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THE IMPACT OF ENVIRONMENTAL CONSTRAINTS ON PRODUCTIVITY IMPROVEMENT AND ENERGY EFFICIENCY IN INTEGRATED PAPER AND STEEL PLANTS[1]

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Analysis that assess the level of energy efficiency (or inefficiency) raises the economic question, *Is efficiency of energy use different from other inputs?* In this study, energy efficiency is examined from the perspective of total factor efficiency, i.e. energy is treated the same as all other inputs, which are all examined for evidence of technical inefficiency. In addition, the linkage between input usage, productivity, and *levels of pollution output* are examined. This paper present the methodology and empirical results for two energy and pollution intensive sectors, the integrated steel and paper industries.

The methodology for measuring efficiency is based on the output distance function and the Hyperbolic graph efficiency measure, both of which are mathematical representations of the 'best practice' production technology. Data on levels of pollution emissions are used to measure plant level efficiency in environmental performance, i.e. reducing pollution levels. Observed data on emissions, rather than permits, violations etc., are used to assess environmental *performance*, as opposed to *compliance*. Empirically observed differences between average performance and the 'best practice' are given as evidence of so-called 'win-win' environmental, energy, and productivity improvements, as suggested by Porter and others.

To assess the claims that mandated pollution abatement investment 'squeezes out' other productivity and energy efficiency investments, data on pollution abatement investment costs are used to measure plant level productivity under various constraints on abatement investment. The productivity and energy efficiency implications of pollution abatement investment constraints are explored using interplant productivity and energy intensity comparisons using an input distance function, also a mathematical representation of the production technology. Abatement investment is treated as a constraint within total plant investment to explore the implication of possible capital rationing on productivity and energy efficiency.

The analytic approach uses plant level data economic data from the Census Bureau and pollution data from the EPA. Linear programming is used to compute the input, output, and Hyperbolic distance functions for each plant in the data set and compares that

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I. Introduction[1]

Analysis that assess the level of energy efficiency (or inefficiency) raises the economic question, *Is efficiency of energy use different from other inputs?* In this study, energy efficiency is examined from the perspective of total factor efficiency, i.e. energy is treated the same as all other inputs, which are all examined for evidence of technical inefficiency. In addition, the linkage between input usage, productivity, and *levels of pollution output* are examined. This paper present the methodology and empirical results for two energy and pollution intensive sectors, the integrated steel and paper industries.

The release of pollution outputs has moved from a secondary concern of production to one which rival the attention paid to the choice of production inputs, outputs and the choice of production technology. An important policy concern regards the trade offs producers make when choosing among multiple goals. In particular, concern has been expressed that improved environmental performance may come at the expense of energy efficiency and productivity improvements. Some commentators, e.g. Michael Porter, have claimed that there are large 'win-win' opportunities available, where pollution can be reduced and productivity improved simultaneously. This paper looks for evidence of these opportunities among U.S. manufacturing plants.

This paper examines plant level efficiency in production energy use and pollution minimization in sectors of the economy which are particularly energy and pollution intensive. The two industries analyzed are the integrated segments of the steel and paper industries. Utilizing an unique plant level data set which includes information on production output, inputs, pollution outputs and plant technology plant level performance is evaluated. This performance is evaluated using efficiency measures based upon the input distance function. These measures are calculated via linear programming techniques. We find that industry energy use and pollution could be reduced 3% to 9% and that the constraints from mandated environmental investments reduce productivity 3-5%.

The ability to measure productivity and efficiency depends on the ability to represent the underlying technology of production. There is an extensive literature on the choice of functional forms and estimation technique in order to accurately represent production. Virtually all of the discussed possibilities are variations of a function which utilizes

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several inputs to produce a single output. An alternative method of representing the production technology is the input distance function. This function is an extremely general method of representing the inputs and outputs of a process. This representation is very intuitive and is unfortunately underutilized. The distance function computes the largest possible proportional reduction of the inputs that can still produce a particular level (and mix) of the outputs. The distance function is easily computed from the solution of a set of linear programming problems, sometimes called data envelopment analysis (DEA).

In this paper we use two variations of the distance function for our analysis, (i) a hyperbolic distance function which includes the environmental pollution outputs of the plant as well as the other inputs and outputs of the plant and (ii) an input distance function which distinguishes between environmental and other types of investment.

