Emissions Trading and Profitability: The Swedish Pulp and Paper Industry*

Runar Brännlund[1], Yangho Chung[2], Rolf Färe[2] and Shawna Grosskopf[2]
[1]Department of Economics
University of Umeå
S-901 87 Umeå, Sweden

[2]Department of Economics
Southern Illinois University at Carbondale
Carbondale, IL. 62901-4515, USA.

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1. Introduction

In a recent paper Brännlund *et al.*(1995) studied the effects of environmental regulations on the profits of Swedish pulp and paper firms. They constructed nonparametric (DEA) frontier models with and without regulation. Relative to those models they computed and compared profit for the individual firms. The main result in that study was that for a substantial number of plants the current regulations did not affect profit. This result, that some of the plants were not affected, while others faced a substantial decrease in profits may be an indication that the prevailing command-and-control regulation system is not cost efficient[1]. In order to eliminate these potential inefficiencies, one could employ an alternative approach such as a system of tradeable permits. As is well known from the literature (see e.g. Baumol and Oates (1988)), a tradeable permit system will, under certain assumptions, give us the prescribed environmental quality at the least cost[2]. Despite the substantial cost savings, surprisingly few applications of emission trading programs can be seen in practice. In addition, for the cases where trading opportunities exist, it turns out that trading is infrequent, implying quite moderate cost savings. The search for reasons for the divergence between the potential and real world cost savings has generated a large literature, see for example Atkinson (1994) for an overview.

The purpose of this paper is to develop models with and without emissions trading and to compare industry profits under the two regimes. The model in which emissions trading is permitted is a nonparametric industry frontier model in the spirit of Färe, Grosskopf and Li (1992). It is relative to this model that industry profit is computed. This profit is compared to the profit without emissions trading to give an estimate of the potential gains that can be realised by allowing for emissions trading. The model, which is applied to data for the Swedish pulp and paper industry, thus provides evidence as to the cost efficiency of the prevailing individual regulations for this particular industry.

Although the primary aim of this paper is to develop a framework for estimating the potential gains of emissions trading based on the current level of emissions, we also simulate the cost of a more stringent environmental policy in terms of required emissions reductions from the Swedish pulp and paper industry.

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[1] Given, of course, that the plants use the same technology, and that the marginal damage from each plant is equal.

[2] A system with tradeable permits was first suggested by Dales (1968), but a proof of cost efficiency was first shown by Montgomery (1972).

The rest of the paper is structured as follows. The remainder of this introductory section is devoted to some facts about the empirical problem in this paper, while we develop the theoretical framework in section 2. Section 3 of paper is devoted to a discussion of the data and empirical results. Some concluding comments are included in section 4.

The reasons for analyzing the cost of environmental regulation in the Swedish pulp and paper industry are at least twofold. First of all, and most important, is that this industry places a fairly heavy burden on the environment in Sweden, especially the marine environment. More than fifty percent of the total discharge of biological oxygen demand (BOD) and virtually all of the discharge of chlorinated compounds (AOX) in Sweden originates from the pulp and paper industry. Since most of the pulp and paper mills are located along the east cost of Sweden, the emissions end up in the Gulf of Bothnia, the Bothnian Sea and the Baltic Sea.

As is well-known, discharges of oxygen demanding substances, measured as BOD and COD, have negative impacts on marine life. The quantitative effects of the discharges, however, are uncertain due to variations in temperature, the amount of oxygen in the water, etc. The production of pulp also produces discharges of suspended solids (SS) which are known to have effects on both the behaviour of fish and their ability to grow and breathe. Discharges of SS can also create mud-banks which change the structure of the sea-bed and, thereby, affect fish and other creatures in the sea.

