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ESTIMATING THE IMPACT ON EFFICIENCY OF THE ADOPTION OF A VOLUNTARY ENVIRONMENTAL STANDARD: AN EMPIRICAL STUDY OF THE GLOBAL COPPER MINING INDUSTRY

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Estimating the Impact on Efficiency of the Adoption of a Voluntary Environmental Standard: An Empirical Study of the Global Copper Mining Industry

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Abstract: This paper uses data on the world's copper mining industry to measure the impact on efficiency of the adoption of the ISO 14001 environmental standard. Anecdotal and case study literature suggests that firms are motivated to adopt this standard so as to achieve greater efficiency through changes in operating procedures and processes. Using plant level panel data from 1992-2007 on most of the world's industrial copper mines, the study uses stochastic frontier methods to investigate the effects of ISO adoption. The variety of models used in this study find that adoption either tends to improve efficiency or has no impact on efficiency, but no evidence is found that ISO adoption decreases efficiency.

Key Words: ISO 14001 environmental standard; firm performance; stochastic frontier cost function; copper mining industry.

Running Title: Efficiency & Voluntary Standards in the Global Copper Industry

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1 Introduction

ISO 14000 is a series of voluntary standards for environmental management. It 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 what firms must do to implement 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 (ISO 2005).

Case study and anecdotal evidence suggests that few firms adopt the ISO 14001 standard 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, e.g. market access, attention to stakeholder requirements, relief from mandatory regulation, reduced legal liabilities, a greener public image, lower costs and greater efficiency (Morrow and Rodinelli 2002; O'Connor 2002). Given that the adoption of standards poses substantial opportunity costs for firms, it is important to determine if it provides any real benefits. A focus of this study is whether one of these benefits – enhanced efficiency – is associated with the adoption of the standard.

We have plant level data from 1992-2007 on most of the world's industrial copper mines. Excluding copper sulfide mines, which use a different technology, the study covers over 85% of the world's copper mines. The copper industry is a truly global industry, one which is both highly competitive and polluting. In general, we are interested in estimating and understanding the production technology (as measured by a cost frontier) and inefficiencies in this unique data set. Our specific research question of most interest is whether the adoption of the

14001 standard impacts on inefficiency. The study use data on both the intention to seek ISO 14001 certification (measured a year before certification is gained, when firms have made or are making necessary changes in their operations, after formally announcing the intention to gain certification) and the period when and after certification is achieved. It examines their impact on mine inefficiency using several approaches, all of which fall within a stochastic frontier framework. All approaches measure inefficiency relative to a cost frontier. However, inefficiency is modelled in several different ways, depending on whether inefficiency is treated as a random or fixed effect and whether explanatory variables are included in the inefficiency distribution. Furthermore, we present results for different sub-samples of mines (i.e. open pit and underground). Although it empirically focuses on the ISO 14001 standard, it is worthwhile noting that the ISO 9000 and SA 8000 standards are quality management systems similar in spirit to the ISO 14000 series. All require similar implementation and auditing behavior. Hence the study's findings have implications for these other voluntary standards.

The remainder of the paper is structured as follows. Section 2 motivates the paper in the context of a brief discussion of the ISO 14001 standard, focussing on quantitative studies measuring its relationship to mine inefficiency. Section 3 introduces the econometric model. Section 4 discusses the data set used in the analysis. It also discusses aspects of the copper mining industry relevant for the empirical analysis. Section 5 presents empirical results. Section 6 provides a summary and conclusion.

2 Context: Voluntary Standards & Firm Performance

The relationship between environmental standards and firm performance has been a hotly debated issue in the economic and management literature for some years. Some economists argue that any standards[2] will impose costs on a company that will divert resources from other areas of an operation and undermine its competitiveness. They reason that, if efficiency gains from adopting standards exist, then a rational mine would have already adopted them and would not await for ISO standard to inspire them to do so. In contrast, others argue that such standards have beneficial outcomes for a firm's bottom line, enforcing a discipline on firms through the implementation of an environmental management system (EMS) that forces managers and staff to continuously think about and act on reducing the environmental impacts of their production every step of the way.[3] This in turn, leads to less waste and greater conservation of energy and other resources. In addition, such discipline provides other benefits or "low hanging fruit" in the form of efficiency gains. These are assumed to be achieved, for example, through the adoption of lean green technologies and inputs and the reduction of costs associated with pollution liabilities and waste management (Porter and van der Linde 1995).