Hyperbolic Analysis of Production and Environmental Performance

The hyperbolic efficiency estimates are based on an analysis of five production inputs: capital, labor, material, fossil fuel, and electricity and, as described above, two types of outputs: 'good' outputs, measured as the dollar value of shipments, and a set of 'bad' outputs, namely the quantity of criteria air and water pollutants or toxic releases. The calculation procedure estimates the proportion that plants could reduce production inputs and all 'bad' outputs, while at the same time increasing 'good' output by the same proportion. The estimates do not take into account any short run constraints. We assume that the less efficient plants can take advantage of the technologies available in the best practice plant with a similar mix of inputs and outputs. Hence the measure is exploiting observable differences between plants.

It is important to note that the hyperbolic analysis uses a very strict criteria for identifying production inefficiency, i.e. 'win-win' improvements. The analysis measures the amount by which inputs and environmental 'bad' outputs could be reduced, while simultaneously increasing output by the *same proportion*. This means that one type of improvement is not considered more valuable than another. Instead, only those production efficiency opportunities that would lower inputs of energy, labor, and materials, *and* lower pollution levels, *and* increase output levels is estimated. This gives a very conservative estimate of win-win opportunities, since a plant that is unable to reduce any *single* input or pollutant while increasing output is not considered 'win-win' in this analysis. Only those plants that can 'do it all' are included in the estimate of environmental/productivity 'win-win' opportunities.

To measure the output loss due to regulation, it is assumed that pollution regulations can be represented by the assumption that the pollutants are not 'freely disposable', i.e. reduction in pollutant requires some reduction in output (for an efficient plant). This potential productivity loss due to regulation is estimated by computing the hyperbolic efficiency measure with and without the disposability constraint and comparing the two results. The difference between the two productivity measures gives an estimate of the overall costs, as represented by productivity due to regulation. These implied costs include both direct costs, labor, capital and materials diverted to abatement activities, as well as indirect costs, plant down time, etc.

Estimating the Effect of Pollution Abatement Expenditure Constraints

One source of production inefficiency driven by implementing environmental controls is in the company allocation of investment capital to pollution abatement instead of production efficiency improvements. Mandatory environmental investments may reduce the money that is put into other more productive areas of a plant. This loss of productive capital due to capital expenditures on pollution abatement is referred to as the *abatement capital constraint*. This potential effect is examined in the second segment of plant data analysis by modifying the framework used to measure the production efficiency component of productivity.

In the hyperbolic analysis the capital stock is measured as a perpetual inventory of past investments and depreciation of existing stock. To estimate the effect of pollution abatement expenditure constraints, the following three kinds of capital inputs are considered: existing stock, new plant and equipment, and new abatement capital.

It is possible to infer the magnitude of production efficiency loss at a plant due to the requirement that a fixed share of new investment be spent on abatement technology rather than on production improvements. This is done by comparing the level of plant production efficiency (i.e. how far from best practice a plant is positioned) under two alternative assumptions about the composition of capital expenditures made each year: (i) both productivity and abatement expenditures are made — new plant and equipment and abatement capital must be spent in the observed quantities, or (ii) only productivity expenditures are made — all new investment expenditures were hypothetically made in the new plant and equipment category with no abatement expenditures. The difference in the production efficiency in these two cases is a estimate of the production efficiency loss due the abatement capital constraint.

In the next section the hyperbolic efficiency measure and the investment constrained input distance function are developed from the input distance function. It is then shown that these measures can be calculated as the solution of a set of linear programming problems. In section III the sources of the plant level data are discussed. Section IV presents the results of the two sets of analysis on impact of environmental constraints. Section V concludes.

II. Methods

The precursors to the tools used in this paper is the input distance function of (Shepard 1970). This function allows for a very flexible characterization of the relative efficiency of production units. The basic formulation is defined for a vector of inputs and a vector of desirable outputs. The problem of interest for this paper requires that undesirable outputs be included as well. This expanded function is used to create the hyperbolic graph efficiency measure. The final portion of this paper address the concern that mandated environmental investments crowd out other investments. The tool applicable to this problem is an expanded input distance function that differentiates between the different types of investment. As an introduction to the more specialized tools used to evaluate the impact of environmental constraints we will briefly review the basic formulation of the input distance function. From this function of the other specifications are easily motivated. A complete discussion of distance functions may be found in (Färe, Grosskopf, and Lovell 1985).

