the three technical attributes, we also include the two strategic attributes. Model V is simply a variant of Model IV, where the levels (rather than logs) of *Lagged P2* and *Cumulative P2* are used.

Models I-IV show that not all attributes are important in promoting more *P2s* among *TQM* adopters compared to non-*TQM* adopters. We find that *TQM* adopters have higher adoption rates for *P2s* that involve *Procedural Changes*, but not for *P2s* that involve *Equipment* or *Material* modifications, as evidenced by the positive statistically significant coefficients of *TQM+TQM*Procedure* but insignificant coefficients of *TQM+TQM*Equipment* and *TQM+TQM*Materials*. These results imply that *TQM* enables firms to identify specific areas that require changes in operational practices and procedures that might not be identified by non-*TQM* adopters, possibly because the latter do not benefit from the expertise and knowledge-sharing among various “grass-roots” employees. However, *TQM* may create a counter-productive effect on *P2s* that require *Equipment* or *Material* modifications. Indeed, we find that *TQM*Equipment* and *TQM*Materials* have large negative and statistically significant coefficients which offset the positive coefficient of *TQM*; the impact of these attributes on adoption of *P2* practices by *TQM* adopters is therefore statistically insignificant. This suggests that identification and implementation of the equipment and material modifications needed to prevent pollution do not necessarily require an organizational structure such as *TQM*. These results indicate that *TQM* adopters, compared to *TQM* non-adopters do not undertake more *P2s* that require *Equipment Modifications* or *Material Modifications* or both.

While the technical attributes do not seem to be strong drivers for higher *P2* adoption levels among *TQM* adopters, except for *Procedural Changes*, Models III-IV show that the two strategic attributes of *P2s* are strong significant motivators for higher adoption rates among *TQM* adopters than non-adopters. We find that *TQM+TQM*Consumers* and *TQM+ TQM*Savings* are always positive and statistically significant, implying that the presence of *P2* features that could improve the firm's reputation among consumers and those that could enhance efficiency increase the count of *P2s* adopted by *TQM* firms. These findings support our expectation that product-related improvements and cost-reducing activities are more likely to be implemented by firms that have a *TQM* framework because they are in a better position to have the tools and the communication networks to identify such practices.

In addition to *P2* attributes, we find that experience with *P2* adoption in the past has two distinct effects on *New Specific P2* adoption: learning effects as well as diminishing returns. We find that while specific *Lagged Specific P2* leads to higher levels of *New Specific P2*, the *Cumulative P2* adopted has a negative effect on incremental adoption rates. This implies that while adoption of *Specific P2* in the past contributed to the complementary assets and expertise available to a firm and aids the adoption of more *New Specific P2*, the stock of knowledge from all types of *P2* that a firm has adopted until *t-1* has a negative effect, suggesting diminishing returns to *P2* adoption.

All models also consistently show that the number of opportunities to undertake *P2* activities increases the count of *New Specific P2s* adopted. Further, Model V shows the robustness of the preceding results. Except for *Cumulative P2* which has a statistically insignificant effect when measured in levels, all other results discussed above are invariant to the use of levels or logs of *Lagged P2* and *Cumulative P2*. We also find evidence of secular trends in technical change, as evidenced by the positive and significant signs of the year dummies in Models II, IV and V after controlling for the dynamic effects of past *P2* adoption (*Lagged P2* and *Cumulative P2*). However, the negative significant signs of the time dummies in models I and III indicate that, in those models, diminishing returns are being captured by the time dummies because *Lagged P2* and *Cumulative P2* are not accounted for.

We investigate the effect of the technical attributes further by combining *Equipment Modifications* and *Material Modifications* into *Physical Modifications* in Models VI and VII in Table 3. Results show that *P2s* that require any type of *Physical Modifications* do not result in *TQM* adopters undertaking more *P2* than *TQM* non-adopters. However, *Procedural Changes*, and the two strategic attributes, *Visibility to Consumers* and *Production-Efficiency-Enhancing* continue to be the key attributes promoting *P2* adoption by *TQM* firms. Because most of the *P2s* that are *Production-Efficiency Enhancing* involve *Procedural Changes* (see Table 1) we also analyzed models where the *Production-Efficiency Enhancing* attribute is dropped from the models (Models VIII and IX). We find results that are similar to those derived above: *TQM* motivates the adoption of more *P2s* that are *Visible to Consumers* and involve *Procedural Changes*.

We also analyze whether the effect of *TQM* on *P2* adoption varies between firms who always adopted *TQM* (at least during our sample period), i.e., the *Existing TQM Adopters*, and those who switched from non-adoption to adoption within our sample period, the *New TQM Adopters*. These models are presented in Table 4. Models X, XI, XII and XIII correspond to Models IV, VI, VII and IX, but they now allow for a differential effect of *TQM* between *Existing TQM Adopters* and *New TQM* Adopters. We constructed a *New TQM* dummy variable to indicate the first time that a firm adopts *TQM*. Models XI-XIII show that while *Existing TQM Adopters* do not undertake more *P2s* that involve *Equipment* and *Material Modifications*, *New TQM Adopters* do, as shown by the positive significant coefficients for *TQM+New TQM*+TQM*Equipment and TQM+New TQM*+TQM*Materials*. However, the converse is true for *P2s* that are *Production Efficiency-Enhancing*. It is the *Existing TQM Adopters* that adopt more of this type of *P2*, rather than the *New TQM Adopters*. One possible explanation for this is that existing adopters of *TQM* might have decided to adopt *P2* early primarily to gain competitive advantage by reducing waste and costs while increasing the appeal of their products to consumers,. With increasing environmental consciousness among the public and growing stringency of environmental regulations, the later adopters of *TQM*, the *New Adopters*, on the other hand, may be more willing to adopt practices that involve modifications to equipment and materials to reduce pollution at source. We do not find conclusive evidence that there is a difference in the effect *TQM* between *Existing* and *New TQM Adopters* on *P2s* that involve *Procedural Changes* and those which are *Visible to Consumers*.

Finally, we also find that other types of *P2*s that do not possess the attributes identified above respond very strongly to *TQM* as evidenced by the strong and positive significance of the coefficient of *TQM* in all models. These *P2*s may comprise the less typical types of *P2*s as classified by the regulator, and instead, may be composed of those types which firms themselves developed. This further indicates the bottom-up nature of *TQM* which stimulates adoption of innovative *P2*s.

5.3. Simulations

We use the results of Model IV for our simulations which consist of two parts. The first part consists of counterfactual predictions of *P2* counts among *TQM* non-adopters in 1996 if they will adopt *TQM* in 1997 and 1998, and the second part consist of the predicted *P2* counts of first-time *TQM* adopters in each year had they not adopted *TQM*.