In most cases these benefits have been determined to exist on the basis of case study and anecdotal evidence only. An example of such a study is Newbold (2006), who presents a number of case studies of the global mining industry. One company analyzed is Codelco, all of whose copper mines are represented in our sample. In 1996 the company decided to become more environmentally respon-

[2]We use the word "standard" when describing ISO 14001 certification rather than voluntary regulation or self-regulation, which is common in the literature. Regulations arise from and are enforced by governments and are legally binding, whereas standards (which may eventually become regulations) are developed by like-minded associations. Unlike regulations, standards focus on process rather than outcomes. It could be argued that the main beneficiary of regulations is society. In contrast, customers (and the firms themselves) are potentially the main beneficiaries of standards.

[3]It is important to stress that two very similar firms could have quite different environmental measures, processes and goals but still gain ISO 14001 certification. In essence, the ISO 14001 is a flexible standard that leaves it up to the firm to decide how it is going to achieve certification within the parameters of the ISO 14001 EMS.

Adoption of the standard involves 5 steps: a) the development of an environmental policy that has the commitment of senior executives; b) the identification of legal/regulatory commitments and targeting of areas 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 and non-compliance); and e) constant re-evaluation by senior management of the effectiveness of all internal programs, systems, products, and targets.

sible and seek ISO 14001 certification across all its mines. Once the decision was made at the senior level to commit resources to environmental improvement the next step involved the compilation of a registry of environmental impacts and applicable legislation and regulations. The control of CO2 emissions, in particular was a high priority. Specific areas were prioritized for CO2 mitigation projects and the reduction of energy use through the use of cleaner production technologies.[4] Other steps included engaging the willing participation of all workers in both its mines and companies in its supply chain, awareness training of the environmental targets and procedures for their implementation, and the introduction of better procedures for dealing with other environmental issues, such as the handling of waste. Agreements were also forged between authorities in respect to on-going management and monitoring of the environment (see Newbold 2006).

In contrast to these case studies, there are far fewer empirical studies measuring whether voluntary standards provide any benefits for the firm. The vast majority of these empirical studies are concerned with analyzing the relationship between environmental outcomes and the adoption of voluntary standards. These studies tend to find a mixed story, with some reporting a positive impact (e.g. Dasgupta et al 2000; Anton et al 2002, King et al 2005) while others find only weak or no evidence (e.g. Barla 2007). Moreover, little of this research has examined whether the adoption of voluntary environmental standards affects the economic performance of the firm. One exception is the study by Boyd and McClelland (1999), who use a DEA approach to measure the loss from potential productive output due to pollution abatement spending in US paper plants. Productive inefficiency is measured 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 was found to contribute to a small decrease in productivity. Similarly, Anton et al (2002) find that S&P 500 firms with higher levels

[4] The company found that during 1999 alone, it had emitted 4671 kton equivalent of CO2 directly or indirectly, largely from electricity use.

of environmental self-reporting also have higher levels of profitability; however, whether this was related to their higher levels of environmental efficiency – the focus of the study – is unclear. Most of the studies looking at the relationship between firm economic performance and the adoption of voluntary standards focus on the ISO 9000 and other service standards. By and large they have found benefits for firms from the adoption of such standards in the form of entry into new markets, higher volume of sales and better financial performance (Corbett et al 2005; Terlaak and King 2005; King and Lenox (2001)).

This study will attempt contribute to this small body of empirical literature. It focuses on the role that the ISO 14001 standard has on one measure of economic performance: efficiency. As far as we are aware, ours is the first such study to empirically investigate the relationship between ISO 14001 and efficiency. To this end, we use a stochastic cost frontier model, which allows for the estimation of mine-specific inefficiency. Specifically, we attempt to answer: Do the economic costs of meeting environmental standards lead to lower efficiency for the firm? Or, by forcing firms to think and act in a disciplined way about environmental management, does it lead them to become more efficient? In our measure of ISO 14001 adoption we distinguish between the intention to seek ISO 14001 certification (the year before certification when firms are making or have made necessary changes to their operations and management) and the period when and after certification is achieved. Our data set indicates that achieving the 14001 certification can take a mine as long as 6-9 years from the date of announcement of intention. Hence we also want to capture any potential efficiency improvements before certification since the vast bulk of the steps in the EMS will be in place by then.

