THE RIMINI CENTRE FOR ECONOMIC ANALYSIS

WP 03_09

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ESTIMATING THE IMPACT ON EFFCIENCY FROM VOLUNTARY REGULATION: AN EMPIRICAL STUDY OF THE GLOBAL COPPER MINING INDUSTRY

Estimating the Impact on Efficiency from Voluntary Regulation: An Empirical Study of the Global Copper Mining Industry

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Abstract: This paper uses plant level data on the world's copper mining industry to measure changes in efficiency from the adoption of the ISO 14001 environmental standard. The ISO 14001 is a voluntary standard that sets out minimum guidelines and procedures that firms should follow in order to achieve more effective management of the environment. Anecdotal and case study literature suggests that firms are motivated to adopt the ISO 14001 standard and seek certification for a number of reasons. One important reason is the desire to achieve greater efficiency and cost savings through changes in operating procedures and processes aimed at the minimization of waste pollution and reduction in the use of resource inputs. Using plant level data from 1992-2007 on virtually all of the world's industrial copper mines the study tests this hypothesis in a stochastic frontier and random effects model framework. The study measures the impact on operations of ISO 14001 adoption both in respect to the intention to seek ISO 14001 certification (the period before certification when firms must make necessary changes to their operations and management) and the period when and after certification is achieved. The study finds no evidence that adoption of the ISO 14001 standard imposes a cost on firms — either through lower efficiencies or higher costs. In fact, in many cases adoption is associated with higher efficiency, and to a certain extent, lower costs. Thus, the study's findings would tend to go against the claims of much of the academic literature that regulation has negative impacts on the firm. Although findings were not robust to model choice or a subset sample, our results clearly indicate that, at a minimum, the adoption of the ISO 14001 does not raise costs or lower efficiency for firms.

Key Words: ISO 14001; stochastic frontier production function; efficiency; cost savings; mining.

1 Introduction

ISO 14000 is a series of voluntary standards for environmental management. The series provides a set of "best practice" tools and techniques that if adopted will ostensibly help firms minimize their environmental footprint and conserve resources. Currently firms can gain certification in only one standard, ISO 14001. This particular standard is the core of the 14000 series. It outlines the specific criteria firms should follow for implementing an environmental management system (EMS). The number of firms that have certified their operations under the 14001 EMS has increased rapidly since 1996. Adoption and certification have been particularly high among major multinational corporations. A survey published by the ISO in 2005 reported the number of ISO 14001 certifications stood at 561,943 worldwide in 138 countries/economies [23].

Case study and anecdotal evidence suggests that few firms adopt the ISO 14001 standard do so out of a concern for the environment or to improve their own environmental performance. Firms are more likely to give other reasons for the adoption of the standard such as: improved market share through the promotion of a green image, relief from mandatory regulation, reduced legal liabilities, and achievement of efficiency and cost savings. The latter are two oft-cited, non-environmental reasons for seeking ISO 14001 certification. They are especially important given the general belief among economists that regulation, even voluntary, imposes costs on firms and diverts resources away from other areas of an operation. Hence it is important to determine if there are any savings and efficiency outcomes for firms that adopt the standard.

Using plant level data from 1992-2007 on virtually all of the world's industrial copper mines the study tests the hypothesis that the adoption of the 14001 standard is associated with greater efficiency and cost savings. The copper industry is a truly global industry, one which is both highly competitive and highly polluting. The study measures both the intention to seek ISO 14001 certification – the period before certification when firms make necessary changes to their facility's operation and management – and the period when and after certification is achieved. It examines these impacts on mine performance using a stochastic frontier and random effects model framework.

The remainder of the paper is structured as follows. Section II motivates the paper in the context of a brief discussion of the ISO 14001 standard. It also reviews the academic literature on motivations for and outcomes of the adoption of the 14001 standard, with a focus on firm performance. Section III discusses the model and its estimation using a stochastic frontier cost function approach. Section IV presents and discusses the data set used in the analysis. It also discusses aspects of the copper mining industry relevant for the efficiency analysis. Section V summarizes the paper's results. Section VI provides a summary and conclusion, focusing on the implications of the study's findings for understanding firm motivations for adopting the ISO 14001 standard.

2 Literature Review

2.1 Nature & Characteristics of the ISO 14001 Standard

The ISO 14000 series is a voluntary set of standards inaugurated in 1996 by the International Association of Standards. A collaborative effort between industry representatives, national standards associations, governmental and environmental bodies worldwide, the impetus for 14000 guidelines arose from the Uruguay Round of Trade GATT negotiations and the Rio Earth Summit in 1992 [28]. Although many other national and regional environmental standards (e.g. BSO 7750, EU and American eco-labelling programs) exist, the 14000 series is the only international set of guidelines. The ISO 14000 series provides a common set of standards for environmental management covering 5 areas: management systems, auditing, performance evaluation, labelling, life-cycle assessments, and products standards.

The 14001 component within this series relates to a firm's environmental management system (EMS). The EMS is a systematic and coherent framework specifying the policies, targets, assigned responsibilities, and procedures a firm should follow in order to minimize its environmental footprint and conserve resources. Adoption of the standard involves 5 steps: a) the development of an environmental policy that has the commitment of senior executives; b) a plan for identification of environmental areas, legal and regulatory commitments and targets for improvement of environmental performance; c) a system for implementation of targets (including programs for training all employees in environmental awareness and competency), the delineation of clear responsibilities and channels of communication and documentation of the EMS, and procedures for control of environmental impacts of all operations in the firm; d) a system for continual monitoring, measurement and improvement of environmental performance (including an audit system for reporting problems and non-compliance); and e) constant re-evaluation by senior management of the effectiveness of all internal programs, systems, products, and targets [6, 39].