The predicted count of *P2*s in 1997 and 1998 among firms who have yet to adopt *TQM* in 1996 and these results are shown in Table 5. (We only show the result with year fixed effects. The forecasts without year fixed effects are lower than the ones with fixed effects). We can see that when these firms will adopt in 1997, they will adopt on average, 44% fewer *Total P2* than they did in 1996 when they did not adopt *TQM*. These predicted rates of change among late adopters are a lot higher than the 12% average rate of reduction in *Total P2* over the 1992-1996 period (last column of Table 1). Further, the count of *P2* from all *P2* categories will fall. The highest rate of reduction is 83% for categories 35 (Installation of vapor recovery systems) and 64 (Improvement of draining procedures), and the lowest is 35% for category 19 (Other changes in operating practices).

The forecasts for 1998 are slightly higher than those in 1997, with *Total P2* higher by 16% on the average, but still much lower than the count of *P2*s in 1996, when they have not yet adopted *TQM*. These results seem to imply that there may be some firm-specific motivations for delaying or not adopting *TQM* at all. These firms may already have another organizational structure in place that is more suitable to the types of *P2* activities they choose to undertake than *TQM* is.

The results of the retrospective counterfactual simulation which estimates how much of the *P2* adopted by early *TQM* adopters can be attributed to *TQM* is in Table 6. These are the firms who adopt *TQM* for the first time in 1993. We find that on average, 19% of *Total P2* undertaken by early *TQM* adopters in 1993 can be attributed to the organizational structure, *TQM*. On a *P2* category level, while the average *P2* adoption rates due to *TQM* seem modest, the variations across different types of *P2*s are quite substantial and show that *TQM* accounts for a large portion of some of the *P2*s adopted. For example, in 1993, out of 43 *P2* categories, 25 categories get a boost from *TQM* (hence, the negative figures or a % reductions indicated in the 5th column), and for one *P2*s category, 67 (Improved rinse equipment design), *TQM* accounts for 100% of the count of these *P2s*. On the other hand, there are also 12 *P2* categories would have had higher counts of *P2* had these early adopters not adopted *TQM* (hence the positive figures or % increases indicated in the 5th column)[4]. Our findings show that not adopting *TQM* would increase the average adoption of one type of *P2*, 51 (Instituted recirculation within a process) by more than 137% if *TQM* early adopting firms had chosen not to use *TQM*.

In 1994-1996, different types of *P2*s experience a boost from the organizational structure among the new *TQM* adopters. In 1994 only 4% of the *Total P2*, on average can be attributed to *TQM*. However, the effect on each type of *P2* also varies significantly across each of the 43 categories. For 1995 and 1996, the *TQM* was shown to have a negative effect on *Total P2*. Hypothetically taking away the effect of organizational structure increases *Total P2* by 0.1% and 57% in 1995, and 1996, respectively.

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[4] This includes the 23 and 83 which will have positive counts without *TQM*, and zero counts with *TQM*, in italics. One has zero actual and zero predicted P2.

These two simulations imply that *TQM* does not have uniform effect across all types of *P2*s, and that it does not have a uniform effect between early and late *TQM* adopters. The last two simulations, particularly show the appropriateness of *TQM* varies for different firms. Early *TQM* adopters may derive more value from the organizational structure *TQM* provides, or may find it to be more suitable to their existing organizational structure or innovation strategy, which might be the reason they adopted *TQM* early. In contrast, "late adopters" may be better off not adopting *TQM* at all since it will on average reduce *P2* counts. These may be the firms whose technical capacity are suitable to certain types of *P2*s, which may not require *TQM*, or its organizational structure that is different from TQM may be more suited to the types of innovative activities it undertakes, the way *TQM* is for early *TQM* adopters. This may be the reason they had not adopted *TQM* as late as 1996.

6. Conclusions

Organizational structure plays a large role in dictating the number and type of innovative activities that firms undertake. The impact of a management structure such as *TQM*, on different *P2* activities is not uniform because some *P2* activities are more complementary to the philosophy of quality management than others. These are the *P2*s that improve overall firm quality by boosting a firm's competitiveness through improved reputation among consumers and enhanced efficiency. *TQM* does not seem to promote specific improvements in the physical composition of inputs and equipment among all *TQM* adopters, but instead, it stimulates these activities among late *TQM* adopters only.

Because the effect of *TQM* on *P2*s is not uniform, we were able to use our model to predict how different *P2*s of late and future adopters are affected by *TQM* and to isolate the number of *P2*s that can be attributed to *TQM* among early and late *TQM* adopters. While as much as 12% of *Total P2*s of early *TQM* adopters (those who first adopted in 1993) can be attributed to the management structure, late adopters (those who first to adopt in 1997) may undertake approximately 44% fewer *P2*s activities than they did in 1996 if they will be adopt *TQM* in 1997. These preceding two results together have implications on both the suitability and timing of the effect of *TQM* on particular *P2*s. They suggest that *TQM* adoption and *P2* activities are indeed firm-specific. Because, *TQM* is not adopted by all firms at the same time, our results lend further credence to the assertion that *TQM* may not be a suitable an innovation driver to all types of firms and will have different impacts on a firm's innovative activities, which in turn depend on when *TQM* is adopted.

Table 1. Types of *P2*, their Attributes and Mean and Standard Deviations of *P2* Adoption Rates.

P2 Activities and Codes		Consumer	Equipment	Materials	Procedure	Savings	Remarks	*TQM* Adopters	Non-*TQM* Adopters	Total Sample	Average Annual Δ In P2
1 Good Operating Practices	W13 Improved maintenance scheduling, record keeping, or procedures				✓	✓	This activity involves changes in procedures for basic upkeep and for documentation of activities which provides firms with time savings.	2.990 (6.202)	2.165 (4.293)	2.685 (5.584)	(0.10)
	W14 Changed production schedule to minimize equipment and feedstock changeovers				✓	✓	Similar to W13, for procedural changes associated with planning of operating activities.	0.970 (3.186)	0.716 (2.493)	0.876 (2.949)	(0.20)
	W19 Other changes made in operating practices				✓	✓	Similar to W13 and W14.	3.519 (17.244)	2.426 (4.381)	3.115 (6.356)	(0.05)
2 Inventory Control	W21 Instituted procedures to ensure that materials do not stay in inventory beyond shelf-life				✓	✓	It is a procedural change as it involves modifications in the cataloging of and accounting of stocks and materials. As such, it saves inventory costs and reduces disposal of expired materials.	0.633 (2.163)	0.436 (1.222)	0.560 (1.872)	0.03
	W22 Began to test outdated material — continue to use if still effective				✓	✓	Similar to category W21.	0.175 (1.246)	0.155 (0.656)	0.168 (1.066)	(0.16)
	W23 Eliminated shelf-life requirements for stable materials					✓	This activity saves inventory costs by improving management of inputs and materials. It may or may not be a procedural change.	0.006 (0.077)	0.024 (0.152)	0.012 (0.111)	0.18
	W24 Instituted better labeling procedures				✓	✓	This improves procedures for the classification of supplies and in effect provides time savings.	0.127 (0.834)	0.139 (0.574)	0.131 (0.748)	(0.12)
	W25 Instituted clearinghouse to exchange materials that would otherwise be discarded [b/]					✓	Similar to W23.	0.181 (0.791)	0.047 (0.242)	0.131 (0.648)	(0.10)
	W29 Other changes made in inventory control					✓	Characterization of these activities depends on W23 and W25, See footnote [b/].	0.700 (2.486)	0.341 (1.364)	0.568 (2.146)	(0.02)