Input Distance Function

The firm employs a vector of inputs, $x=(x_1,...,x_N)\in\mathbb{R}_+^N$, to produce a vector of outputs, $y=(y_1,...,y_M)\in\mathbb{R}_+^M$. The firm's technology can then be specified as $T = \{(x,y) : x\in \mathbb{R}_+^N, y\in\mathbb{R}_+^M$, x can produce y$\}$. Alternatively the technology defines the input correspondence, $L(y)=\{x: y\in\mathbb{R}_+^M$, x can produce y$\}$. see Fare 1988 p.9 We then define the input distance function for $(x,y)\in\mathbb{R}_+^{N+M}$ as $D_i(y,x)=\sup\{ \lambda : x/\lambda \in L(y)\}$. Hence $D_i(y,x) \leq 1$ and $D_i(y,x)=1$ defines the isoquant. This definition corresponds to the intuitive notions of the best practice of plants and the efficiency differences between plants. The plants which define the isoquant, or the best practice among plants, will have a distance function equal to one. Those plants that lie inside of the isoquant will have a distance function less than one. The value of the distance function is the proportion of the inputs which are needed to produce the given level of output if that plant was on the frontier. Clearly this is a measure of the production efficiency of the plant.

We solve for the distance function by allowing the observed plant performance to define the boundary of the production set. Then relative to the plants placed on the isoquant the relative efficiency of each plant is measured. Hence the distance function provides a plant specific measure of efficiency relative to a level of achieved plant performance. The distance function provides several useful characterizations of efficiency. The distribution of the distance function across plants provides a characterization of the opportunities available to improves efficiency. For example if 90 percent of plants have a distance function equal to one there are relatively few plants with opportunities for improvement. Then the value of the distance function for these plants indicates the size of the opportunities for those plants. In order to calculate the improvement if all plants could be moved to the frontier each plant's inputs are deflated by the value of the distance function. This intuitive notion of efficiency is used to measure the impact of environmental constraints on plants. The function defined above is expanded so the we can include the effects of the environmental decisions of the firms. Then the differences between the plants which define the frontier (lie on the isoquant) are explored.

Hyperbolic Analysis

The appealing characteristic of the distance function is that it readily captures performance over multiple dimensions into a single measure. Hence we can characterize a world where there are non-priced outputs to production which the plant manger has a interest in controlling. These outputs, such as pollution, are easily captured by altering the assumptions under which the function is derived. This approach was introduced by (Färe et al. 1989). For the problem considered here it is convenient to decompose output vector into two subvectors, $y = (g,b)$ which represent the desirable, g, and undesirable outputs, b, of the production technology. The difference between these two vectors is captured via the disposability assumptions. We assume that the desirable outputs are freely disposable in that for any $x\in \mathbb{R}_+^N$, $(g,b) \in P(x)=\{(g,b): (g,b)\in\mathbb{R}_+^M$, x can produce $(g,b)\}$ and $0<g'<g$ implies that $g'\in P(x)$. In other words, if x can produce g then x can produce something less than g. Meanwhile we may assume that the undesirable outputs are only weakly disposable, $x\in \mathbb{R}_+^N$, $(g,b) \in P(x)$ and $0< \lambda <1$ implies that $(\lambda g,\lambda b)\in P(x)$. This simply means that if x can produce g and b, then to produce something less than b one must also produce proportionally less of g. To measure the efficiency of production we want to include a measure of the ability of the plant to minimize the production of the undesirable outputs. A measure which does this is the hyperbolic efficiency measure which measures the ability to expand desirable output and contract undesirable output at the same rate with a given set of inputs. That is:

$$H(x,g,b) = \min\{ \lambda : (\lambda x, \lambda^{-1} g, \lambda b) \in P(x)\}$$

In order to evaluate the extent the regulations alter the disposability of environmental pollutants the hyperbolic is calculated under two different assumptions, that b is freely disposable and that it is weakly disposable. These measures can be computed as a solution to the linear programming problems.[2]

$$\begin{gathered}\text{Min } \Gamma_\omega \\ \text{Subject to} \\ z \cdot G_t \geq g_{t+1} \\ z \cdot B_t = \Gamma b_{t+1} \\ z \cdot X_t \leq \Gamma x_{t+1} \\ 1 \cdot z \leq 1,\ z \geq 0,\ \Gamma_\omega \geq 0 \\ \text{Efficiency} = \lambda_\omega = \Gamma_\omega^{1/2}\end{gathered}$$

where:

x_t = Observed inputs for a single plant,
g_t = Observed "good" outputs for a single plant,
b_t = Observed "bad" outputs for a single plant,
X_t = Matrices of inputs
B_t, G_t = Matrices of outputs
z = An activity vector.

To compute the pollution control output loss a modified linear programming problem is run, replacing the equality constraint for the undesirable output, B, with an inequality, $z \cdot B_t \geq \Gamma b_{t+1}$ and define the strong efficiency measure as $\lambda_s = \Gamma_s^{1/2}$. The ratio of the two efficiency measures obtained in each problem give the percentage output loss. These two LP problems are each run for every plant in the data set for each year in the sample. The value of the distance function, λ_s or λ_w, denotes the distance the plant is from the boundary of the production set, this is a measure of plant efficiency. A measure of the output loss due to pollution constraint is given by the ratio of the two measures:

$$\text{output loss} = \lambda_s / \lambda_w$$

If the change is the disposability has no effect then the two linear programs above will provide the same value for the distance function and the output loss function will equal one. From this we would conclude that the hypothesized environmental constraint is not binding. An output loss less than one indicates that output is that percentage of what the unregulated output would be, e.g. output loss = 0.95 would be interpreted as that the environmental constraint reduces output by 5 percent.