It is important to note that the 14001 standard is a process rather than a products or technical standard. As such, it leaves it up to the firm to decide how it will design and implement its EMS to achieve its stated environmental goals. Thus, while for each firm the requirements for the EMS will be the same, environmental targets and the technical and other means for achieving them will differ greatly. This flexibility means that the standard can be applied in a variety of organizations and its components implemented in a variety of ways. Irrespective of what the firm chooses to do, it must comply with any environmental legislation and regulations required by a country or trade agreement. In addition, firms must commit to continually improve their environmental performance [23]. Once the 14001 EMS is in place the facility will usually seek certification from an accredited external organization. While some firms choose to simply adopt their internal processes according to the 14001 standard, most will seek formal certification [39].

Proponents of the standard argue that apart from its beneficial environmental impacts, adoption of the ISO 14001 standard also has far-reaching benefits for firm competitiveness. First, efficiency and cost savings can be achieved through the introduction of an EMS that cuts waste, lowers pollution, uses fewer resources, raises employee awareness of the environmental impacts of operations, and lowers the costs associated with environmental accidents and poor performance. Second, by forcing firms to think about the impacts of their operations on the environment every step of the way, adoption can bring useful environmental expertise and employee accountability to the firm [36, 37,21]. This proactive attitude can in turn help to generate new skills and innovative technologies, with potentially positive outcomes for a firm's competitiveness [19, 6].

Third, because it enforces a standard of performance over and above current mandatory regulations, proponents argue that the standard may also serve to cut costs in other ways. For example, it may help to inoculate firms against the costs of current and future liabilities arising from public expectations of corporate responsibility and environmental quality. By providing consistent information to shareholders and managers about the possible environmental performance of its operations, the standard can also help reduce legal liabilities through reduced accidents and environmental incidents. Insurance may also be reduced since the standard signals that firms are adopting "due diligence" [4, 26, 1]. Finally, voluntary adherence can also increase a firm's status and legitimacy in the eyes of the green consumer, potentially raising profits, share value and investor confidence [2, 28, 11, 18, 27, 3].

This view contrasts sharply with conventional thinking on the impacts of environmental regulations on firm performance. This literature argues that environmental regulation imposes burdensome financial costs on firms that reduce their overall competitiveness (e.g. see [10, 12, 24, 35]). According to critics, even voluntary regulations divert resources away from areas where true efficiency and cost-savings might be achieved, discouraging firms from seeking real solutions to problems of waste and pollution [24, 10, 35]. Most importantly, voluntary regulations can lead to regulatory desertion, leaving environmental quality up to the perpetrators of pollution and waste rather than public officials. This may especially be the case with small to medium sized businesses. Discouraged by the high costs of achieving ISO 14001 certification, and having met the legal standard, smaller firms may decide to forgo any further investments in pollution abatement, energy use or waste control [8].

The ISO 14001 standard, in particular, may impose substantial costs on firms in respect to process and product changes, employee time and training, auditing, reporting, marketing, and legal expertise.[1] Since firms could implement any changes without adoption of the costs of the standard, critics charge that they simply do so out of the desire to advertise a green image, which could be achieved more cost-effectively with an effective marketing campaign [41].

In view of the conflicting evidence of the merits of adopting the ISO 14001 standard, and the costs it can impose on firms, it is worthwhile to ask: Does its implementation really provide any beneficial outcomes for a firm? There is a paucity of research on this issue, which this study aims to address. Most evidence on the impacts of ISO 14001 certification on firm performance comes from case studies and anecdotal evidence compiled from interviews with senior management.

Overall, this qualitative literature suggests that firms are motivated to adopt the standard for a variety of reasons: greater efficiency and cost savings, improved environmental performance, enhanced employee participation in envi-

[1] For example, Szymanki and Tiwari [41] report that US companies can spend up to US$100,000 a year on obtaining and maintaining certification.

ronmental management, deflection of attention from regulators, better community relations, customer pressures for environmentally friendly products, improved control over personnel and work methods, harmonization of production processes across plants, and entry into certain markets [9, 13, 17, 32, 39, 40, 18]. Interestingly, qualitative evidence from managers from a variety of industries suggests that environmental concerns are not the main reason for adoption of the standard. Moreover, many reasons reflect managers' perceived beliefs about what the standard will achieve (or has achieved) rather than objectively demonstrating actual outcomes. Even retrospective surveys do not indicate whether outcomes are based on subjective perceptions and beliefs or have actually indeed been achieved in practice.

For example, managers at ABB Automation's Ohio plant claim that ISO 14001 certification has led to reduced costs of energy use and waste disposal and the adoption of environmentally positive processes earlier than planned. Managers also claim an increase in employee morale as a result of their participation in environmental protection [34]. Likewise, in their study of the Honda Transmission Manufacturing of America plant in Ohio, McManus & Sanders [30] report Honda managers as claiming a range of beneficial impacts of ISO 14001 certification, none of them directly motivated by concern for the environment, including reduced costs associated with fewer environmental incidents. Rodinelli & Vastag [39] find that managers at Alcoa's Mt. Holly plant identified greater operational efficiency as a result of IS0 14001 certification in addition to stronger environmental management practices, cost savings and greater employee and managerial awareness of environmental impacts.