Table 1. *(continued)*

P2 Activities and Codes		Consumer	Equipment	Materials	Procedure	Savings	Remarks	*TQM* Adopters	Non-*TQM* Adopters	Total Sample	Average Annual Δ In P2
3 Spill and Leak Prevention	W31 Improved storage or stacking procedures				✓	✓	This activity involves changing the system for organization of materials and equipment and can save time and space.	0.359 (1.400)	0.314 (1.244)	0.236 (0.916)	0.11
	W32 Improved procedures for loading, unloading, and transfer operations				✓	✓	Similar to W31, except it is a procedural change for transporting materials and equipment.	0.552 (1.746)	0.595 (1.734)	0.669 (1.715)	(0.27)
	W33 Installed overflow alarms or automatic shut-off valves		✓			✓	Installation of such fixtures can save costs of cleanup as it can prevent leaks and spills.	0.194 (0.904)	0.170 (0.803)	0.128 (0.591)	(0.12)
	W35 Installed vapor recovery systems		✓			✓	This equipment change can serve to save of clean up costs associated with residue from vapors and can also conserve material.	0.401 (1.339)	0.286 (1.106)	0.091 (0.438)	(0.31)
	W36 Implemented inspection or monitoring program of potential spill or leak sources				✓	✓	This is a procedural change which can save firms cost of clean-up.	1.998 (6.562)	1.530 (5.406)	0.733 (2.171)	(0.15)
	W39 Other changes made in spill and leak prevention					✓	Other category 3 *P2s* are presumed to provide savings like all other category 3 *P2s*. However, we cannot characterize them according to other attributes,	1.450 (4.078)	1.114 (3.407)	0.540 (1.600)	(0.08)
4 Raw Material Modifications	W41 Increased purity of raw materials			✓			This activity involves a physical change in materials and inputs Raw material modifications may or may not bring about savings.	0.169 (0.695)	0.149 (0.616)	0.115 (0.451)	(0.20)
	W42 Substituted raw materials	✓		✓			Similar to W41.	2.268 (4.160)	2.029 (3.947)	1.622 (3.525)	(0.11)
	W49 Other raw material modifications made			✓			Similar to W41 and W42.	0.891 (3.439)	0.681 (2.791)	0.324 (0.857)	0.14

Table 1. *(continued)*

P2 Activities and Codes		Consumer	Equipment	Materials	Procedure	Savings	Remarks	*TQM* Adopters	Non-*TQM* Adopters	Total Sample	Average Annual Δ In P2
5 Process Modifications	W51 Instituted re-circulation within a process		✓			✓	This activity involves installation of new equipment It may provide savings.	0.609 (1.446)	0.794 (2.663)	0.677 (1.986)	(0.22)
	W52 Modified equipment, layout, or piping		✓				It involves physical equipment changes. It may or may not bring about savings.	2.313 (5.183)	2.051 (3.960)	2.216 (4.766)	(0.13)
	W53 Used a different process catalyst			✓			The use of a new catalyst is a change in materials used. It may or may not bring about savings.	0.077 (0.399)	0.101 (0.416)	0.086 (0.405)	(0.27)
	W54 Instituted better controls on operating bulk containers to minimize discarding of empty containers				✓	✓	This is a procedural activity that needs to be done regularly as part of periodic checks in operations. This can also provide firms savings in clean up costs from possible spills that may result from operation of bulk containers.	0.357 (1.414)	0.166 (0.752)	0.286 (1.215)	(0.06)
	W55 Changed from small volume containers to bulk containers to minimize discarding of empty containers		✓			✓	These involve physical changes and can provide savings in packaging and waste disposal.	0.212 (0.946)	0.348 (1.537)	0.262 (1.200)	(0.15)
	W58 Other process modifications made						It is difficult to characterize "other" category 5 *P2s* due to differences among *P2s* in this category.	3.304 (7.168)	1.753 (3.606)	2.730 (6.141)	(0.11)
	W59 Modified stripping/cleaning equipment		✓				Similar to W52.	0.226 (0.931)	0.115 (0.553)	0.185 (0.813)	(0.20)
6 Cleaning and Decreasing	W60 Changed to mechanical stripping/cleaning devices (from solvents or other materials)		✓				Because this activity involved a shift from material inputs to a physical equipment it is characterized by both equipment and material modifications.	0.058 (0.382)	0.071 (0.366)	0.062 (0.376)	(0.09)
	W61 Changed to aqueous cleaners (from solvents or other materials)			✓			This is a change in materials.	0.811 (2.343)	0.682 (1.952)	0.764 (2.206)	(0.38)
	W63 Modified containment procedures for cleaning units				✓		This is a procedural change.	0.067 (0.372)	0.034 (0.215)	0.055 (0.323)	(0.19)
	W64 Improved draining procedures				✓		Similar to W63.	0.097 (0.437)	0.010 (0.100)	0.065 (0.355)	(0.10)
	W65 Redesigned parts racks to reduce drag out		✓				This is a physical equipment change.	0.026 (0.193)	0.020 (0.163)	0.024 (0.182)	(0.28)