Evaluating Abatement Expenditure Constraints

One of the primary channels that environmental regulation is presumed to impact firm performance is via mandated pollution abatement investment. This investment may crowd out other investments if capital rationing occurs. In order to evaluate the hypothesis that mandated pollution abatement constraints crowd out other investments, an alternative efficiency measure is constructed. The proportion of investment devoted to pollution abatement is measured and treated as a constraint on total investment.

In a similar method to the hyperbolic analysis, we calculate an input distance function under alternative assumptions to evaluate the extent that the amount of pollution abatement investment constrains other investments. We define the set of inputs such that $x=(v, k^1, k^2, k^3)$ where v are the variable inputs in production, k^1 is the previous period capital stock, k^2 is investment net of pollution abatement investment, and k^3 is pollution abatement investment. We formulate three alternative definitions of the input distance function under differing assumptions in order to assess the effect of pollution abatement investment on productivity. To measure the productivity loss due the constraint on capital

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[2] The hyperbolic distance function is formulated as a non-linear program, but a transformation of variables allows for the above LP to provide the solution. see (Färe et al. 1989)

expenditures a series of LP problems are evaluated. They each measure the productivity of a plant, relative to best practice, under alternative assumptions about the composition of new capital, i.e. current period investment.

First we assume that the two types of investment, k^2 and k^3, are different inputs and evaluate the input distance function via the following linear programming problem.

$$\begin{gathered}\text{Min } \lambda_1 \\ \text{Subject to} \\ z \cdot U_t \geq u^o \\ z \cdot X_t \leq \lambda x^o_t \\ z \cdot K^1_t \leq \lambda k^{1o}_t \\ z \cdot K^2_t \leq \lambda k^{2o}_t \\ z \cdot K^3_t \leq \lambda k^{3o}_t \\ 1 \cdot z \leq 1, z \geq 0, \lambda_1 \geq 0\end{gathered}$$

where:

x_t^o = Observed variable inputs for a single plant,
k_t^{io} = Observed capital for a single plant,
u_t^o = Observed outputs for a single plant,
X_t = Matrices of variable inputs for the entire sample,
K_t = Matrices of variable inputs for the entire sample,
V_t = Matrices outputs for the entire sample, and
z = An activity vector.

Partitioning K into three components $K = (K^1_t, K^2_t, K^3_t)$ where

K^1_t = previous period capital stock (perpetual inventory method)
K^2_t = current period investment less current period pollution abatement capital expenditures
K^3_t = current period pollution abatement capital expenditures

The above linear program is the most restrictive, since it requires capital expenditures on abatement in the current period. We successively relax the definition of the production technology to obtain a less restrictive efficiency measure. The ratio of the resulting efficiency scores is the loss due to capital rationing or other capital constraints.

In the second LP formulation we allow the two types to investment, k^2 and k^3, to be treated as a single capital input. By comparing the values of the resulting distance functions we can construct a measure of the efficiency, or productivity, loss due to the abatement capital constraints.

$$\begin{gathered}\text{Min } \lambda_2 \\ \text{Subject to} \\ z \cdot U_t \geq u^o \\ z \cdot X_t \leq \lambda x^o_t \\ z \cdot K^1_t \leq \lambda k^{1o}_t \\ z \cdot (K^2_t + K^3_t) \leq \lambda (k^{2o}_t + k^{3o}_t) \\ 1 \cdot z \leq 1, z \geq 0, \lambda_2 \geq 0\end{gathered}$$

Finally we apply the least restrictive definition, where no pollution abatement is in the technology, but current period spending on non abatement capital (K^2_t) is allowed to be equal to the observed plant level total ($k^{2o}_t + k^{3o}_t$).

$$\begin{gathered}\text{Min } \lambda_3 \\ \text{Subject to} \\ z \cdot U_t \geq u^o \\ z \cdot X_t \leq \lambda x^o_t \\ z \cdot K^1_t \leq \lambda k^{1o}_t \\ z \cdot (K^2_t) \leq \lambda (k^{2o}_t + k^{3o}_t) \\ 1 \cdot z \leq 1, z \geq 0, \lambda_3 \geq 0\end{gathered}$$

The ratios of the efficiency scores from these problems provides a measure of the loss due to the rationing of capital or other capital constraints.