3 Empirical Analysis

3.1 Model & Methods

In order to investigate the impact of the adoption of ISO standard and, more broadly, the efficiency of the copper mines in our data set, we use stochastic frontier methods. The model begins with a cost frontier where costs of mine i at time t, C_{it}, depends on output , Q_{it}, and r input prices, $p_{j,it}$ (for $j = 1,..,r$, $t = 1,..,T$ and $i = 1,..,N$). The translog cost frontier, which defines the minimum levels of costs achievable by a mine producing Q_{it} facing input prices $p_{it,1},..,p_{it,r}$, can be written as:

$$\begin{gathered} \ln\left(C_{it}\right) = \alpha + \beta_1 \ln\left(Q_{it}\right) + \beta_2 \ln\left(Q_{it}\right)^2 + \\ \sum_{j=1}^{r} \gamma_j \ln\left(Q_{it}\right) \ln\left(p_{it,j}\right) + \sum_{j=1}^{r} \delta_j \ln\left(p_{it,j}\right) \quad , \\ + \sum_{s=1}^{r} \sum_{j \leq s} \delta_{sj} \ln\left(p_{it,s}\right) \ln\left(p_{it,j}\right) + \varepsilon_{it} + u_{it} \end{gathered} \tag{1}$$

where ε_{it} reflects measurement error and is assumed to be i.i.d. $N\left(0, \sigma^2\right)$ and $u_{it} > 0$ is the inefficiency of mine i at time t. We will discuss the treatment of u_{it} below. Suffice it to note that (1) is a standard stochastic frontier cost function and, by restricting u_{it} to be positive, it is given the interpretation as reflecting inefficiency (i.e. u_{it} measures how far the costs of mine i are above best practice at time t). Given our log specification, efficiency can be defined as $\exp\left(-u_{it}\right)$.

Due to data limitations and in an attempt to control for mine heterogeneity, we modify this conventional translog cost frontier by adding other explanatory variables geological and physical factors of the mine that impact on costs. We call these variables $Z_1,..,Z_k$ and include them in the cost frontier as:[5]

[5] 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).

$$
\begin{gathered}
\ln\left(C_{it}\right)=\alpha+\beta_1\ln\left(Q_{it}\right)+\beta_2\ln\left(Q_{it}\right)^2+\\
\sum_{j=1}^{r}\gamma_j\ln\left(Q_{it}\right)\ln\left(p_{it,j}\right)+\\
\sum_{j=1}^{r}\delta_{it,j}\ln\left(p_{it,j}\right)+\sum_{s=1}^{r}\sum_{j\leq i}\delta_{sj}\ln\left(p_{it,s}\right)\ln\left(p_{it,j}\right)+\\
\sum_{j=1}^{k}\zeta_j\ln\left(Z_{it,j}\right)+\varepsilon_{it}+u_{it}
\end{gathered}
. \qquad (2)
$$

The key question addressed in this paper is whether certification and the intention to seek certification (designated in the study by the acronyms, ISOACC and ISOINT, respectively) have an important effect on inefficiency. Beginning with Schmidt and Sickles (1984), a variety of approaches to inefficiency measurement have been suggested when using panel data (see also Battesi and Coelli, 1992). These approaches differ in their treatment of three issues: i) whether inefficiency is treated as random or fixed, ii) whether inefficiency depends on other explanatory variables, and iii) whether inefficiency is time-varying or not. Given the research question of this paper, we want inefficiency to depend on explanatory variables such as ISOACC. In many ways, it is desirable to allow for time variation in inefficiency and, accordingly, our main results allow for inefficiency to vary over time. However, allowing for inefficiency to vary over both i and t can lead imprecise estimation due to the need to estimate TN inefficiencies. Accordingly, as a robustness check we also estimate models where inefficiency for each mine is constant over time. Finally, most of our models assume inefficiency is a random variable drawn from a known distribution and we refer to such models as random effects stochastic frontier models below. However, as another robustness check, we present results based on the fixed effects inefficiency estimator of Schmidt and Sickles (1984).

We adopt the Bayesian methods for efficiency analysis with panel data developed in Koop, Osiewalski and Steel (1997). This allows us to estimate the entire model, as opposed to a two stage method where the researcher first estimates mine inefficiencies and then runs a second stage regression of inefficiency estimates on explanatory variables. The reader is referred to Koop, Osiewalski and Steel (1997) for complete technical details,[6] which includes a description of the posterior simulation algorithms used to produce our empirical results. Here it is sufficient to describe the basic modelling ideas.

Let u be $TN-$ vector containing all the u_{it}s. We can handle both the time varying and time-invariant inefficiency cases by writing $u = Dv$ where D is a known matrix and v is a vector containing the distinct inefficiencies in the model. If $D = I$ and v is a $TN-$ vector, then $u = v$ and there is a distinct inefficiency at each point in time for each mine. The case where $D = I_N \otimes \iota_T$, where ι_T is a T-dimensional vector of ones and $\otimes$ denotes the Kronecker product, implies inefficiency terms which are specific to each mine, but constant over time. The case of the unbalanced panel is the slight extension of this where $D = I_N \otimes \iota_{T_i}$ where T_i is the number of observations for mine i.