Table 1. *(continued)*

	P2 Activities and Codes	Consumer	Equipment	Materials	Procedure	Savings	Remarks	*TQM* Adopters	Non-*TQM* Adopters	Total Sample	Average Annual Δ In P2
6 Cleaning and Decreasing	W66 Modified or installed rinse systems		✓				Similar to W65 except that it does not involve material modification	0.029 (0.192)	0.020 (0.183)	0.026 (0.189)	(0.11)
	W67 Improved rinse equipment design		✓				Similar to W65 and W66.	0.083 (0.543)	0.024 (0.192)	0.061 (0.447)	0.12
	W68 Improved rinse equipment operation				✓		Similar to W63 and W64.	0.153 (1.010)	0.024 (0.152)	0.105 (0.809)	(0.06)
7 Surface Preparation and Finishing	W71 Other cleaning and decreasing modifications made						It is difficult to characterize “other” category 7 *P2s* due to differences among *P2s* in this category.	0.514 (1.303)	0.358 (1.144)	0.456 (1.248)	(0.28)
	W72 Modified spray systems or equipment		✓				Similar to W65, W66 and W67.	0.308 (1.429)	0.324 (1.488)	0.314 (1.450)	(0.22)
	W73 Substituted coating materials used			✓			This involves a physical change in materials.	0.621 (1.810)	0.834 (2.354)	0.700 (2.029)	0.02
	W74 Improved application techniques				✓		This may only be a procedural change since the physical changes are covered by W72 and W73.	0.549 (3.291)	0.294 (1.469)	0.455 (2.762)	0.04
	W75 Changed from spray to other system		✓				Similar to W72.	0.046 (0.413)	0.064 (0.507)	0.052 (0.449)	1.12
	W78 Other surface preparation and finishing modifications made						It is difficult to characterize “other” category 7 *P2s* due to differences among *P2s* in this category.	0.117 (0.535)	0.071 (0.337)	0.100 (0.472)	(0.21)
Model8 Product Modifications	W81 Changed product specifications	✓					This activity is visible to consumers but may not require changes in physical equipment or materials.	0.401 (1.392)	0.311 (1.311)	0.367 (1.363)	(0.17)
	W82 Modified design or composition of product	✓		✓			This is also visible to consumers but may or may not involve equipment modification. However, change in composition implies changes in materials.	0.556 (1.836)	0.297 (0.867)	0.460 (1.554)	0.03
	W83 Modified packaging	✓		✓			Packaging is definitely visible to consumers and usually involves physical change in material.	0.014 (0.117)	0.027 (0.259)	0.019 (0.183)	0.38
	W89 Other product modifications made	✓					Other product modifications would definitely visible to consumers. However, other attributes may or may not be present.	0.442 (1.912)	0.206 (0.756)	0.355 (1.5389)	0.27
Total P2								29.58 (46.38)	19.91 (28.67)	26.00 (41.00)	0.12

Table 2. The Role of Technical versus Strategic Attributes on *P2* Adoption.

Variables	Model I	Model II	Model III	Model IV	Model V
TQM	0.488 (4.65)***	0.444 (4.35)***	0.484 (4.21)***	0.44 (3.94)***	0.566 (4.94)***
*TQM**Equipment	-0.56 (5.15)***	-0.56 (5.16)***	-0.554 (5.04)***	-0.554 (5.06)***	-0.554 (5.05)***
*TQM**Materials	-0.366 (3.60)***	-0.366 (3.62)***	-0.39 (3.18)***	-0.39 (3.20)***	-0.39 (3.20)***
*TQM**Procedure	-0.242 (2.63)***	-0.242 (2.64)***	-0.231 (2.03)**	-0.231 (2.03)**	-0.231 (2.03)**
*TQM**Consumer			0.05 (0.410)	0.05 (0.410)	0.05 (0.410)
*TQM**Savings			-0.007 (0.070)	-0.007 (0.070)	-0.007 (0.070)
Total Lagged *P2*		0.645 (6.33)***		0.645 (6.33)***	0.004 (3.80)***
Cumulative Total *P2*		-0.704 (2.84)***		-0.704 (2.84)***	0 -0.04
Number of Chemicals	0.87 (5.48)***	0.696 (4.40)***	0.87 (5.48)***	0.696 (4.40)***	0.893 (5.69)***
Year 2	-0.116 (2.20)**	0.403 (2.31)**	-0.116 (2.20)**	0.403 (2.30)**	-0.078 -1.46
Year 3	-0.227 (4.03)***	0.588 (2.20)**	-0.227 (4.03)***	0.588 (2.20)**	-0.162 (2.73)***
Year 4	-0.406 (6.85)***	0.668 (1.99)**	-0.406 (6.85)***	0.668 (1.99)**	-0.297 (4.64)***
Year 5	-0.539 (8.94)***	0.743 (1.92)*	-0.539 (8.94)***	0.743 (1.92)*	-0.386 (5.63)***
Constant	-4.548 (4.39)***	-4.572 (4.41)***	-4.547 (4.39)***	-4.572 (4.41)***	-4.617 (4.46)***
TQM+*TQM**Equipment	-0.073 (0.67)	-0.117 (1.10)	-0.071 (0.61)	-0.114 (1.01)	0.012 (0.10)
TQM+*TQM**Materials	0.121 (1.15)	0.077 (0.76)	0.094 (0.72)	0.050 (0.39)	0.177 (1.35)
TQM+*TQM**Procedure	0.246 (2.61)***	0.202 (2.23) **	0.252 (1.74)*	0.208 (1.47)	0.335 (2.31)**
TQM+*TQM**Consumers			0.533 (3.51)***	0.489 (3.27)	0.616 (4.03)***
TQM+*TQM**Savings			0.477 (3.85)***	0.433 (3.54)***	0.559 (4.49)***
Firm dummies (χ^2 stat)	1872.95***	5246.96***	1843.44***	275.24***	1390.09***
P2 dummies (χ^2 stat)	5218.30***	275.24***	5219.76***	52248.82***	5226.25***
Residual squared	98.0	77.76	98.04	77.76	88.13
Number of Observations	34400	34400	34400	34400	34400

[a/] Lagged *P2* and Cumulative *P2* are in logs. [b/] Lagged *P2* and Cumulative *P2* are in levels. t-statistics in parentheses: *** Significant at 1%, ** significant at 5%, * significant at 10%.

Table 3. The Role of Physical Attributes and Efficiency-Enhancing Attributes on *P2* Adoption.

Variables	Model VI	Model VII	Model VIII	Model IX
TQM	0.483 (4.20)***	0.439 (3.93)***	0.481 (4.53)***	0.438 (4.23)***
*TQM**Equipment			-0.554 (5.04)***	-0.554 (5.06)***
*TQM**Materials			-0.388 (3.26)***	-0.388 (3.28)***
*TQM**Physical	-0.486 (5.12)***	-0.486 (5.14)***		
*TQM**Procedure	-0.205 (1.83)*	-0.205 (1.83*	-0.236 (2.53)**	-0.236 (2.54)**
*TQM**Consumer	0.13 (1.26)	0.13 (1.27)	0.051 (0.41)	0.051 (0.42)
*TQM**Savings	-0.03 (0.32)	-0.03 (0.32)		
Lagged Total *P2*		0.645 (6.33)***		0.645 (6.33)***
Cumulative Total *P2*		-0.704 (2.84)***		-0.704 (2.84)***
Number of Chemicals	0.87 (5.48)***	0.696 (4.40)***	0.87 (5.48)***	0.696 (4.40)***
Year 2	-0.116 (2.20)**	0.403 (2.30)**	-0.116 (2.20)**	0.403 (2.30)**
Year 3	-0.227 (4.03)***	0.588 (2.20)**	-0.227 (4.03)***	0.588 (2.20)**
Year 4	-0.406 (6.86)***	0.668 (1.99)**	-0.406 (6.85)***	0.668 (1.99)**
Year 5	-0.539 (8.95)***	0.743 (1.92)*	-0.539 (8.94)***	0.743 (1.92)*
Constant	-4.546 (4.38)***	-4.571 (4.41)***	-4.548 (4.39)***	-4.572 (4.41)***
TQM+*TQM**Equipment			-0.073 (0.67)	-0.117 (1.10)
TQM+*TQM**Materials			0.094 (0.72)	0.049 (0.39)
TQM+*TQM**Physical	-0.003 (0.03)	0.0047 (0.47)		
TQM+*TQM**Procedure	0.278 (1.93)*	0.234 (1.66)*	0.246 (2.61)***	0.202 (2.23)**
TQM+*TQM**Consumers	0.613 (4.39)***	0.569 (4.15)***	0.532 (3.57)***	0.488 (3.33)***
TQM+*TQM**Savings	0.449 (3.70)***	0.405 (3.38)***		
Firm dummies (χ^2 stat)	1874.35***	275.31***	1873.41***	275.23***
P2 dummies (χ^2 stat)	5238.45***	5267.74***	5215.95***	5244.79***
Residual squared	98.04	77.76	98.04	77.76
Number of Observations	34400	34400	34400	34400

t-statistics in parentheses: *** Significant at 1%, ** significant at 5%, * significant at 10%.