III. Data

The approach used in this paper is very data demanding. The calculations described above require data on plant output; inputs, including detailed information of the types if investment; pollution emissions; and technology in use. The technology data is needed to assure that the production set is meaningful. In order to get all these elements we had to merge several data sets together. We use the U.S. Bureau for the Census data on economic inputs, outputs, and environmental investments, EPA data on air, water and toxic pollution, and industry information on plant technology.

The Longitudinal Research Database, LRD, is the primary source of plant input and output information for this study. The LRD was developed by the Center for Economic Studies at the Bureau of the Census (CES). CES has constructed a panel of plant level data from the Annual Survey of Manufactures (ASM) and the Census of Manufacturers (CM). Under Title 13 of the U.S. Code this data is confidential, however CES does allow researchers designated as Specially Sworn Employees to use this data on site at CES. While the confidentiality restrictions prevent the disclosure of any information which would allow for the identification of any plant's or firm's activities, aggregate figures or coefficients which mask the identity of individual establishments and firms can be released publicly.

In order to consider the impact of environmental constraints, information from other sources was matched to the LRD. These sources are the Pollution Abatement Costs and Expenditures (PACE) survey which is conducted by the Census Bureau and three databases maintained by the EPA, the Aerometric Information Retrieval System (AIRS), the Permit Compliance System (PCS), and the Toxic Release Inventory (TRI) which contain information on air, water and toxic pollution discharges respectively. The PACE survey asks plants to report their investments in pollution abatement equipment. The EPA databases report the release of the various pollutants in to the ambient environment.

The estimates are based on an analysis of five production inputs; capital, labor, material, fossil fuel, and electricity; a desirable output, measured as dollars of shipments; and undesirable outputs. The pollution outputs considered are two air pollution outputs, Sulfur Dioxides (SO_2) and Total Suspended Particulates (TSP); two water pollution outputs, Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD); and three toxic outputs, Chlorine, Methanol and Sulfuric Acid. We choose the air and water pollutants, since they are very basic criteria pollutants that have been regulated since the beginning of the Clean Air and Clean Water Acts. The amount discharged of these pollutants are also available for virtually all the paper plants in the sample. The toxic pollutants where chosen because of the high emissions for this industry, all are among the top ten toxic pollutants for the industry. The pollution data comes from three different data sets and the are only available for a subset of the plants. Rather than restricting our analysis to the union of the data sets we analyze the subsets separately. We analyze air pollution for 1985 and 1990, water pollution for 1988-1992 and toxics for 1988-1992. For 1990 we also compute the hyperbolic measure where both the air and water pollutants are included.

The data for pollution abatement capital expenditure (PACE) was collected for the years 1988-1992. The PACE survey's sample changes each year hence requiring plant to be observed in each year would greatly diminish the usable sample. Thus each year the sample of the mills is different although the sample statistics are similar. Because of the sample difference we will focus on differences we observed between plant in a given year rather than differences across time.

IV. Results

The method of analysis is that we solve the linear programs to measure the various distance functions described in Section VI. We exploit differing assumptions to explore the degree that environmental constraints alter the behavior of plants; the hyperbolic analysis alters the assumptions regarding the disposability of pollution outputs while the investment analysis alter the assumption regarding the extent that environmental expenditures are mandated. Hence we create two measures of efficiency using the same data, the differences between these measures reflect the importance of the environmental constraint. This efficiency difference is summarized in the loss functions. These represent the proportional loss in terms of output foregone. In addition, the values of the distance functions themselves represent the total inefficiency of the plant. Hence we can determine what the contribution of environmental constraints are compared to other sources of efficiency change.

Hyperbolic Analysis

This section presents estimates of the potential for simultaneous productivity, energy, and environmental improvements. We estimate the inefficiency that would allow plants to reduce production inputs and the pollution outputs, while simultaneously increasing shipments values. The estimates do not, however, take into account any constraints implied by technology in place, but assume that the inefficient plants can take advantage of the best practice technologies that are implied by the other plant level data with similar mix of inputs and outputs.

Table 1 reports the average hyperbolic efficiency measures under the assumption that the undesirable outputs are weakly disposable and the output loss ratio. They show that the industry average inefficiency, accounting for environmental constraints, is between three and nine percent. This is based on the assumption that undesirable outputs are weakly disposable, i.e. that observed pollution is constrained by regulations. When we relax this constraint the output loss due to these assumed environmental constraints is an additional three to five percent. For the water and toxic emissions we have multiple years of observations. The hyperbolic efficiency measures based on water and toxic emissions are stable over time.