Let M denote the number of distinct inefficiencies in the model (i.e. $M = TN$ or $M = N$). Let $W = (w_{lj})$ for $l = 1, .., M$ be a matrix of explanatory variables for the inefficiencies for $j = 1, .., r$. The first column of W contains an intercept (i.e. all its elements are one). Koop, Osiewalski and Steel (1997) allow for such explanatory variables to influence the mean of the inefficiency by introducing a hierarchical structure which adds an s-dimensional extra parameter vector $\phi = (\phi_1, \ldots, \phi_s)'$ with all elements being positive. Given ϕ, v has the following p.d.f.:

$$p(v|\phi) \propto \prod_{l=1}^{M} f_G\left(v_l|1, \lambda_l(\phi)\right), \tag{3}$$

where $f_G(z|a, b)$ denotes the p.d.f. of a Gamma distribution with mean a/b and variance a/b^2 and, thus, the mean of the inefficiency distribution of observation l is $\lambda_l(\phi)^{-1}$. We set the first argument of the Gamma to 1, which implies an exponential distribution.

Note that the use of an exponential distribution (a common choice in stochastic frontier analysis) ensures that inefficiencies are positive. We allow $\lambda_l(\phi)$

[6] Koop, Osiewalski and Steel (1997) derive results for a balanced panel with time-invariant inefficiencies. For the slight extensions of the algorithm necessary to handle an unbalanced panel with time-varying inefficiencies, see Fernandez, Koop and Steel (2000).

to depend on ϕ in the following way

$$\lambda_l(\phi) = \prod_{j=1}^{r} \phi_j^{w_{lj}}. \tag{4}$$

Our w_{lj}s will be dummy variables (plus an intercept). Thus, in this specification ϕ_j will measure the impact of explanatory variable j on inefficiency. To aid in interpretation of our empirical results consider the following example. In one of our models, W will contain an intercept and the ISOACC dummy variable. In this case ϕ_2 will measure the impact of adopting ISO standards on inefficiency. Mines which have adopted ISO standards will have mean inefficiency of $(\phi_1\phi_2)^{-1}$ whereas those which have not have mean inefficiency of $(\phi_1)^{-1}$. If $\phi_2 > 1$ then ISO accredited firms will have lower inefficiency than non-accredited firms. But if $\phi_2 < 1$ then non-accredited firms will have lower inefficiency. If $\phi_2 = 1$ then ISO accreditation has no impact on inefficiency.

In our empirical results, we implement this model with the two different choices for D described above, with different choices for W and with different sub-samples of the data. Note that, for most of our mines, the elements of W are constant over time (e.g. most of the mines either have ISO accreditation for all periods or for none). For the exceptions to this, when we are working with time-varying inefficiencies, the components of W will be time-varying. But when we are working with time-invariant inefficiencies, we set the appropriate element of W to 1 if ISO standards are adopted at any point in time (and it is set equal to zero only if ISO standards are never adopted).

Equations (2), (3) and (4) can be thought of as a stochastic frontier variant of a random effects panel data model, since the inefficiencies are assumed to be drawn from the random distribution given in (3). Koop, Osiewalski and Steel (1997) also derive a fixed effects version of the stochastic frontier model based on the fixed effects efficiency analysis of Schmidt and Sickles (1984). That is, instead of assuming a specification like (3) for the inefficiencies, they are modelled using mine-specific dummy variables and transformed into inefficiencies as described in Schmidt and Sickles (1984) or Koop, Osiewalski and Steel (1997). The reader is referred to these papers for additional details. It is sufficient at this stage to note that the inclusion of so many mine specific dummy variables can often result in imprecise estimation. Moreover, it is also difficult to generalize this approach to allow for explanatory such explanatory variables as ISOACC to explain the inefficiencies. For these reasons, most researchers prefer to work with random effects specifications. However, fixed effects specifications are typically interpreted as being more robust to endogeneity concerns and, hence, we also estimate fixed effects stochastic frontier models as a robustness check.[7]

Further to the issue of endogeneity we note that our model involves two main equations: one defines a cost frontier and the second one relates the inefficiencies to explanatory variables. Endogeneity is not an issue in the cost frontier since it can simply be interpreted as a mechanical method for estimating a best-practice frontier. Intuitively, the frontier that mine A faces is defined by mines with similar input prices and outputs and other characteristics (e.g. geology). Endogeneity issues are not relevant to this part of the analysis. It is only in our second equation, where we try to interpret why some mines are more or less efficient than others that the problem of endogeneity becomes relevant. That is, our model will be able to estimate the impact of ISO adoption on inefficiency. However, it may be difficult to distinguish between various stories for why this impact is occurring and whether any impact we find is causal. This issue is discussed in further detail in the empirical results section below, but suffice it to say that it is for this reason that we include results from the fixed effects approach as a robustness check on our results.