Table 4. Adoption of *P2* by Existing *TQM* Adopters and New *TQM* Adopters.

	Model X	Model XI	Model XII	Model XIII
TQM	0.526 (4.01)***	0.512 (3.92)***	0.555 (4.15)***	0.449 (3.74)***
*TQM**Equipment	-0.478 (4.19)***			-0.479 (4.20)***
*TQM**Materials	-0.454 (3.65)***			-0.469 (3.92)***
*TQM**Physical		-0.47 (4.76)***	-0.47 (4.75)***	
*TQM**Procedure	-0.255 (2.22)**	-0.249 (2.20)**	-0.249 (2.19)**	-0.218 (2.23)**
*TQM**Consumer	0.044 (0.35)	0.062 (0.56)	0.062 (0.56)	0.035 (0.27)
*TQM**Savings	0.062 (0.58)	0.055 (0.52)	0.055 (0.52)	
New *TQM**Equipment	-0.357 (2.45)**			-0.354 (2.46)**
New *TQM**Materials	0.22 (1.22)			0.298 (1.66)*
New *TQM**Physical		-0.064 (0.50)	-0.064 (0.50)	
New *TQM**Procedure	0.123 (0.57)	0.203 (0.98)	0.203 (0.98)	-0.077 (0.58)
New *TQM**Consumer	0.018 (0.11)	0.253 (1.90)*	0.253 (1.90)*	0.055 (0.32)
New *TQM**Savings	-0.319 (1.52)	-0.39 (1.95)*	-0.39 (1.94)*	
Total Lagged *P2*	0.645 (6.35)***	0.645 (6.33)***		0.645 (6.35)***
Cumulative Total *P2*	-0.704 (2.85)***	-0.704 (2.84)***		-0.704 (2.84)***
Number of Chemicals	0.696 (4.40)***	0.696 (4.40)***	0.87 (5.48)***	0.696 (4.41)***
Year 2	0.403 (2.31)**	0.403 (2.30)**	-0.116 (2.20)**	0.403 (2.31)**
Year 3	0.588 (2.21)**	0.588 (2.20)**	-0.227 (4.04)***	0.588 (2.20)**
Year 4	0.668 (1.99)**	0.668 (1.99)**	-0.406 (6.87)***	0.668 (1.99)**
Year 5	0.743 (1.93)*	0.743 (1.92)*	-0.539 (8.96)***	0.743 (1.92)*
Constant	-4.571 (4.41)***	-4.57 (4.41)***	-4.546 (4.38)***	-4.572 (4.41)***

Table 4. (*continued*).

	Model X	Model XI	Model XII	Model XIII
TQM + *TQM**Equipment	0.048 (0.32)			-0.03 (0.22)
TQM + *TQM**Materials	0.072 (0.46)			-0.02 (0.14)
TQM + *TQM**Physical		0.042 (0.31)	0.086 (0.62)	
TQM + *TQM**Procedure	0.271 (1.66)*	0.263 (1.63)	0.307 (1.86)*	0.231 (1.80)*
TQM + *TQM**Consumers	0.569 (3.24)***	0.573 (3.48)***	0.617 (3.67)***	0.483 (2.86)***
TQM + *TQM**Savings	0.588 (3.94)***	0.566 (3.84)***	0.610 (4.07)***	
TQM + New *TQM**Equipment + *TQM**Equipment	-0.309 (2.13)**			-0.385 (2.90)***
TQM + New *TQM**Equipment + *TQM**Materials	0.292 (1.59)*			0.277 (1.49)
TQM + New *TQM**Physical+ *TQM**Physical		-0.023 (0.18)	0.021 (0.16)	
TQM+ New *TQM**Procedure + *TQM**Procedure	0.394 (1.59)	0.466 (1.96)**	0.510 (2.12)**	0.154 (1.45)**
TQM + New *TQM**Consumers + *TQM**Consumers	0.588 (2.95)***	0.826 (5.07)***	0.869 (5.30)***	0.538 (2.69)***
TQM + New *TQM**Savings + *TQM**Savings	0.269 (1.30)	0.176 (0.87)	0.219 (1.09)	
Firm dummies (χ^2 stat)	276.15***	275.45***	1872.57***	275.72***
P2 dummies (χ^2 stat)	5272.68***	5266.50***	5236.17***	5282.84***
Residual squared	77.76	77.76	98.04	77.76
Number of Observations	34400	34400	34400	34400

Lagged *P2* and Cumulative *P2* are in logs for all models in this table. t-statistics in parentheses: [/]*** Significant at 1%, ** significant at 5%, * significant at 10%.. [b/] Using only technical attributes in Model X yields similar conclusions; [c/] Dropping *Production Efficiency-Enhancing* attribute and separating *Physical Modifications* into *Equipment Modifications* and *Material Modifications* in Model XII yields similar results.

Table 5. Predicted P2 Counts of Late TQEM Adopters w/ and w/o Secular Change.