Table 1 - Summary of Hyperbolic Results

Sample	Number of Plants	Hyperbolic - Free	Hyperbolic- Weak	Output Loss
1990 Air and Water	118	0.9224	0.9694	0.9517
1988 Water	146	0.8867	0.9302	0.9542
1989 Water	146	0.8780	0.9138	0.9619
1990 Water	146	0.8971	0.9228	0.9724
1991 Water	146	0.8938	0.9266	0.9647
1992 Water	146	0.8880	0.9160	0.9691
1985 Air	140	0.9173	0.9374	0.9785
1990 Air	140	0.9068	0.9379	0.9675
1988 Toxics	81	0.9387	0.9715	0.9664
1989 Toxics	81	0.9043	0.9546	0.9479
1990 Toxics	81	0.9159	0.9600	0.9543
1991 Toxics	80	0.9130	0.9580	0.9532
1992 Toxics	80	0.9080	0.9522	0.9541

Table 2 details the distribution of the efficiency and output loss measures. The table reports whether the plant is on the frontier, within 10% of the frontier, or more than 10% away. For the output loss ratio it is reported how may plants have no loss, a positive loss of less than 10%, or more than 10%. Most paper plants (58%) are considered best practice; they have an efficiency measure of one. This means that there was at least one input or pollutant that could not be reduced any further. About one third of the plants are close (within 10%) of best practice. This means that those plants could only reduce inputs and pollution by less than 10%. This implies that, for the paper industry 'win-win' opportunities are modest, if the opportunities are embodied in a technology which represents sunk capital that is difficult to replace. However, if these opportunities are the result of poor management or plant practices then one might argue that this opportunities are important. Although the 'win-win opportunities appear modest, one should note that our definition of 'win-win' is very strong, all inputs and pollutants must be able to be reduced to be considered 'win-win'. We did not examine the potential for a subset of inputs and pollutants to be reduced, e.g. energy and air emissions. This is explored in a sensitivity analysis below. Table 2 also reports the distribution of the output loss function. Slightly more than a third of the plants have no output loss, while about a fifth of the plants have losses of more than ten percent; thus almost two thirds of the plants show some loss due to environmental regulation.

Figure 1 presents the reductions in average industry energy and pollution intensities if inefficiencies were to be eliminated and all plants were operating at best practice for 1990. The figure includes the reductions using all four sets of the hyperbolic analysis for this year; for air pollution, water pollution, toxics and air and water combined. The percentages are lower when the four air and water pollutants are included. This indicates that there are differing levels of performance across pollutants. Since our measure only includes reductions that can occur across all pollutants and inputs the inclusion of additional pollutants would be expected to reduce the amount of inefficiency. Energy and fuel use show the greatest potential for reductions, in the case of the water pollution measure the reductions are more than 8%. Other input intensities decline as well. Declines in pollution intensity are somewhat less than the input reductions, when each media is calculated separately the reductions range from 2.2 to 5.7%. The air pollutants show somewhat larger potential reductions, perhaps because of the close link between air pollution and energy use.

Table 2 - Distribution of Plant Hyperbolic Efficiency and Output Loss Measures

	Percent of Plants in the Sample					
	Hyperbolic Efficiency Measure			Output Loss Measure		
	< 0.9	0.9 - 1	= 1	< 0.9	0.9 - 1	= 1
1990 Air & Water	12%	30%	58%	17%	49%	34%
1988 Water	33%	32%	35%	19%	64%	16%
1989 Water	42%	29%	29%	13%	70%	17%
1990 Water	37%	37%	26%	*	77%	23%
1991 Water	36%	27%	36%	11%	67%	22%
1992 Water	41%	29%	29%	9%	64%	27%
1985 Air	34%	26%	40%	*	54%	46%
1990 Air	28%	31%	41%	14%	44%	42%