Furthermore, motivated by the potential endogeneity issue, some of our results include an extra explanatory variable, CO2 (in addition to the ISOACC variable) in the inefficiency distribution. This variable is defined in the next section, but it is worthwhile here to explain why we include it. For present

[7]Bayesian methods require a prior. Throughout we use noninformative priors. That is, for the coefficients of the frontier and σ^2 we use conventional noninformative priors. In the random effects model, for the parameters characterizing the inefficiency distribution, we use the same relatively noninformative priors as in Koop, Osiewalski and Steel (1997).

purposes, note that it is a measure of whether a mine is emitting a relatively high or low level of CO2 emissions. As such, it can be thought of as reflecting each mine's current environmental performance. To see why the inclusion of CO2 as an explanatory variable in the inefficiency distribution should mitigate worries about endogeneity, let us consider how endogeneity might arise in the first place. Suppose we find that mines which adopt ISO standards are more efficient. It could be that this reflects a causal relationship in that the actions taken as part of ISO adoption are leading to higher efficiency. But it is possible that environmentally-minded firms are both more efficient to begin with and are more likely to adopt ISO standards. If such a story is true, then ISO standards are not having a direct causal effect on inefficiency. If we can find a measure of "environmentally-mindedness" we can control for this and, if the ISO variable is still associated with higher efficiency, then we can be more confident that endogeneity worries are not a problem. We conjecture that CO2 might be a measure of "environmentally-mindedness" that is not directly associated with the variables in the cost frontier and, thus, might help assuage the reader of endogeneity concerns.

4 Data

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 proprietary industry datasets (Minecost 2007; RMG 2007) which measure a range of geological, production and cost data for the global mining industry. CO2 emissions data were calculated using emission coefficients for each country's electricity use, according to the IPCC standards for GHG inventories.[8] Table 1 lists the variables, their acronyms along with their definitions. Table 2 provides descriptive statistics for our unbalanced panel of 99 copper mines from 1992 to 2007 which contains 1265

[8] Available at:
http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

observations. The sample has a representation from the major copper producing countries of the world, with important medium level producers such as Zambia and Peru. More than one half of the mines are situated in four countries: USA, Canada, Chile and Mexico. All variables measured in monetary units are expressed in US dollars with local currencies being converted into US dollars using the annual average exchange rate.

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

Group 1: Total costs

Group 2: Output measure

Group 3: Prices of inputs

Group 4: Investment

Group 5: Physical/geological factors

Group 6: ISO and CO2 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 US 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 input prices. Two price inputs measure energy costs: diesel and electricity. Diesel (DIESEL) costs are measured in US cents/liter. Electricity (ELECT) costs are measured in US cents/kwh. Other inputs include grinding media (the costs of metallic and other materials for grinding ore) in US dollars per tonne. Reagents/acid input prices

(REAGENT), another important input price relevant to the milling stage, is measured in US cents/kg. The price of labour (WAGES) is measured as the average hourly labor cost in US dollars. Another input price (GRIND) applies to grinding media (the price of metallic balls for grinding and crushing ore). It is measured in US dollars/tonne.

Group 4. The study's investment variable measure capital investment as capital expenditure (CAPEX) in US millions of dollars per year.

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 equipment and manpower is required to mine and mill it. The first of these variables (TYPE) controls for type of mine, i.e. open pit vs. underground. It is 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). This variable is 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 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 apply to underground and open pit mines, respectively, we interact them with their respective underground/open pit dummy variables. 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 ore and is measured in kwh/t.

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 (Barla 2007; Videras & Alberini 2000; Arora & Cason 1995). 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, the variable YEARS controls for the number of years the mine has been in operation. Its inclusion is meant to control for the fact that newer mines are likely to have more sophisticated equipment, particularly, environmental controls in place, making ISO certification easier to obtain and thus make less substantive difference in heir operations. However, it is worth stressing that a majority of mines in the study are relatively recent (i.e. opened in the late 1980s and early 1990s). This variable is measured in years since the opening of the mine. We also include a variable named DAYS, designed to captured durational differences in operation that may affect costs. It controls for the number of days per year the mine is in operation.

Group 6. Two variables measure aspects of the ISO 14001 voluntary standard. One regulatory variable (ISOINT) measures the intention of mines to seek ISO 14001 certification. This dummy variable is observed one year before a mine seeks certification. At this point, the mine will have made and/or be making changes in its management en-route to eventual certification. The attainment of 14001 certification is 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 a firm several or more years. In short, certification does not come immediately after the expressed intention to seek certification. Certification must be obtained by accredited external agencies who are also responsible for on-going monitoring to ensure compliance.