While this qualitative literature provides useful insights into the potential benefits of ISO certification, it is largely subjective – and with a few exceptions where structured survey analysis techniques have been employed – anecdotal in nature. Moreover, case study literature is restricted to examining anticipated and actual reported benefits within a single facility. This narrow focus may provide an unrepresentative view of the true impacts of the ISO 14001 standard. Little if any objective data exist on whether stated outcomes are in fact achieved or even intended. For example, they do not report what sort of efficiency gains or savings occurred, how they were achieved, or even measured.

The small body of econometric studies on voluntary regulation overwhelmingly focus on measuring the determinants of voluntary environmental agreements rather than on their impacts [3, 14, 18, 15, 22]. However, a few econometric studies have attempted to measure objectively the impacts of the 14001 standard on firm performance. For example, Dasgupta et al. [14] use responses to a survey of Mexican firms to measure whether their self-certified EMS impacts positively on environmental performance. Results suggest that those firms that instituted ISO 14001-type internal management processes did indeed exhibit higher environmental performance. The latter was measured by the gap between the regulatory standard and the plant's cost-minimizing emissions intensity.

Similarly, Khanna et al. [25] use a DEA approach to measure the impact on environmental efficiency of environmental self-reporting (their proxy for voluntary regulation) among S&P 500 industries. The authors examine both the determinants and level of environmental efficiency. Environmental efficiency is measured as an index of the opportunity costs (or loss of desirable outputs) relative to the costs of reducing undesirable outputs. The study finds that differences in ESR explain differences in environmental efficiencies across firms but the impact varies across industries. With two exceptions, firms in industries that have high environmental efficiencies have a higher degree of ESR (as well as a higher profitability). Although they do not measure regulatory impacts of ESR on environmental efficiency, Boyd & McClelland [7] also use a DEA approach to determine the loss from potential productive output due to pollution abatement spending in US paper plants. Their study measures productive inefficiency in terms of the allocation of investment capital away from production efficient improvements to pollution abatement spending arising from environmental controls. This abatement capital constraint is found to contribute to a small decrease in productivity.

Finally, Barla [4] carries out an econometric examination of environmental performance (measured by such indicators as the quantity of rejected process water, levels of biological oxygen demand (BOD) and total suspended solids (TSS) in water) in 37 ISO certified Quebec pulp and paper plants. The author finds that ISO 14001 certification has no impact on TSS or quantity of rejected process water but does reduce BOD in plants by 9%. Interestingly, over time, it is the non-adopting plants that experienced more significant emission reductions than plants that adopted ISO 14001 certification. The impacts of certification also vary across plants; some plants significantly reduced emissions but a majority of those certified maintained and even increased emissions.

To the best of this author's knowledge, no study on firm performance measures efficiency and/or cost savings outcomes of voluntary regulation. Of the few studies that focus on efficiency, interest is in environmental outcomes rather than efficiency and/or cost savings. Only the study by Khanna et al. [25] examines the impact of voluntary regulation on productive efficiency but not specifically in respect to the 14001 standard. Moreover, very few analyze voluntary agreements and efficiency outcomes at the plant level – the level at which ISO 14001 is applicable. Of these studies most focus on measuring performance across disparate industries where the standard, being highly flexible, will be applied in many different ways. This heterogeneity makes it impossible to determine in any meaningful way what its impacts on performance may be. Finally, no study examines the impacts of the adoption of voluntary regulation in a global context, irrespective of whether the focus is on efficiency or some other performance measure (e.g. pollution levels, share price). And none does so in respect to voluntary standards such as ISO 14001. Previous research (case study or econometric) focuses entirely on the impacts of voluntary management schemes in one or at most a few countries (i.e. the US or the OECD). Since the 14001 standard is truly an international standard, it is important that empirical analysis examine relationships of interest in a global context.

This study contributes to the small but growing body of econometric literature on the impact of voluntary regulations on firm performance. It will attempt to overcome the empirical omissions of existing studies by focusing on one industry only, and in a global context. It also examines the impact of the adoption of the ISO 14001 standard on two hitherto overlooked but important reasons cited in the case study and anecdotal literature for adopting the standard: greater efficiency and cost savings.

3 Econometric Methodology

This study uses a stochastic cost frontier to estimate copper mine efficiencies. The basic intuition behind the model can be expressed by the simple cost frontier where costs of mine i at time t, C_{it}, depends on output , Q_{it}, and M input prices, $p_{j,iy}$ (for $j = 1,..,M$, $t = 1,..,T$ and $i = 1,..,N$). The cost frontier, which defines the minimum levels of costs achievable to produce Q_i for a mine facing input prices X_i, can be written as:

$$C_{it} = f(p_{1,it},..,p_{M,it},Q_{it}) \tag{1}$$

In practice, mines may not achieve this minimum so we can write

$$C_{it} = f(p_{1,it},..,p_{M,it},Q_{it})\tau_{it}, \tag{2}$$

where $\tau_{it} \geq 1$ measures efficiency. $\tau_{it} = 1$ indicates that the mine is fully efficient (at the frontier) while higher values indicate lower levels of efficiency (i.e. τ_{it} is the degree to which costs are above the minimum possible). We turn this into an econometric model by assuming particular forms for τ_{it}, adding measurement error, assuming a log-linear cost function and extending the basic ideas above to allow for or panel data set.