Because of these and other impacts on the environment, the pulp and paper industry is subject to environmental regulation. The substances which are regulated, apart from the afore-mentioned emissions of BOD, AOX and SS, include chemical oxygen demand (COD), and nutritive salts such as nitrogen. In Sweden, the emissions standard applied to all of these substances is a plant specific absolute pollution standard, which means that each firm is allowed to discharge a specific amount of pollutants. The standard, or permit, is set by the 'Environmental Protection Agency' (Koncessionsnämnden för Miljöskydd), which consists of two lawyers and two engineers, one from the paper and pulp industry and one from the Swedish Environmental Protection Board. The important thing in this context is that these permits are nontradable.

A second reason for analyzing this particular industry is that it is a fairly important sector of the Swedish economy. The paper and pulp industry in Sweden consists of relatively few plants which produce a fairly homogeneous good.

2. Firm and Industry Models of Production

Two reference technologies are developed in this section, one firm level and one industry level. Short run profit is computed for both models. At the firm level we compute short run profit when the firms are individually regulated with regard to emissions, i.e., this is a model of the status quo in Sweden. At the industry level we compute short run profit under industry regulations which allow for total allowable emissions to be optimally allocated among the firms. A comparison between the two approaches gives us a measure of the potential gains from permit trading.

Here we denote inputs by $x = (x_1, ..., x_N) \in \Re^N_+$, and we assume that the first $(x_1, ..., x_{\tilde{N}})$ are variable inputs and that the last $(x_{\tilde{N}+1}, ..., x_N)$ are fixed inputs. We assume further that there are $y = (y_1, ..., y_M) \in \Re^M_+$ good, or desirable, outputs, which are produced together with $b = (b_1, ..., b_I) \in \Re^I_+$ undesirable, or bad, outputs. The technology, expressed by the output sets, consists of all feasible input/output vectors, i.e.

$$P(x) = \{(y, b) : x \text{ can produce } (y, b)\}, x \in \Re^N_+. \tag{2.1}$$

Among the properties we impose on the technology, the most notable ones are ((i) weak disposability of outputs, and (ii) nonincreasing returns to scale. The former states that:

$$(y, b) \in P(x) \text{ then } \ (\theta y, \theta b) \in P(x) \text{ for } \ 0 \leq \theta \leq 1. \tag{2.2}$$

This assumption models the idea that some of the outputs, $b = (b_1, ..., b_I)$ are bads.[3] In addition, desirable outputs are assumed to be freely disposable. Our assumption (ii) is modelled as:

$$P(\lambda x) \subseteq \lambda P(x), \quad \lambda \geq 1 \tag{2.3}$$

which implies that (long run) profit is nonnegative.

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[3] This models the idea that the good and bad outputs are produced jointly, i.e., positive good output is accompanied by nonzero amounts of bads. It also captures the idea that, under regulation, disposal of bads is not 'free'.

Furthermore we assume that there are $k = 1, ..., K$ observations of inputs and outputs, and we use activity analysis to model our reference technology. In particular,

$$
\begin{array}{lll}
P(x) = \{(y,b): & \sum_{k=1}^{K} z_k y_{km} \geq y_m, & m = 1, ..., M, \\
& \sum_{k=1}^{K} z_k b_{ki} = b_i, & i = 1, ..., I, \\
& \sum_{k=1}^{K} z_k x_{kn} \leq x_n, & n = 1, ..., \tilde{N}, \\
& \sum_{k=1}^{K} z_k x_{kn} \leq x_{kn}, & n = \tilde{N}+1, ..., N \\
& \sum_{k=1}^{K} z_k \leq 1, & z_k \geq 0, \ k = 1, ..., K, \}.
\end{array}
\tag{2.4}
$$

Here the equalities in expressions $i = 1, ..., I$ are the restrictions which impose weak disposability of bad outputs. The restriction $\sum_{k=1}^{K} z_k \leq 1$ on the intensity variables imposes nonincreasing returns to scale on the model.