Our final variable is a dummy variable. For the reasons discussed at the end of Section 3, we include a CO2 measure as a control for endogeneity. The variable measures whether a mine's CO2 emissions per unit of metal produced are above or below average based on total CO2 emissions from electricity generation. Specifically, it is calculated from the kwh of electricity generated per unit ton of ore produced for each mine, using greenhouse gas emissions conversion factors for electricity production for each country's national grid. It excludes CO2 emissions from diesel fuel, another important energy source for mines. Diesel fuel use, and thus the level of resulting CO2 emissions generated, is not always directly under the mine's control (e.g. the steepness of the terrain will affect on site transportation and thus the amount of diesel fuel used).

Equations (2) and (4) describe precisely how these variables enter the model, where the Group 1 variable is labelled y_{it}, the Group 2 variable Q_{it}, Group 3 variables are the $p_{it,j}$, Groups 4 and 5 are the $Z_{it,j}$ and Group 6 are in w_{lj}.

****Tables 1 & 2 Here****

5 Empirical Results

We use two main stochastic frontier methodologies: random effects with time varying efficiencies and random effects with time invariant efficiencies. We also consider three different choices for our explanatory variables in the inefficiency distribution: only ISOACC, a dummy for either ISOACC or ISOINT, and both the ISOACC and CO2 variables. Moreover, we consider three different subsamples of the data: a) all the mines; b) open pit mines only; and c) underground mines only. This gives us 18 main sets of results (i.e. 2x3x3). In addition, we use the fixed effects analysis to independently investigate the robustness of results in certain key dimensions. In the interest of brevity, we do not present results from all these analyses. For the coefficients in the cost frontier we only present results for 3 cases: random effects with ISOACC as only variable in the efficiency distribution (time varying and time invariant cases) and the fixed effects model. The crucial issue in the paper is the relationship between the ISO variables and inefficiency. For this issue we present a complete set of results for all cases. Note that underground mines have 668 observations (53 mines); open pit mines 597 observations (47 mines).

5.1 Results for the Cost Frontier

Tables 3 and 4 present point estimates (posterior means) and posterior standard deviations for the coefficients of the cost function for the study's three different modelling approaches. We informally refer to point estimates as being "significant" if the posterior mean is two standard deviations from zero. The basic story from these tables is that the 3 different approaches are broadly similar. For variables which enter linearly (as in Table 4) this is evidently clear. The coefficient estimates for these investment and physical/geological variables are, for the most part, highly significant and of the expected sign. Note that the coefficient on DAYS is negative. But, since the dependent variable is measured as costs per day, this is not necessarily counter-intuitive. For the variables which enter nonlinearly, it is less clear that the implied frontier is similar for the different econometric approaches. But an examination of implied marginal effects of each variable indicate that they quite similar across the different approaches. 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 often significant.

****Tables 3 & 4 Here****

5.2 Results for the Inefficiency Distribution

Table 5 presents results for the coefficients on the explanatory variables in the inefficiency distribution. Their interpretation is discussed after (4) and the reader is reminded that a coefficient estimate of one indicates the explanatory variable has no effect on inefficiency. Thus, we refer to a variable as being significant if it is two posterior standard deviations from one. The 18 rows of the table correspond to the 18 main sets of results described above.

Results using all the observations (i.e. with only a dummy variable to account for differences between open-pit and underground mines) are strong and significant when we allow for a time-varying inefficiency distribution. ISO accreditation is associated with less inefficiency (or, equivalently, higher efficiency). This holds true regardless of whether we use a variable for actual ISO accreditation or actual or intended accreditation. Importantly, it also holds true when we include the CO2 variable in the inefficiency distribution. For reasons discussed at the end of Section 3, inclusion of CO2 should control for one potential endogeneity issue. The fact that the coefficient CO2 variable is less than one (and significant) indicates that mines with high CO2 emissions are likely to be more inefficient. However, even controlling for this effect, we are still finding ISO accreditation to have a significant impact on inefficiency.

These findings, however, are not that robust to our different statistical methodologies and choice of sub-samples of the observations. When we use a time-invariant inefficiency distribution, ISO accreditation has no significant impact on inefficiency (even when we control for CO2). Similarly, when we work only with open pit mines, nothing is significant. It is only for underground mines that we find results that are similar to those described in the previous paragraph (although posterior standard deviations tend to be larger with this smaller data set and, hence, we have fewer significant results).

Note however, that there is one way in which we could argue that our results are robust. This is in respect to the main research question motivating this paper: Does the adoption of the ISO 14001 EMS have any impact on inefficiency? Our results may disagree about whether ISO accreditation is good for efficiency or has no impact on efficiency. However, no econometrician could reasonably interpret the results to mean that adopting the ISO 14001 standard leads to greater inefficiency (even allowing for potential endogeneity).