The econometric methods are all based on cost functions and, throughout, we use the flexible translog functional form for the cost function. A conventional translog cost function takes the form:

$$\begin{array}{c} \ln(C_{it}) = \alpha + \beta_1 \ln(Q_{it}) + \beta_2 \ln(Q_{it})^2 + \sum_{j=1}^{M} \gamma_j \ln(Q_{it}) \ln(p_{it,j}) + \\ \sum_{j=1}^{M} \delta_j \ln(p_{it,j}) + \sum_{s=1}^{M} \sum_{j \leq s} \delta_{sj} \ln(p_{s,it}) \ln(p_{it,j}) \end{array}. \tag{3}$$

However, due to data limitations and in an attempt to control for mine heterogeneity, we modify this conventional form in the following ways. First, we add as additional explanatory variables geological and physical factors of the mine that impact on costs. We call these variables $Z_1,..,Z_k$. Second, given a lack of data on the price of capital, we include investment as one of these extra explanatory variables. This is commonly done in the literature and gives our cost function the interpretation of a short run cost function (as well as helping correct for mine heterogeneity). With these assumptions, our translog cost function is given as:[2]

$$\begin{array}{c} \ln(C_{it}) = \alpha + \beta_1 \ln(Q_{it}) + \beta_2 \ln(Q_{it})^2 + \sum_{j=1}^{M} \gamma_j \ln(Q_{it}) \ln(p_{it,j}) + \\ \sum_{j=1}^{M} \delta_{it,j} \ln(p_{it,j}) + \sum_{s=1}^{M} \sum_{j \leq i} \delta_{sj} \ln(p_{it,s}) \ln(p_{it,j}) + \sum_{j=1}^{k} \zeta_j \ln(Z_{it,j}) \end{array}. \tag{4}$$

Finally, to get to our econometric models, we use two different approaches. The key question addressed in this paper is whether accreditation or intention to seek accreditation (designated in the study by the acronyms, ISOACC and ISOINT, respectively) has an important effect on mine costs or efficiencies. The

[2] Note that some of the variables in $Z_1,..,Z_k$ have zero values (e.g. are dummy variables) and are directly included in the cost function (i.e. are not logged).

most direct way of addressing this question is to simply include dummy variables measuring both ISO 14001 accreditation and the intention to seek ISO14001 accreditation in the regression. Given that we have panel data, this amounts to adding the dummy variables as additional explanatory variables in our translog function (4) in a random effects model. That is, we have:[3]

$$\begin{aligned} \ln (C_{it}) = \alpha_i + \beta_1 \ln (Q_i) + \beta_2 \ln (Q_{it})^2 + \textstyle\sum_{j=1}^{M} \gamma_j \ln (Q_{it}) \ln (p_{j.it}) \\ + \textstyle\sum_{j=1}^{M} \delta_j \ln (p_{j,it}) + \sum_{s=1}^{M} \sum_{j \leq i} \delta_{sj} \ln (p_{s,it}) \ln (p_{j,it}) \\ + \textstyle\sum_{j=1}^{k} \zeta_j \ln (Z_{j,it}) + \lambda_1 ISOINT_{it} + \lambda_2 ISOACC_{it} \end{aligned} \quad , \qquad (5)$$

The coefficients on $ISOINT$ and $ISOACC$ can be examined to address the question: "After controlling for mine characteristics, does accreditation (or intention to seek accreditation) of the ISO 14001 standard have an effect on a mine's costs?"

An alternative approach is to estimate each mine's efficiency using stochastic frontier methods, and see whether mine efficiency is associated with certification or the intention to seek ISO certification. Accordingly, we adopt two different implementations of panel data stochastic frontier models (e.g. see [29]). The first of these is the standard stochastic frontier function based on:

$$\begin{aligned} \ln (C_{it}) = \alpha + \beta_1 \ln (Q_i) + \beta_2 \ln (Q_{it})^2 + \textstyle\sum_{j=1}^{M} \gamma_j \ln (Q_{it}) \ln (p_{j.it}) + \\ \textstyle\sum_{j=1}^{M} \delta_j \ln (p_{j,it}) + \sum_{i=1}^{M} \sum_{j \leq i} \delta_{ij} \ln (p_{i,it}) \ln (p_{j,it}) + \\ \textstyle\sum_{j=1}^{k+1} \zeta_j \ln (Z_{j,it}) + v_{it} + u_i \end{aligned} \quad , \qquad (6)$$

where v_{it} reflects measurement error and u_i is inefficiency Given the log specification, efficiency is time invariant:

$$\tau_i = \exp (u_i) . \qquad (7)$$

The second is the time-varying efficiency model of Battesi and Coelli [5], which is the same as (6) except that u_i becomes the time varying u_{it} which takes the form:

$$u_{it} = \exp \{-\eta (t - T_i)\} u_i \qquad (8)$$

where T_i is the number of years available for mine i. With this specification, efficiency is:

$$\tau_{it} = \exp (u_{it}) . \qquad (9)$$

Note that cost efficiencies, when defined in these ways, are greater than one, with higher values indicating less efficiency. We estimate both stochastic frontier models using a maximum likelihood procedure which assumes measurement error is Normally distributed and inefficiency is truncated Normal. Once we have obtained estimates of these efficiencies we then use regression methods to see if they are associated with ISO 14001 standard.