To formulate the k' firm specific profit maximization problems, suppose that the prices of the good output and the variable inputs are given. They are denoted by $p_{k'm}$, $m = 1, ..., M$, and $w_{k'n}$, $n = 1, ..., \tilde{N}$, respectively. The pollution permit for bad output i for firm k' is denoted by $\bar{b}_{k'i}$, $i = 1, ..., I$. Under these conditions we may calculate:

$$
\pi_{k'} = \max\left(\sum_{m=1}^{M} p_{k'm} y_m - \sum_{n=1}^{\tilde{N}} w_{k'n} x_n\right) \tag{2.5}
$$

$$
\begin{array}{lll}
s.t & \sum_{k=1}^{K} z_k y_{km} \geq y_m, & m = 1, ..., M, \\
& \sum_{k=1}^{K} z_k b_{ki} = b_i, & i = 1, ..., I, \\
& \sum_{k=1}^{K} z_k x_{kn} \leq x_n, & n = 1, ..., \tilde{N}, \\
& \sum_{k=1}^{K} z_k x_{kn} \leq x_{k'n}, & n = \tilde{N}+1, ..., N, \\
& \sum_{k=1}^{K} z_k \leq 1, & z_k \geq 0, \ k = 1, ..., K, \\
& b_i \leq \bar{b}_{k'i}, & i = 1, ..., I.
\end{array}
$$

In this model we do not account for the cost that the bad output imposes on the environment, we only incorporate the pollution permits $\bar{b}_{k'i}$. Maximum profit under the fixed permit constraint is computed for each firm $k' = 1, ..., K$, based on problem (5). We note that the maximization occurs over z, y, and b as well as the variable inputs $x_n, n = 1, \ldots, \tilde{N}$. Fixed inputs, however, are taken as given.

In our industry model, individual firms are not given pollution permits, but rather the aggregate emissions of the industry as a whole are restricted to be no greater than the total emissions allowed under the individual permit system. This allows us to calculate the socially optimal allocation of pollution permits.

The short run industry profit is calculated as the sum of maximum profits for all firms relative to the technology constraint including all firms. This model generalizes Färe *et al.* (1992) by incorporating regulatory constraints. The maximization problem is:

$$\Pi = \max \sum_{k=1}^{K} \left(\sum_{m=1}^{M} p_{km} y_m^k - \sum_{n=1}^{\tilde{N}} w_{kn} x_n^k \right) \tag{2.6}$$

firm 1

$$\begin{array}{lll} s.t & \sum_{k=1}^{K} z_k^1 y_{km} & \geq y_m^1, \; m = 1, ..., M \\ & \sum_{k=1}^{K} z_k^1 b_{ki} & = b_i^1, \; i = 1, ..., I \\ & \sum_{k=1}^{K} z_k^1 x_{kn} & \leq x_n^1, \; n = 1, ..., \tilde{N} \\ & \sum_{k=1}^{K} z_k^1 x_{kn} & \leq x_{1n}, \; n = \tilde{N}+1, ..., N \\ & \sum_{k=1}^{K} z_k^1 & \leq 1, z_k^1 \geq 0, \; k = 1, ..., K, \; . \end{array}$$

firm k′

$$\begin{array}{lll} s.t & \sum_{k=1}^{K} z_k^{k'} y_{km} & \geq y_m^{k'}, \; m = 1, ..., M \\ & \sum_{k=1}^{K} z_k^{k'} b_{ki} & = b_i^{k'}, \; i = 1, ..., I \\ & \sum_{k=1}^{K} z_k^{k'} x_{kn} & \leq x_n^{k'}, \; n = 1, ..., \tilde{N} \\ & \sum_{k=1}^{K} z_k^{k'} x_{kn} & \leq x_{k'n}, \; n = \tilde{N}+1, ..., N \\ & \sum_{k=1}^{K} z_k^{k'} & \leq 1, z_k^{k'} \geq 0, \; k = 1, ..., K, \; . \end{array}$$

firm K

$$\begin{array}{lll} s.t & \sum_{k=1}^{K} z_k^{K} y_{km} & \geq y_m^{K}, \; m = 1, ..., M \\ & \sum_{k=1}^{K} z_k^{K} b_{ki} & = b_i^{K}, \; i = 1, ..., I \\ & \sum_{k=1}^{K} z_k^{K} x_{kn} & \leq x_n^{K}, \; n = 1, ..., \tilde{N} \\ & \sum_{k=1}^{K} z_k^{K} x_{kn} & \leq x_{Kn}, \; n = \tilde{N}+1, ..., N \\ & \sum_{k=1}^{K} z_k^{K} & \leq 1, z_k^{K} \geq 0, \; k = 1, ..., K, \; . \end{array}$$