P2 Category	1996 Actual Without TQEM	Forecast with TQM 1997 w/ Year Fixed Effects		% Change from Previous Year	
		1997	1998	1997	1998
W13 Improved maintenance scheduling, record keeping, or procedures	2.07 (3.32)	1.34 (2.25)	1.48 (2.48)	(0.35)	0.11
W14 Changed production schedule to minimize equipment and feedstock changeovers	0.48 (1.55)	0.22 (0.76)	0.21 (0.73)	(0.54)	(0.03)
W19 Other changes made in operating practices	2.26 (3.15)	1.46 (2.32)	1.69 (2.74)	(0.35)	0.16
W21 Instituted procedures to ensure that materials do not stay in inventory beyond shelf-life	0.52 (1.31)	0.30 (0.97)	0.36 (1.26)	(0.43)	0.22
W22 Began to test outdated material — continue to use if still effective	0.10 (0.37)	0.03 (0.11)	0.03 (0.14)	(0.71)	0.17
W23 Eliminated shelf-life requirements for stable materials	0.02 (0.15)	0.01 (0.04)	0.01 (0.04)	(0.75)	(0.09)
W24 Instituted better labeling procedures	0.14 (0.47)	0.06 (0.20)	0.07 (0.25)	(0.61)	0.19
W25 Instituted clearinghouse to exchange materials that would otherwise be discarded	0 0	0 0	0 0	0	0
W29 Other changes made in inventory control	0.24 (0.73)	0.10 (0.37)	0.11 (0.41)	(0.56)	0.10
W31 Improved storage or stacking procedures	0.31 (1.05)	0.18 (0.73)	0.22 (0.96)	(0.42)	0.24
W32 Improved procedures for loading, unloading, and transfer operations	0.43 (0.97)	0.20 (0.52)	0.21 (0.56)	(0.53)	0.05
W33 Installed overflow alarms or automatic shut-off valves	0.12 (0.63)	0.05 (0.24)	0.05 (0.25)	(0.55)	0.01
W35 Installed vapor recovery systems	0.02 (0.15)	0.004 (0.03)	0.003 (0.02)	(0.83)	(0.23)
W36 Implemented inspection or monitoring program of potential spill or leak sources	0.76 (1.83)	0.44 (1.52)	0.54 (2.02)	(0.42)	0.21
W39 Other changes made in spill and leak prevention	0.43 (1.11)	0.18 (0.51)	0.18 (0.55)	(0.58)	0.03
W41 Increased purity of raw materials	0 0	0 0	0 0	0	0
W42 Substituted raw materials	1.24 (2.13)	0.80 (1.30)	1.08 (1.84)	(0.36)	0.35
W49 Other raw material modifications made	0.36 (0.79)	0.19 (0.47)	0.29 (0.88)	(0.47)	0.51
W51 Instituted re-circulation within a process	0.19 (0.45)	0.07 (0.19)	0.09 (0.24)	(0.61)	0.19
W52 Modified equipment, layout, or piping	1.86 (2.97)	1.04 (1.94)	1.22 (2.39)	(0.44)	0.17
W53 Used a different process catalyst	0 0	0 0	0 0	0	0

Table 5. *(continued)*.

W54 Instituted better controls on operating bulk containers to minimize discarding of empty containers	0.31 (1.20)	0.16 (0.69)	0.17 (0.72)	(0.49)	0.04
W55 Changed from small volume containers to bulk containers to minimize discarding of empty containers	0.24 (1.27)	0.12 (0.66)	0.12 (0.71)	(0.51)	0.05
W58 Other process modifications made	1.45 (2.35)	0.90 (1.70)	1.07 (2.11)	(0.38)	0.19
W59 Modified stripping/cleaning equipment	0.10 (0.48)	0.03 (0.13)	0.02 (0.11)	(0.73)	(0.14)
W60 Changed to mechanical stripping/cleaning devices (from solvents or other materials)	0 0	0 0	0 0	0	0
W61 Changed to aqueous cleaners (from solvents or other materials)	0.21 (0.72)	0.10 (0.30)	0.11 (0.34)	(0.56)	0.11
W63 Modified containment procedures for cleaning units	0.02 (0.15)	0.004 (0.03)	0.003 (0.02)	(0.83)	(0.23)
W64 Improved draining procedures	0.02 (0.15)	0.00 (0.03)	0.00 (0.02)	(0.83)	(0.23)
W65 Redesigned parts racks to reduce drag out	0 0	0 0	0 0	0	0
W66 Modified or installed rinse systems	0 0	0 0	0 0	0	0
W67 Improved rinse equipment design	0.02 (0.15)	0.01 (0.07)	0.01 (0.07)	(0.55)	0.07
W68 Improved rinse equipment operation	0 0	0 0	0 0	0	0
W71 Other cleaning and decreasing modifications made	0.05 (0.22)	0.01 (0.05)	0.01 (0.05)	(0.78)	0.02
W72 Modified spray systems or equipment	0.26 (0.86)	0.11 (0.42)	0.12 (0.40)	(0.56)	0.04
W73 Substituted coating materials used	0.98 (2.88)	0.60 (1.84)	0.67 (2.06)	(0.39)	0.12
W74 Improved application techniques	0.19 (0.71)	0.10 (0.39)	0.11 (0.43)	(0.48)	0.08
W75 Changed from spray to other system	0.10 (0.62)	0.05 (0.30)	0.05 (0.29)	(0.51)	(0.04)
W78 Other surface preparation and finishing modifications made	0 0	0 0	0 0	0	0
W81 Changed product specifications	0.31 (1.70)	0.13 (0.80)	0.12 (0.73)	(0.57)	(0.08)
W82 Modified design or composition of product	0.29 (0.86)	0.12 (0.40)	0.13 (0.44)	(0.59)	0.11
W83 Modified packaging	0.02 (0.15)	0.01 (0.04)	0.01 (0.04)	(0.75)	(0.09)
W89 Other product modifications made	0.17 (0.70)	0.07 (0.30)	0.07 (0.29)	(0.58)	(0.03)
Total P2	16.29 (16.74)	9.19 (7.54)	10.64 (7.83)	(0.44)	0.16

Standard deviations are in parentheses.

End Notes

[1] This is referred to as Total Quality Environmental Management (TQEM). The Global Environmental Management Initiative is recognized as the creator of TQEM which embodies four key principles: customer identification, continuous improvement, doing the job right first time, and a systems approach (http://www.bsdglobal.com/tools/systems_tqem.asp).

[2] TQM is "science-based because individuals at all levels of the organization are trained to use scientific method in everyday decision making. It is non-hierarchical in that it provides a process for allocating decision rights in ways that do not correspond to the traditional corporate hierarchy.

[3] Technology characteristics have been shown to be significant drivers for the adoption and diffusion of specific technologies in other areas. Innovations that are costly and require a considerable investment were found to diffuse at a slower rate in manufacturing industries (Romeo 1975&1977, Stoneman and Karshenas 1993). Similarly, Karlson (1986) found that new innovations that are expected to yield higher cost savings and improve profitability tend to be adopted faster in the steel industry. In the agriculture sector, new innovations that were less risky, less complex and expected to increase yield and quality were adopted much faster than other (Batz et al 1999; Adesina and Baidu-Forson 1995, Adesina and Zinnah 1993).

[4] Pareto analysis is used to identify the major factors that contribute to a problem and to distinguish the vital few from the trivial many causes. Cost of quality analysis is used to highlight the cost-savings that can be achieved by doing the work right the first time (Hackman et al.)

[5] For example, employees under quality management are likely to readily understand how their actions affect cycle time or how they can reduce waste or scrap rates.

[6] A survey of U.S. manufacturing firms in 1995 by Florida (1996) found that 60% of respondents considered P2 to be very important to corporate performance and two-thirds of these had also adopted TQM. Of the 40% of firms that considered P2 to be only moderately important, only 25% had adopted TQM. A survey of U.S. manufacturing plants in 1998 found that among the P2 adopters, the percentage of firms practicing TQM was twice that for other plants (Florida, 2001). A survey of Japanese manufacturing firms found that plants adopting a green design were more likely to be involved in TQM than other plants (Florida and Jenkins, 1996).