[3] To estimate this model, we use Stata's maximum likelihood algorithm which assumes the random effect is Normally distributed as is the regression error.

4 Data

Variable definitions, sources and acronyms are described more fully below and are also summarized in Appendix A. The study measures efficiency and cost savings in 99 copper mines from 1992 to 2007 and contains 1265 observations. A subset of mines in the sample for which start-up costs were available has 641 observations for 52 mines.

The study conceptually defines variables through their inclusion in the following groups.

Group 1: Total costs
Group 2: Output measure
Group 3: Price inputs
Group 4: Investments
Group 5: Physical/geological factors
Group 6: Regulatory variables

4.0.1 Dependent Variable

Group 1. The study's dependent variable measures total costs (TOTAL) for the mine of mining and milling Cu ore. This variable is measured in terms of US millions of dollars per day. It includes all onsite milling and mining costs involved in the extraction and processing of metal from ore using the inputs of energy, capital and labour.

4.0.2 Independent Variables

Group 2. Output measure. The study's output measure (METAL) is the amount of Cu metal produced in kilotonnes per year.

Group 3. The study includes a number of price inputs. Two price inputs measure energy costs: diesel and electricity. Diesel (DIESEL) costs are measured in US c/liter per day. Electricity (ELECT) costs are measured in US c/kwh per day. Other inputs include grinding media (the costs of metallic and other materials for grinding ore) in US dollars per tonne per day. Reagents/acid price inputs (REAGENT), another important price input relevant to the milling stage, is measured in US cents/kg per day. The price of labour (WAGES) is measured as the average hourly labor cost in US$ per hour per day. Another price input (GRIND) applies to grinding media (the price of metallic balls for grinding and crushing ore). It is measured in US $/tonne per day.

Group 4. The study's investment variables measure capital investment. Capital investment is measured in two ways: a) Capital expenditure (CAPEX) and b) setup costs (SETUP). CAPEX is measured in US millions of dollars per year. Setup costs are also a potentially important variable affecting differences in efficiency across mines. SETUP measures capital costs of establishing the mine, measured in millions US dollars per year. Although not ideal in that data on set-up costs are available for only a subset of mines in the analysis, other variables in the study (e.g. scale of mining (MILL), output (METAL) and capital expenditures (CAPEX) will capture the impact of start-up costs on efficiency on the assumption that larger mines would handle more ore, produce more output and have greater capital expenditures.

Group 5. These factors relate to both geological and other characteristics of the mine that affect how difficult it is to access the ore and how much "work" (i.e. equipment and manpower) it requires to mine and mill it. The first of these variables (TYPE) controls for type of mine, i.e. open pit vs. underground. It is measured as a dummy variable; 1 for underground and 0 for open pit. In the few cases where mines have both open pit and underground operations, the study assigns them the value of 1 for underground mines on the basis that open pit mines are often precursors to underground mines. Another geological characteristic that impacts on the costs of both mining and milling is grade of ore (OREGRADE), measured as the percentage of Cu metal within the ore. Lower grade ores, for instance, are harder to access and create more waste in the processing of the ore.

Another variable (DRILLCOND) is an index measure of geological characteristics summarizing drilling patterns and power usage. This index ranges from 0.6 (good) to 2.0 (poor) and applies to open pit mines only. Its underground mine counterpart (GROUNDCOND) is an index that depends on rock competence and other conditions. This number ranges from 1 (good) to 5.0 (poor). Since DRILLCOND and GROUNDCOND only apply for underground and open pit mines, respectively, we interact them with underground/open pit dummies, respectively. An ore work index (WORK) is also included; this variable is applicable to both types of mining practices. It measures the amount of power required to crush and grind the ore and is measured in kwh/t. Specifically, it is the amount of power required to break ore from a theoretically infinite feed size to 80% passing 100 m.

In addition to these physical/geological factors, the study controls for scale of mining. Recent research suggests that size of an operation may influence to a certain degree whether firms will be likely to join voluntary programs as a result of lower marginal abatement costs due to economies of scale and greater number of personnel and exposure to liabilities [4, 42, 3, 2, 14].[4] This scale variable (MILL) is measured as the total ore treated in each mine in kilotonnes per year. The study uses a milling measure rather than a mining measure of total output since the former is an end product of the operations the study measures; it represents the pure ore, treated after extraction, crushing and grinding, to remove waste rock and other metals. Finally, another variable (DAYS) captures durational differences in operation that may affect costs. DAYS controls for the number of days per year the mine is in operation.

Group 6. Two independent variables measure the regulatory aspects of the study. One regulatory variable (ISOINT) measures the intention of mines to seek ISO 14001 certification. This dummy variable represents the period when the mine makes changes in its management en-route to eventual certification. The attainment of 14001 certification is measured as a dummy variable, ISOACC. As part of the process of eventual certification all firms have to publicly announce their intention to seek ISO 14001 certification. Obtaining certification can take several or more years; hence certification does not come immediately after the expressed intention to seek certification. Certification must be obtained by

[4] There is also some evidence to suggest that polluting industries will be more likely to adopt the ISO 14001 standard than cleaner or non-polluting industries (see e.g. [33]). Although pollution data at the mine level were not available for this study, it is reasonable to assume for the copper mining industry that the more ore that is milled the more enivronmental impact the process will have.

accredited external agencies who are also responsible for on-going monitoring to ensure compliance.