Regulatory constraints

$$\sum_{k=1}^{K} b_i^k \quad \leq \quad B_i, \; i = 1, ..., I$$

where B_i is the aggregate constraint for output i. Various formulations of the regulatory constraints will be used in the calculations. These will be discussed in the following section.

3. Data and Results

In order to produce pulp, y, we assume that three variable inputs are used; labor, wood fibre, and energy, and one fixed factor, capital.

The data we use, which is the same as in Brännlund *et al.* (1995), is a panel data set for the Swedish pulp and paper industry. The data sources are primary data for the pulp and paper industry gathered by Statistics Sweden and the Swedish Environmental Protection Board.

The part of the data set used here contains annual information from 41 pulp mills for the period 1986-90. It includes information on quantities, both in physical and monetary terms, of sulfate pulp, sulfite pulp and mechanical pulp. The bad outputs we are considering in this study are the emissions of oxygen demanding substances measured as Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), as well as Suspended Solids (SS). The emissions data are the sum of daily emissions, divided by the number of production days, i.e., the daily average level. Prices of the output as well as all variable inputs, labor, energy and materials, are calculated by dividing the production and input values by the respective quantities. Also included in the data set is information on firm specific regulations of emissions of BOD, COD and SS. Unfortunately, these data are only available for 1989 and 1990, which means that the model can only be estimated for the period 1989-90. Another problem is that no data on investment in abatement capital exists. For this reason we view this model as a short run model where all capital is fixed. Descriptive statistics for the data are presented in Table A.1 (1989) and Table A.2 (1990) in the appendix.

In order to calculate profit under the permit trading regime, we need to determine the aggregate level of permits. This is a problem since some of the plants are not subject to any regulations, i.e., their emissions are not restricted. If we simply sum up the individual permits, we will be imposing a more stringent overall limit on emissions than under the current system. To solve this problem, and still be able to make a normative comparison between the current regulatory system and a system in which permit trading is allowed, we add up permit levels of all firms which are currently regulated, and allow permit trading only among them:

$$\sum_{k=1}^{K} b_i^k \leq \sum_{k=1}^{K} \bar{b}_{ki} = B_i \;\; if \; \bar{b}_{ki} \neq 0, \;\; i = 1, ..., I. \tag{3.1}$$

This guarantees that the aggregate profit under permit trading will be at least as large as under the individual regulatory system.

Given these benchmark profits it is possible to calculate the loss in profit from a more stringent environmental policy. In this second case, we include the plants which are not currently subject to any restrictions on emissions in the trade, i.e.,

$$\sum_{k=1}^{K} b_i^k \leq \sum_{k=1}^{K} \bar{b}_{ki} = B_i, \quad i = 1, ..., I. \tag{3.2}$$

The results from applying these two trading schemes are displayed in Table 1 and Table 3 respectively. Note that under our second scenario (in which plants which previously were unregulated must now have a permit) the overall profit cannot be higher than in the benchmark case. This follows from the fact that emissions are reduced in the aggregate by the amount the unregulated firms emit under the current regulatory regime. The difference between the profits under the restriction in equation (3.1) and (3.2) respectively, can then be interpreted as the 'least cost' of a more stringent environmental policy. Another way to interpret the difference is as a 'shadow price' for a portfolio of permits[4].

The first interesting thing to note from Table 1 is that the profits from a tradeable permit system which maintains current total emissions (case 1) coincide with unregulated profits (third column).[5] This suggests that emissions in the unregulated case are identical to emissions under the trading solution. In turn, since *total* emissions under the first trading scheme are by definition the same as under the current regulatory model, that regulatory regime has had no effect on total emissions.