* Cell was suppressed for disclosure reasons

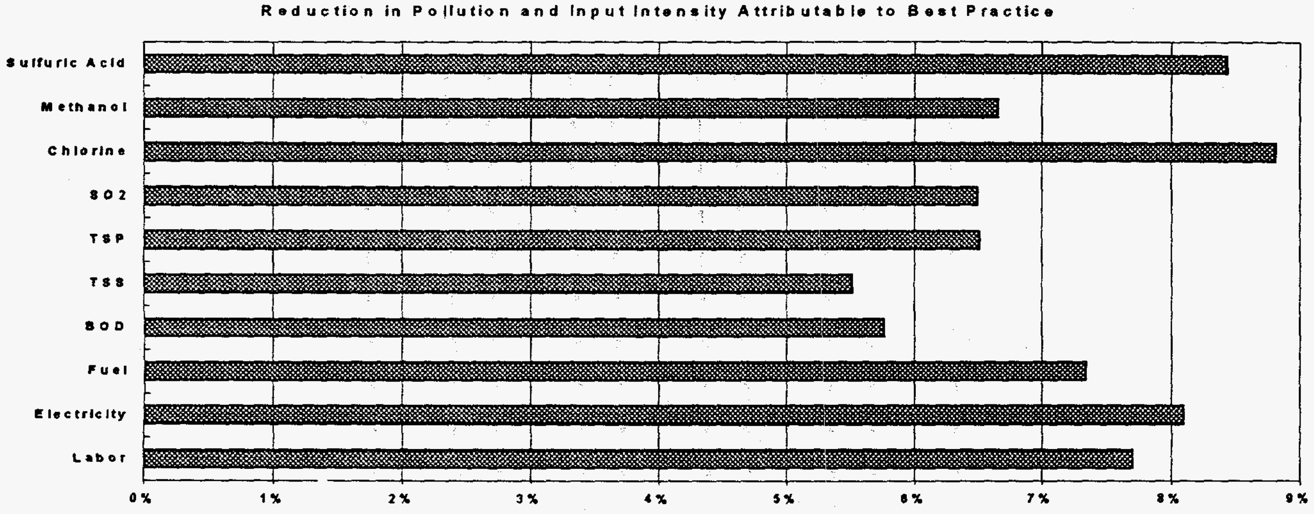

Figure 1 Individual Pollutant and Input Results for 1990

In the above analysis a majority of plants are considered best practice and about twelve percent have productive efficiency less than 90%. Because the efficiency measure is constructed as the solution to a linear programming problem it is possible that the results may be sensitive to the specification of the problem. This is because the linear programming routine may consider some plants that are outliers as best practice, simply because there are no other plants similar enough to compare them to.

In order to evaluate the sensitivity of our conclusions to this issue, the amount of detail specification of the outputs and inputs was varied. In all cases the desirable output as well as two inputs, labor and capital, were included as the most basic specification. Various combinations of the four air and water pollutants, BOD, TSS, SO_2, and TSP were included as well as different aggregations of non-labor variable inputs: fuel, electricity and other materials. By reducing the dimension of the LP problem fewer plants may be mis-assigned to best practice as a result of extreme values in a particular measure of an input or output. Hence by evaluating how the results change as the setup of the problem change insights may be gained into forces driving the results.

The estimates of "win-win" environmental improvement is sensitive to the choice of pollutants included. When more pollutants are considered, i.e. are evaluated by the analysis for potential reduction then the estimate of potential improvement is lower and about eight more plants are considered best practice. The estimates of productivity loss due to pollution control shows greater losses as the number of pollutants increases. This indicates that the four pollutants considered are not perfectly correlated. Some plants can improve productivity and environmental performance for a subset of pollutants, but may not be able to make as large a gain when more pollutants are targets for reduction. As the number of inputs increases about ten fewer plants show no output loss and the mean amount of loss decreases.

The sensitivity of the results to the choice of pollution outputs included are probably due to unique plant differences. These differences may be in the specific regulations effecting a plant or production technology differences among the paper plants. One pollutant may be controlled in a highly efficient manner for one plant while a different pollutant may we efficiently controlled for other plants. Hence our results vary as different combinations of pollution outputs are included in the problem.

The implication of this is that, while "win-win" potential improvements may be modest when a large set of goals are considered, i.e. many pollutants and input efficiency goals, there may be additional potential in reducing a single pollutant or energy input, by applying best practice. This would require a more targeted strategy, rather than looking for the sweeping inefficiencies that allow for multiple goals to be achieved. Nevertheless, the analysis does find evidence that nearly half of the plants could make such sweeping changes. Whether the glass is 'half-empty' or 'half-full' depends upon how much these inefficiencies are embodied in fixed technology and capital stock.

Abatement Investment Constraints

One potential source of inefficiency relative to environmental controls is in the allocation of capital. As discussed above, capital rationing and requirements to make inflexible environmental investments may reduce the money that is put into other more productive areas of the plant. We examine this potential effect by modifying the framework used to measure production efficiency to incorporate reported data on pollution abatement capital expenditures.

This analysis compares, in each year, how much more productive the best practice plants are than the less efficient counterparts. If the allocation of abatement capital expenditure contributes to a decline in production efficiency, then we can assess how large an effect this is. Table 3 reports the results of the analysis. The average value of the distance function is between 0.77 and 0.85. Approximately a third of the plants are considered best practice while more than 70% of the plant have distance functions less than 0.9. Then if we exploit the differing assumptions with regards to pollution abatement investment we can construct an output loss measure. The impact, the production efficiency loss due to abatement capital expenditure, as measured by the difference in the distance function, is about three percent. This difference is generally one fifth, or less, than the total estimated gap between an average plant and a best practice plant. In other words, the abatement capital constraint accounts for only 1/5 of the production efficiency differences between an average plant and the best plants.