All variables definitions and acronyms are summarized in Table 1, Appendix A. Data for the study came from a variety of sources. ISO data came from annual company reports and direct inquiries with head office. Other data came from company annual reports, stock exchange filings, and two industry proprietary datasets [31, 38] measuring a range of geological, production and cost data for the mining industry.

In this study output (METAL), price inputs (WAGES, POWER, GRIND, REAGENT, DIESEL), and total cost (TOTALCOST) variables are given the standard full translog treatment as discussed in the methodology section. The study's physical/geological and investment variables are entered as regular explanatory variables in the model to control for these other mine heterogeneity issues. (To give them a full translog treatment would result in a model with a huge number of coefficients to estimate). Treatment of the study's regulatory variables is carried out in two different ways, as described in the methodology section.

5 Empirical Results

5.1 Results for the Cost Frontier

Tables 2 and 3 in Appendix B present estimates and p-values for the coefficients of the cost function for the study's three different modelling approaches (i.e. a random effects model, the stochastic frontier model with time invariant inefficiency and the stochastic frontier model with time varying efficiency). The shape of the cost function does not reveal much about the research question of interest. However, the following points are noteworthy about the results presented in Table 2:

1. All three approaches yield the same rough shapes for the cost frontier. Recall that the random effects specification uses ISOACC and ISOINT as explanatory variables whereas the other approaches do not (i.e. in respect to the latter two models the ISO variables are reserved for the second regression which tries to explain efficiency). Results for the random effects model (when we exclude the ISO variables) are very similar to those produced by the stochastic frontier model with time-invariant efficiency (and thus, for the sake of brevity, are not reported here).

2. There is strong evidence that the use of the translog functional form is important since many of the squares and cross products of the explanatory variables are significant.

3. The remaining coefficients in the translog production function are presented in Table 3 in Appendix B. The coefficient results for these investment, physical/geological and regulatory variables are for the most part highly significant and of the expected sign. One possible exception is DAYS, which is negative. This finding could indicate unmeasured costs associated with the maintenance or re-opening of a mine after temporary shut-down.

5.2 Results for Regulatory or ISO Variables

Most crucial for the research question of this paper is the impact of the ISO variables on efficiency and cost savings. Table 4 presents three different models used to examine this question for the full sample of mines. The motivation given previously suggests that the ISO variables could have a beneficial effect on the efficiency with which a mine is operated by forcing a facility to think about and implement resource savings and reduce pollution impacts on the environment at every point in its operations.

The efficiencies in our two different stochastic frontier models are defined in equations (7) and (9). They are defined such that small values indicate high efficiency and large values low efficiency. If we simply run a regression of the efficiencies on an intercept and ISOINT and ISOACC we obtain the results in Table 4.[5] Table 4 also reproduces coefficients for ISOINT and ISOACC from the random effects regression model first presented in Table 3. Note that these latter coefficients measure the effects of ISO variables on costs (rather than on efficiency) so that the magnitudes of the coefficients are not comparable for the random effects and the efficiency analysis.

Most importantly, however, in respect to the variable coefficients for ISOACC, Table 4 indicates that they are negative for all models. These findings suggest that ISO 14001 accreditation is associated with lower costs and more efficient mining operations. For the regressions using efficiencies as explanatory variables, ISOACC is statistically significant. In the case of the random effects model this variable is not significant. There is also evidence that intention to seek 14001 accreditation is also associated with lower costs and more efficiency; however results are weaker than for the ISOACC variable (in the sense of being less statistically significant). That is, the point estimates of the coefficient on ISOINT in all three models are negative; but only for the model with time varying efficiency do we find the coefficient to be significant at the 5% level.

Results in Table 5 are in exactly the same format as before, except that they apply to the sample of data for which startup costs are available (641 observations available on 52 mines). This variable is included in the translog cost function. For the sake of brevity, we do not present results from the full cost function. The coefficients of the translog cost frontier for all three models were similar to those used for the cost function applied to the full sample of mines (and are available on request). However, results relating to the ISO variables show no significant efficiency outcomes for either the intention to seek ISO 14001 certification or for ISO 14001 accreditation for any model, although many coefficients have the same negative signs as in the full sample (and in the case of using time-varying efficiency, results are almost significant at the 10% level).

Thus, econometricians may disagree about whether the coefficients relating to the ISO variables are either negative (indicating that the adoption of ISO is actually good for mines) or zero (indicating no impact). However, no econometrician could reasonably interpret the results to mean that adopting the ISO 14001 standard leads to higher costs or lower efficiency, contrary to much of the academic literature on regulation.

[5] Note that the ISO variables sometimes vary over time, so all cross-sectional and time series observations are included in the regressions.

****Tables 4 & 5 Here***

This inconsistency in significance for beneficial outcomes of the adoption of the ISO 14001 standard across models and subsamples has been found in other studies that have focused on the environmental performance of firms (e.g. Barla 2007). This inconsistency may relate to the diversity of reasons often given by firms for adopting the standard in the first place. An examination of the individual mine efficiency estimates for both stochastic frontier models indicates strong variability in efficiency across firms. For instance, Table 5 provides estimates of the time varying efficiencies for the top 10 performing mines in 2007 (which are qualitatively the same as the time-invariant measures). In this year, 50% had 1SO 14001 certification, with the top performing mine also being ISO 14001 certified. Likewise, among the 10 least efficient mines in the sample, a nearly identical number (30%) had certification in 2007. As with the most efficient mine in the sample, the least efficient mine was also ISO 14001 certified in 2007. However, these findings do not detract from the overall conclusion of the paper that the adoption of the ISO 14001 standard will not impact inversely on efficiency and may have even lead to greater efficiency.