[7] The USEPA started requiring the reporting of P2 activities to the TRI in 1991.

[8] To match the facilities with their parent companies, the Dun and Bradstreet number is used, in addition, to facility name, location, and SIC code.

[9] There were a few firms for which *TQM* adoption data was not available for some years. To avoid dropping too many observations, we assumed that there is no de-adoption of *TQM*, i.e., if the firm did not report at all to the IRRC survey in a particular year, but reported to the IRRC and adopted *TQM* in the immediately preceding and succeeding years, we assumed that the firm also adopted in the year with missing data and filled in the blank year with "1". In addition, we also assumed that when the first time a firm has reported *TQM* to IRRC shows that it has not adopted *TQM*, we assume that it has never adopted in the past, and we filled in earlier years with missing data to be "0".

[10] Our initial set of attributes include (1) visibility to consumers, (2) visibility to shareholders, (3) visibility to regulator, (4) technological sophistication, (5) level of management decision involved, (6) frequency of activity, (7) time and cost savings, (8) production effects, and (9) final product functionality effects. Because the level of technological sophistication (4) is hard to determine, we instead used procedural changes as an attribute, i.e., whether it is involves changes in operations or procedures. Distinct from, but not necessarily to converse of this is physical changes which we divided into materials and equipment. We dropped visibility to shareholders and to regulators, as these are difficult to ascertain for each P2. We merged consumer visibility (1) and final product functionality effects (9) into one attribute. We also dropped the level of management decision-making involved in implementing each P2 (5) since this attributes is very difficult to determine. We also dropped production effects as these are not easily separable from the consumer visibility attribute

[11] With the exception of elimination of shelf-life requirements for stable materials 23, improved procedures for loading and unloading and transfer operations 32, institution of recirculation within a process 51, change from small to big bulk containers 55, and to a lesser extent, modification of spray systems or equipment 72, substitution of coating materials 73, change from spray to other techniques 75 and modification of packaging 83.

[12] We also estimated the same models without the number of opportunities as an explicit explanatory variable, but instead using it as a measure of exposure, i.e., a variable to reflect the amount of exposure over which the count of P2 were observed for each observation. This procedure yields similar results as those shown in Table 5.

Table 6. Effect of TQM of the Treated by P2 Category of new TQEM Adopters.

P2 Category	1993			1994			1995			1996		
	Act	Proj	% Δ	Act	Proj	% Δ	Act	Proj	% Δ	Act	Proj	% Δ
W13 Improved maintenance scheduling, record keeping, or procedures	5.06 (8.84)	4.70 (9.62)	(0.07)	1.29 (1.80)	1.13 (1.37)	(0.12)	1.500 (2.39)	1.503 (2.79)	0.002	0.500 (1.00)	0.495 (0.58)	(0.01)
W14 Changed production schedule to minimize equipment and feedstock changeovers	1.50 (3.67)	1.21 (3.59)	(0.19)	0.71 (0.76)	0.69 (1.50)	(0.04)	0.25 (0.71)	0 0	(1.00)	0 0	0 0	
W19 Other changes made in operating practices	7.63 (12.37)	4.88 (7.92)	(0.36)	1.14 (1.07)	1.74 (2.09)	0.52	1.75 (3.41)	1.49 (2.64)	(0.15)	2.50 (4.36)	2.52 (5.04)	0.01
W21 Instituted procedures to ensure that materials do not stay in inventory beyond shelf-life	1.19 (2.32)	0.44 (0.87)	(0.63)	0.57 (1.51)	0 0	(1.00)	0.38 (1.06)	0.44 (1.24)	0.16	0.25 (0.50)	0 0	(1.00)
W22 Began to test outdated material continue to use if still effective	0.69 (1.74)	0.31 (0.73)	(0.54)	0 0	0 0		0 0	0 0		0 0	0 0	
W23 Eliminated shelf-life requirements for stable materials	0.063 (0.25)	0.058 (0.23)	(0.07)	0 0	0 0		0 0	0 0		0 0	0 0	
W24 Instituted better labeling procedures	0.063 (0.25)	0.052 (0.21)	(0.18)	0 0	0.43 (1.14)	*0.43*	0 0	0 0		0 0	0 0	

Table 6. *(continued)*

P2 Category	1993 Act	1993 Proj	1993 % Δ	1994 Act	1994 Proj	1994 % Δ	1995 Act	1995 Proj	1995 % Δ	1996 Act	1996 Proj	1996 % Δ
W25 Instituted clearinghouse to exchange materials that would otherwise be discarded	0.38	0.21		0.57	0		0	0		0	0	
	(1.02)	(0.50)	(0.43)	(1.51)	0	(1.00)	0	0	0	0	0	0
W29 Other changes made in inventory control	2.44	1.91		0.14	0.26		0.13	0		0	0	
	(5.73)	(3.86)	(0.21)	(0.38)	(0.47)	0.83	(0.35)	0	(1.00)	0	0	
W31 Improved storage or stacking procedures	0.81	0.17		0.29	0		0	0		0	0.23	
	(1.76)	(0.49)	(0.79)	(0.49)	0	(1.00)	0	0		0	(0.46)	*0.23*
W32 Improved procedures for loading, unloading, and transfer operations	1.13	1.48		0	0		0.13	0.37		0	0.31	
	(2.78)	(3.23)	0.31	0	0	0	(0.35)	(0.52)	1.96	0	(0.62)	*0.31*
W33 Installed overflow alarms or automatic shut-off valves	0.19	0.21		0	0		0.25	0.15		0	0	
	(0.54)	(0.48)	0.12	0	0	0	(0.46)	(0.41)	(0.42)	0	0	0
W35 Installed vapor recovery systems	0	0.17		0	0		0	0.10		0	0	
	0	(0.50)	*0.17*	0	0	0	0	(0.29)	*(0.10)*	0	0	0
W36 Implemented inspection or monitoring program of potential spill or leak sources	1.00	1.80		0.14	0		0.63	0.52		0	0.46	
	(2.99)	(4.34)	0.80	(0.38)	0	(1.00)	(1.06)	(1.22)	(0.17)	0	(0.92)	*0.46*
W39 Other changes made in spill and leak prevention	2.19	0.99		0.14	0.17		0.13	0.20		2.0	2.4	
	(4.07)	(1.98)	(0.55)	(0.38)	(0.44)	0.16	(0.35)	(0.57)	0.62	(4.0)	(4.0)	0.18