A consideration of fixed effects stochastic frontier results also indicate endogeneity is not an important worry in the sense that (where comparable) inefficiency estimates are similar to those found using random effects methods. To be precise: the correlation between the inefficiencies estimated using the random effects stochastic frontier model (with time invariant inefficiency) and fixed effects stochastic frontier model is 0.801. Conventionally, fixed effects models are thought of as being less susceptible to endogeneity worries than random effects approaches. Thus the results can offer some reassurance that our random effects models are not too affected by endogeneity.

Table 5 Here

6 Discussion and conclusion

The number of firms adopting the ISO 14001 standard since its inception in 1996 has risen dramatically. However, while there is a wide body of qualitative case study and anecdotal literature on the consequences of ISO 14001 for firm performance, there has been little empirical research examining whether it lives up to its promise. This study has contributed to the small but growing body of empirical studies that have analyzed the impact of ISO 14001 and 14001-like EMS systems on firm performance. Case study and anecdotal evidence suggests enhanced efficiency is an important motivation for seeking ISO 14001 certification. Some managers consider it to be more important than –indeed, as even driving – environmental concerns. This study has looked at the impacts of ISO 14001 on efficiency in a plant-level study of the global copper industry. We investigated several different econometric methodologies and different sub-sets of the data. Such an approach is useful since results that are robust to different methods are more believable than those presented for a single method.

It found some evidence that ISO 14001 certification may be associated with greater efficiency. On the whole, however, this evidence was not robust across model choice or sample. How do we interpret this indeterminate finding? First, it may be a reflection of the diversity of reasons given by firms for adopting the standard. The case study literature has shown that firms pursue ISO 14001 certification for a variety of reasons. Thus, while mines may make substantive changes in their operations en-route to achieving certification, it could be that these are not impacting primarily on efficiency. Second, as mentioned above, it may be that these outcomes are linked to specific internal or external circumstances and characteristics of mines, which are not easy to identify in this kind of study. Third, managers in the copper industry may be seeking ISO 14001 certification for purely symbolic rather than substantive reasons. If this is the case, then commitment to achieving the objectives of the standard, the integration of support throughout the mine, the financial resources devoted to its implementation, and the level of employee and managerial awareness and effort employed to achieve certification, will be superficial at best. Without more substantive changes, efficiency gains may not be achievable. Finally, the reason may lie outside the internal operations of the firm itself. Although the standard does require third-party auditors, thereby reducing opportunities for shirking and free-riding, accountability to the standard is weakened due to both the lack of disclosure of third-party audits and strong sanctions against non-conformity once certification is achieved. In this case, a standard without sufficient "teeth" or transparency will be unlikely to have much impact on mine performance beyond a very superficial level.

Whichever story is the correct one, our study does provide some comfort to managers in the global copper industry who have implemented or are planning to adopt an ISO 14001 EMS: There is no evidence that it will lower efficiency.

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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 pit; 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 prior to year of certification 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
DAYS	Number of days mine open during the year
OREGRADE	Grade of ore milled (measured as a percentage of metal within the ore)
CO2	CO2 emissions from electricity generation per ton of ore mined & milled 1=above average; 0= below average
YEARS	Number of years mine has been in operation

Table 2: Descriptive Statistics				
Variable	Mean	St Dev	Min	Max
TOTALCOST	1.69×10^5	2.00×10^5	7.65×10^3	2.32×10^6
MTMILL	1.52×10^4	2.65×10^4	59.316	2.34×10^5
METAL	181.492	796.103	0.078	8634.2
TYPE	0.528	0.499	0	1
WAGES	15.455	8.843	1.266	47.698
POWER	5.410	1.475	1.152	18.303
DIESEL	36.304	21.774	1.218	165.520
GRIND	551.071	102.971	21.994	675.203
DRILLCOND	0.267	0.294	0	.9
GOUNDCOND	0.644	0.705	0	4
WORKINX	12.829	2.007	7	23
REAGENT	0.195	0.316	0.001	2.826
ISOINT	.0261	0.159	0	1
ISOACC	0.123	0.328	0	1
CAPEX	11.963	14.507	0	150
DAYS	317.941	69.284	25	365
OREGRADE	0.032	0.117	0.007	0.858
YEARS	31.222	29.275	-8	116
CO2	0.144	0.351	0	1