Table 6 Here

6 Discussion and conclusion

The number of firms adopting the ISO 14001 standard since its inception in 1996 has risen dramatically. However, beyond a small body of case study literature and anecdotal evidence there has been very little, particularly empirical, research examining whether the ISO 14001 standard achieves such oft-cited objectives as improved environmental performance, efficiency and cost savings, increased stock performance, enhanced corporate image, regulatory relief, and reduced legal liabilities. This study has contributed to the few empirical studies that have analyzed the impact of ISO 14001 and 14001-like EMS systems on plant or firm performance. All of these studies have looked at their impact on environmental performance, measured in terms of environmental efficiency (e.g. as a ratio between the costs of the loss of desirable output relative to the costs of reducing undesirable outputs) or in terms of actual pollution levels (e.g. BOD levels).

This study has diverged from this literature by focusing on non-environmental outcomes, namely efficiency and cost savings. These are important, oft-cited objectives of the ISO 14001 standard that are also worthy of measure. Case study and anecdotal evidence suggests efficiency and cost savings are important motivations for seeking ISO 14001 certification. They are considered more important than – and may even drive – environmental concerns [32].

This study has found that ISO 14001 certification was significantly associated with higher efficiency in all models. This significant association, however, did not apply in a subset sample of mines for which start-up costs were measured nor did it apply to cost savings although the latter was marginally significant in the full sample. Findings for the intention to adopt ISO 14001 regulations indicate stronger significance in terms of greater efficiency for both stochastic frontier model specifications, but not for the random effects model measuring cost savings. As in the full sample, the significant fdinding for the intention to adopt the ISO 14001 standard did not carry over to a subset sample of the data for which startup costs were available. Although on the whole findings for both variables were inconsistently significant and not robust across model choice or sample, at the very least, they indicate that neither the intention to adopt the ISO 14001 standard nor the achievement of ISO 14001 certification is associated with greater cost and less efficiency.

Two possible interpretations for the lack of consistent significance and robustness for the ISO 14001 measures examined in this study are as follows: One interpretation may be derived from the case study and anecdotal literature. This literature has shown that firms pursue ISO 14001 certification for a variety of reasons, with efficiency and cost savings being two among many, but perhaps not the most important reasons. Or it may be that the importance of these outcomes for firms are linked to specific internal or external circumstances, which are not easy to identify in this kind of study. These circumstances may make it more likely that if firms were to adopt the ISO 14001 standard and gain certification, they would achieve efficiency and/or cost savings outcomes not open to others. However, irrespective of their circumstances, CEOs in the copper industry may find some comfort from the finding that the adoption of the ISO 14001 standard, at a minimum, will not lead to less efficiency or higher costs.

7 Acknowledgements

I thank the British Academy (Grant:#SG42965) for support for this research. I would also like to thank Gary Koop for many helpful comments on an earlier draft.

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9 Empirical Results: ISO 14001 & Efficiency/Cost Analysis

Table 4: Estimate of the effect of ISO variables on efficiency/costs for full sample

Explanatory Variable	*Random Effects*		*Stoch. Front Constant Eff.*		*Stoch. Front. Time-var Eff.*	
	Coeff.	P-val	Coeff.	P-val	Coeff.	P-val.
ISOINT	-.0253929	0.111	-.276789	0.221	-.7213471	0.002
ISOACC	-.0179503	0.425	-.6483945	0.022	-.6253505	0.033

Table 5: Estimate of the effect of ISO variables on efficiency/costs for subset of mines

Explanatory Variable	*Random Effects*		*Stoch. Front Constant Eff*		*Stoch. Front. Time-var Eff.*	
	Coeff.	P-val	Coeff.	P-val	Coeff.	P-val.
ISOINT	.0192664	0.258	.0445973	0.695	-.192697	0.122
ISOACC	.0106989	0.657	-.0101133	0.944	-.2310763	0.143

Table 6: Time-variant efficiency estimates for ISO 14001 for top 10 and bottom 10 performing mines (2007)

Mine Name	*ISO Accred.*	*Time Variant Efficiency*
Top 10 performing Cu mines in 2007		
1. Tyrone	Yes	1.10
2. Cadia	No	3.10
3. Cuajone	No	3.75
4. Olympic Dam	Yes	4.36
5. El Soldado	Yes	4.61
6. Gunpowder	No	4.66
7. Mantos Blancos	Yes	4.72
8. Francisco Madero	Yes	4.89
9. Peak	No	4.90
10. Voisey	No	5.06
Bottom 10 performing Cu mines in 2007		
1. Roseberry	Yes	13.89
2. KGHM	No	14.41
3. Ontario	No	14.48
4. Batu Hiju	No	15.08
5. Manitoba	No	16.57
6. Oktedi	No	17.40
7. Nchanga Mine	No	17.79
8. Sudbury	Yes	18.27
9. Coeur & Galene	No	18.50
10. Chuquicamata	Yes	26.10