Table 6. *(continued)*

P2 Category	1993			1994			1995			1996		
	Act	Proj	% Δ	Act	Proj	% Δ	Act	Proj	% Δ	Act	Proj	% Δ
W41 Increased purity of raw materials	0.50 (1.26)	0.16 (0.34)	(0.68)	0.29 (0.49)	0.29 (0.76)	0.01	0 0	0.15 (0.41)	*(0.15)*	0 0	0 0	0
W42 Substituted raw materials	6.31 (8.67)	5.13 (7.58)	(0.19)	1.43 (2.30)	1.69 (2.07)	0.18	1.13 (1.46)	0.97 (1.44)	(0.14)	0 0	0 0	0
W49 Other raw material modifications made	3.56 (8.49)	0.78 (1.72)	(0.78)	0.29 (0.49)	0.38 (0.67)	0.33	0.13 (0.35)	0.15 (0.41)	0.16	0 0	0.93 (1.85)	*0.93*
W51 Instituted re-circulation within a process	0.50 (1.51)	1.19 (2.12)	1.37	0.29 (0.49)	0.52 (0.68)	0.83	0.13 (0.35)	0 0	(1.00)	0 0	0 0	0
W52 Modified equipment, layout, or piping	3.88 (6.93)	2.90 (4.28)	(0.25)	0.71 (1.25)	0.09 (0.25)	(0.87)	0.13 (0.35)	0.083 (0.235)	(0.34)	1.25 (2.50)	1.56 (2.55)	0.25
W53 Used a different process catalyst	0.38 (1.02)	0.52 (0.93)	0.38	0.14 (0.38)	0 0	(1.00)	0.13 (0.35)	0.13 (0.37)	0.04	0 0	0.27 (0.53)	*0.27*
W54 Instituted better controls on operating bulk containers to minimize discarding of empty containers	0.69 (2.02)	0.587 (1.64)	(0.16)	0 0	0 0	0	0.13 (0.35)	0.35 (0.66)	1.78	0 0	0 0	0
W55 Changed from small volume containers to bulk containers to minimize discarding of empty containers	0.56 (1.41)	0.39 (1.34)	(0.31)	0 0	0 0	0	0.13 (0.35)	0 0	(1.00)	0 0	0 0	0
W58 Other process modifications made	4.81 (8.77)	4.21 (7.23)	(0.12)	0.43 (0.53)	0.85 (0.79)	0.98	0.38 (0.52)	0.58 (0.91)	0.53	0 0	0.76 (1.01)	*0.76*
W59 Modified stripping/cleaning equipment	0.81 (1.64)	0.60 (1.56)	(0.26)	0 0	0 0	0	0.13 (0.35)	0.20 (0.57)	0.62	0 0	0 0	0

Table 6. *(continued)*

P2 Category	1993			1994			1995			1996		
	Act	Proj	% Δ	Act	Proj	% Δ	Act	Proj	% Δ	Act	Proj	% Δ
W60 Changed to mechanical stripping/cleaning devices (from solvents or other materials)	0.25 (0.58)	0.38 (0.90)	0.52	0 0	0.25 (0.43)	*0.25*	0 0	0 0	0	0 0	0 0	0
W61 Changed to aqueous cleaners (from solvents or other materials)	2.75 (4.89)	2.94 (5.52)	0.07	0.43 (0.79)	0.79 (1.20)	0.85	0 0	0.30 (0.86)	*0.30*	0 0	0 0	0
W63 Modified containment procedures for cleaning units	0 0	0.18 (0.53)	*0.18*	0 0	0 0	0	0.25 (0.71)	0 0	(1.00)	0 0	0 0	0
W64 Improved draining procedures	0 0	0 0	0	0.14 (0.38)	0 0	(1.00)	0.25 (0.46)	0.12 (0.35)	(0.50)	0 0	0 0	0
W65 redesigned parts racks to reduce drag out	0.063 (0.250)	0.116 (0.465)	0.86	0 0	0 0	0	0 0	0.10 (0.29)	*0.10*	0 0	0 0	0
W66 Modified or installed rinse systems	0 0	0 0	0	0.14 (0.38)	0.19 (0.50)	0.33	0 0	0 0	0	0 0	0 0	0
W67 Improved rinse equipment design	0.06 (0.25)	0 0	(1.00)	0 0	0 0	0	0 0	0 0	0	0 0	0 0	0
W68 Improved rinse equipment operation	0.13 (0.50)	0.06 (0.25)	(0.51)	0 0	0 0	0	0 0	0.12 (0.35)	*(0.12)*	0 0	0 0	0

Table 6. *(continued)*

P2 Category	1993			1994			1995			1996		
	Act	Proj	% Δ	Act	Proj	% Δ	Act	Proj	% Δ	Act	Proj	% Δ
W71 Other cleaning and decreasing modifications made	0.88 (1.75)	1.39 (2.57)	0.59	0.14 (0.38)	0.14 (0.38)	0.01	0.13 (0.35)	0.15 (0.41)	0.16	0 0	0 0	
W72 Modified spray systems or equipment	1.25 (3.28)	1.45 (4.62)	0.16	0.14 (0.38)	0.09 (0.25)	(0.34)	0 0	0 0		0 0	0 0	
W73 Substituted coating materials used	1.19 (3.27)	1.74 (3.14)	0.47	0.29 (0.49)	0.11 (0.30)	(0.60)	0 0	0 0		0 0	0 0	
W74 Improved application techniques	2.75 (8.47)	1.55 (3.74)	(0.44)	0.14 (0.38)	0 0	(1.00)	0 0	0 0		0 0	0 0	
W75 Changed from spray to other system	0.19 (0.75)	0.10 (0.41)	(0.45)	0 0	0 0		0 0	0.16 (0.45)	*0.16*	0 0	0 0	
W78 Other surface preparation and finishing modifications made	0.50 (1.21)	0.47 (1.04)	(0.05)	0.29 (0.49)	0.11 (0.30)	(0.60)	0.13 (0.35)	0 0	(1.00)	0 0	0 0	
W81 Changed product specifications	1.44 (2.66)	1.56 (3.32)	0.08	0 0	0 0		0 0	0.1 (0.4)		0 0	0 0	
W82 Modified design or composition of product	1.06 (2.35)	0.48 (1.03)	(0.55)	0.29 (0.49)	0.26 (0.44)	(0.10)	0.13 (0.35)	0.1 (0.2)	(0.34)	0 0	0 0	
W83 Modified packaging	0 0	0.232 (0.930)		0 0	0 0		0 0	0 0		0 0	0 0	
W89 Other product modifications made	1.25 (2.72)	1.07 (1.89)	(0.14)	0 0	0 0		0.25 (0.46)	0.10 (0.29)	(0.60)	0 0	0.31 (0.62)	
Total P2	60.06 (83.83)	48.78 (73.31)	(0.19)	10.57 (6.92)	10.19 (7.41)	(0.04)	8.63 (7.38)	8.63 (8.47)	0.001	6.50 (7.42)	10.20 (8.65)	0.57

Standard deviations are in parentheses. Italicized figures in last column are changes in levels, not % changes.

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