Table 3: Posterior Properties of Conventional Translog Coefficients						
Explanatory Variable	Stoch Frontier Time-varying Eff		Stoch Frontier Time-invariant Eff		Stoch Frontier Fixed Effects	
	Mean	St Dev	Mean	St Dev	Mean	St Dev
METAL	0.027	0.189	-0.272	0.163	-0.559	0.169
WAGE	0.455	0.516	2.645	0.471	2.129	0.491
POWER	1.413	0.659	-0.891	0.563	-2.785	0.533
DIESEL	0.285	0.236	0.279	0.232	0.475	0.246
GRIND	-0.642	0.380	0.089	0.321	-0.518	0.317
REAGENT	0.601	0.206	0.543	0.137	0.354	0.134
$METAL^2$	0.004	0.002	0.011	0.002	0.008	0.003
$WAGE^2$	0.152	0.016	0.065	0.022	0.034	0.025
$POWER^2$	-0.029	0.068	-0.058	0.053	0.067	0.052
$DIESEL^2$	0.030	0.025	0.029	0.016	0.041	0.017
$GRIND^2$	0.025	0.039	0.013	0.033	0.028	0.034
$REGLB^2$	-0.026	0.007	-0.011	0.006	-0.010	0.011
METAL×WAGE	0.006	0.006	0.060	0.008	0.006	0.013
METAL×POWER	-0.004	0.020	-0.032	0.017	-0.041	0.022
METAL×DIESEL	0.019	0.009	0.005	0.007	0.001	0.010
METAL×GRIND	-0.018	0.028	0.011	0.025	0.053	0.026
METAL×REAGENT	-0.030	0.007	-0.030	0.005	-0.030	0.001
WAGE×POWER	-0.222	0.047	-0.132	0.041	-0.097	0.042
WAGE×DIESEL	-0.104	0.026	-0.109	0.020	-0.106	0.022
WAGE×GRIND	-0.049	0.079	-0.322	0.072	-0.228	0.075
WAGE×REAGENT	0.034	0.025	0.179	0.017	0.208	0.018
POWER×DIESEL	0.153	0.055	0.083	0.037	0.052	0.039
POWER×GRIND	-0.141	0.097	0.24	0.083	0.471	0.080
POWER×REAGENT	0.143	0.034	0.064	0.037	0.009	0.038
DIESEL×GRIND	-0.064	0.040	-0.065	0.035	-0.091	0.037
DIESEL×REAGENT	0.028	0.021	-0.030	0.013	-0.020	0.013
GRIND×REAGENT	-0.147	0.023	-0.103	0.022	-0.071	0.021

Table 4: Posterior Properties of Other Coefficients in Cost Frontier						
Explanatory Variable	Stoch Frontier Time-var Eff		Stoch Frontier Time-invariant Eff		Stoch Frontier Fixed Effects	
	Mean	St Dev	Mean	St Dev	Mean	St Dev
CAPEX	0.015	0.001	0.004	0.001	0.004	0.001
TYPE	0.336	0.059	0.373	0.110	0.324	0.167
DRILL	0.150	0.098	0.441	0.159	0.298	0.187
GROUND	0.062	0.024	0.133	0.021	0.187	0.022
WORKINX	0.174	0.059	1.058	0.172	1.123	0.284
DAYS	-0.461	0.036	-0.511	0.024	-0.520	0.025
MILLED	0.416	0.014	0.589	0.017	0.608	0.020
OREGRADE	0.033	0.009	0.047	0.018	-0.011	0.021
YEARS	0.002	0.001	0.005	0.001	-0.003	0.002

Table 5: Posterior Properties of Coefficients in Inefficiency Distribution

Ineff. Dist.	ISOACC		ISOACC+ISOINT		CO2	
	Mean	St Dev	Mean	St Dev	Mean	St Dev
	All Observations					
Time Varying	1.536	0.176	-	-	-	-
Time Varying	-	-	1.521	0.162	-	-
Time Varying	1.507	0.170	-	-	0.726	0.070
Time Invariant	0.972	0.206	-	-	-	-
Time Invariant	-	-	0.995	0.210	-	-
Time Invariant	1.019	0.214	-	-	1.133	0.265
	Open Pit Mines Only					
Time Varying	1.093	0.148	-	-	-	-
Time Varying	-	-	1.089	0.138	-	-
Time Varying	1.078	0.147	-	-	0.835	0.157
Time Invariant	0.847	0.256	-	-	-	-
Time Invariant	-	-	0.894	0.269	-	-
Time Invariant	0.849	0.255	-	-	0.876	0.540
	Underground Mines Only					
Time Varying	1.433	0.277	-	-	-	-
Time Varying	-	-	1.535	0.468	-	-
Time Varying	1.414	0.230	-	-	0.718	0.109
Time Invariant	1.053	0.314	-	-	-	-
Time Invariant	-	-	1.040	0.311	-	-
Time Invariant	1.028	0.312	-	-	0.929	0.259