10 Appendix A: Variables

Table 1: Variable Measures & Acronyms

Variable	*Measure*
TOTALCOST	Total onsite mining and milling costs per day (US $)
MTMILL	Ore milled per year (kt)
METAL	CU metal produced (kt)
TYPE	Underground or open pit mine (0=open; 1=underground)
WAGES	Average Hourly Wage Cost (US $/hour)
POWER	Electricity Costs (US c/kwh)
DIESEL	Diesel Fuel Costs (US c/litre)
GRIND	Grinding Media Costs ($/ton)
DRILLCOND	Drilling conditions (OP mines) Index of drilling patterns/powder usage (Ranges from 0.6=good to 2.0 =severe).
GOUNDCOND	Ground conditions (UG mines) Index of rock competence/ other conditions (Ranges from 1=good to 5=poor)
WORKINX	Ore work index for crushing/grinding ore (kwh/ton) Power required to break ore from a theoretically infinite size to 80% passing 100 m
REAGENT	Reagents/acid (US c/kg)
ISOINT	Intention to seek ISO 14001 accreditation 0=no intention; 1=intention
ISOACC	ISO 14001 accreditation (0=No accreditation; 1=Accreditation)
CAPEX	Capital expenditure on mine and mill (US $ million) per annum
SETUP*	Capital costs of mine & mill (US $ million) per annum
DAYS	Number of days mine open during the year
OREGRADE	Grade of ore milled (measured as a percentage of metal within the ore)
*Applies to subset of mines only	

11 Appendix B: Empirical Translog Cost Function Results

Table 2: Conventional Translog Coefficients

Explanatory Variable	*Random Effects*		*Stoch. Front. Time-Invar. Eff.*		*Stoch. Front. Time-var Eff.*	
	Coeff.	*P-val.*	*Coeff.*	*P-val*	*Coeff.*	*P-val*
METAL	-.13815	0.371	-.1466342	0.337	-.1308845	0.360
WAGE	2.430906	0.000	2.455371	0.000	2.835925	0.000
POWER	.0010088	0.999	.0232285	0.965	-.0818236	0.878
DIESEL	0261997	0.898	.0293939	0.885	.0244861	0.907
GRIND	.1215105	0.703	.161733	0.604	.1748499	0.576
REAGENT	.5160896	0.000	.5129229	0.000	.4179279	0.002
$METAL^2$	.0111763	0.000	.0096736	0.001	.0109051	0.000
$WAGE^2$	.0349559	0.148	.0332127	0.164	.0489728	0.031
$POWER^2$	-.1290901	0.015	-.1250389	0.016	-.11352	0.031
$DIESEL^2$	.0534718	0.001	.0532163	0.000	.0423122	0.007
$GRIND^2$	.0237391	0.455	.020585	0.508	.0219921	0.489
$REGLB^2$	-.0156586	0.004	-.0141919	0.008	-.0173356	0.001
METAL×WAGE	.068382	0.000	.0727404	0.000	.0764238	0.000
METAL×POWER	-.0357	0.043	-.0359186	0.036	-.0354509	0.037
METAL×DIESEL	.0074157	0.289	.0043137	0.515	.0027284	0.681
METAL×GRIND	-.0133452	0.572	-.0117724	0.615	-.0143134	0.511
METAL×REAGENT	-.0293608	0.000	-.029732	0.000	-.027161	0.000
WAGE×POWER	-.0763958	0.074	-.0807604	0.052	-.0921697	0.026
WAGE×DIESEL	-.0922965	0.000	-.0939226	0.000	-.0948464	0.000
WAGE×GRIND	-.3072006	0.000	-.3042692	0.000	-.3717909	0.000
WAGE×REAGENT	.1701081	0.000	.179492	0.000	.1815717	0.000
POWER×DIESEL	.0331064	0.379	.0391694	0.283	.0283384	0.439
POWER×GRIND	.1566218	0.047	.144339	0.060	.1716515	0.027
POWER×REAGENT	.0895273	0.013	.0769907	0.032	.09752	0.006
DIESEL×GRIND	-.0353718	0.285	-.035447	0.279	-.0139878	0.682
DIESEL×REAGENT	-.0267835	0.044	-.0261057	0.043	-.0044549	0.746
GRIND×REAGENT	-.1094056	0.000	-.1065188	0.000	-.1113215	0.000

Table 3: Other Coefficients in Cost Frontier

Explanatory Variable	*Random Effects*		*Stoch. Front Constant Eff*		*Stoch. Front. Time-var Eff.*	
	Coeff.	*P-val.*	*Coeff.*	*P-val*	*Coeff.*	*P-val.*
CAPEX	.0048281	0.000	.0046765	0.000	.004706	0.000
TYPE	.4392844	0.000	.400249	0.000	.3716787	0.000
DRILL	.2691563	0.110	.259429	0.121	.0554608	0.33
GROUND	.132641	0.000	.1337238	0.000	.1261764	0.000
WORKINX	.0673973	0.000	0796593	0.000	.0764039	0.000
DAYS	-.5020681	0.000	-.5056953	0.000	-.5155788	0.000
YEAR	.0007804	0.701	-.0006552	0.725	-.0233739	0.000
MILLED	.5900389	0.000	.5995661	0.000	.5978084	0.000
OREGRADE	.0569626	0.001	.052581	0.003	.0356558	0.042
ISOINT	-.0253929	0.111	–	–	–	–
ISOACC	-.0179503	0.425	–	–	–	–