Table 3 - Results of Investment Constraint Analysis

	1988	1989	1990	1991	1992
Distance Function	0.8287	0.7764	0.8290	0.8482	0.8500
	(0.1516)	(0.1691)	(0.1427)	(0.1424)	(0.1447)
DF = 1.0	27	18	26	28	29
0.9 - 1.0	16	20	23	22	18
DF < 0.9	68	84	78	64	56
Output Loss Ratio	0.9620	0.9611	0.9667	0.9776	0.9716
	(0.0849)	(0.0939)	(0.0649)	(0.0598)	(0.0555)
Loss Ratio = 1	53	50	43	55	39
Loss Ratio < 1	58	72	84	57	64

Standard deviations are in parentheses

What implications does this have specifically on energy use? When the industry average plant energy bill is compared to the bill of an average plant if it did not have any abatement capital constraint there is only a modest reduction. However, when one considers the best practice plant, a larger reduction is seen, over $3 million. It also appears that fossil fuel expenditure fall more than electricity expenditures. This is true only to the extent that fossil fuel expenditures are almost 50% more that electricity expenditures. The percentage reductions for each fuel are virtually the same. While the abatement capital constraint may play a role in contributing to environmental and energy impacts, it is only a small part of overall inefficiency.

However, if we compare the 1990 results for the abatement capital constraint and the 1990 results for the output loss due to pollution controls we find that the abatement constraint lowers productivity by 3.3% , but the productivity loss in general due to pollution control is 9.5%. The general productivity loss estimated in the hyperbolic analysis includes all effects, both direct and indirect. The abatement capital constraint in only one type of an indirect effect. While these two approaches are not strictly comparable, it suggests that the indirect effect of capital spending on abatement is an important part of the productivity impact of pollution regulations.

V. Conclusions

This paper presents a methodology and results for assessing the impact of production and energy efficiency, environmental regulation, and abatement capital expenditure constraints (e.g. capital rationing) on the productivity of energy and pollution intensive sectors. Energy is treated like any other production input when examining evidence of inefficiency. We find that capital rationing and environmental regulations do contribute to productivity and energy efficiency losses, but do not explain all of the production and energy inefficiencies observed in the paper industry. Figure 2 summarizes the source of production inefficiency found in the paper industry. Each source is derived as the incremental contribution., i.e. the first is constraints on capital, the second in environmental regulation *not accounted for by the first,* and the final component is production inefficiency that is *not accounted for my any of the environmental analysis.* While the methods are very data intensive, they reveal much more that analysis of aggregate data, since the only plant level data can provide the estimates of inefficiency that this methodology employs.

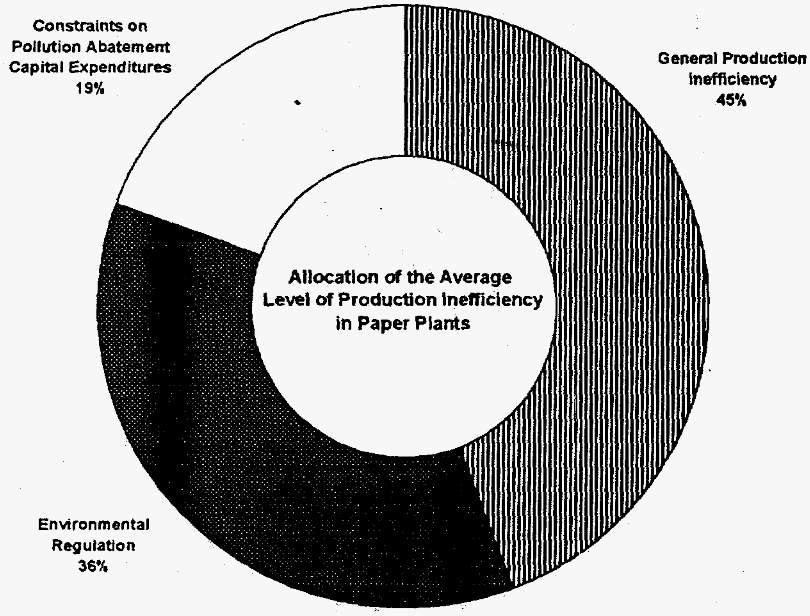

Figure 2 Source of Average Plant Level Production Inefficiency

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