On the other hand, there is a clearcut difference in profits between the current regulatory regime and the permit trading regime. If we think of these differences in profits as the cost of using the inefficient regulatory scheme, we see that these are 'large': 1.2 billion SEK in 1989 and 0.4 billion SEK in 1990. When we break this information out by the specific process used, the qualitative results are similar. In particular, the average loss in profit per mill is very similar across the different process categories.

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[4] The shadow price of the constraint can be expressed as $p_b = \partial\pi/\partial b$
Thus we have that $\Delta\pi = \pi(b^1) - \pi(b^0) = \int_{\tilde{b}} \frac{\partial\pi}{\partial b} db$. An approximation of the shadow price is then $p_b \approx \Delta\pi/\Delta b$.

[5] Unregulated profits are computed as in (6) but without the aggregate regulatory constraint.

Table 1
PROFITS UNDER THE REGULATORY AND EMISSION TRADING REGIME
(MILLION SEK)
Case 1: Total emissions unchanged
(Standard deviation in parentheses.)

	π^R/π^T	$\pi^T/\pi^{\max}$	$\Delta\pi$	$\Delta\pi^{mean}$	$NOBS$
			ALL PLANTS		
89	0.95	1	1238	30.2	41
	(0.09)			(58.4)	
90	0.99	1	421	10.3	41
	(0.03)			(31.4)	
			MECHANICAL		
89	0.92	1	329	29.9	11
	(0.11)			(0.92)	
90	0.99	1	130	11.8	11
	(0.03)			(39.3)	
			SULFATE		
89	0.96	1	685	29.8	23
	(0.07)			(54.4)	
90	0.99	1	181	7.9	23
	(0.02)			(24.6)	
			SULFITE		
89	0.96	1	224	32.0	7
	(0.01)			(84.6)	
90	0.98	1	110	15.7	7
	(0.05)			(41.6)	

$\pi^R = total\ regulated\ profit$
$\pi^T = total\ profits\ under\ trade$
$\pi^{\max} = unregulated\ profits$
$\Delta\pi = \pi^T - \pi^R$
$\Delta\pi^{mean} = (\pi^T - \pi^R)/K,\ NOBS = \#\ obs.$

Table 2 summarizes the information about the pattern of permit trading in case 1 (where the total level of emissions is unchanged). A firm is considered to be a buyer of permits if the optimal amount of the particular bad in the trading scheme exceeds the regulated amount. The number of traders varies by year and by process. Also, the number of buyers is less than the number of sellers in general, suggesting that the buyers are buying from several sellers.

Table 2

PATTERN OF TRADING WITH PERMITS: CASE 1

	BOD	COD	SS
Seller	10(13)	18(21)	4(5)
Buyer	7(3)	5(2)	6(4)
Total	17(16)	23(23)	10(9)

Number of firms in 1989(1990)
If optimal emissions exceed regulated levels,
the firm is a buyer.

The results in Table 3 show that if the mills which are currently not subject to any regulations are included in the trading scheme, i.e., they need a permit, then total industry profit is approximately 7.2 billion SEK lower in 1989 and 5.6 billion SEK lower in 1990, compared to the maximum profit under trading with current emissions levels (case 1) for each year. Including mills which previously were unrestricted means that total allowable emission must be reduced by the amount the unregulated mills currently emitting. The corresponding reductions in total emissions are 332 and 204 thousand tons in 1989 and 1990, respectively. The 'shadow price' of the 'emissions portfolio', column six, indicates that the emission constraints are hurting this industry more in 1990 than in 1989. If we look at the different processing categories, we see that an industry regulation of this kind has quite varied effects on profits depending on processing category. The 'shadow prices' for the sulfate plants are substantially higher than for the mechanical and sulfite plants. On the margin, however, the 'true' shadow prices should be equal across all plants, which means that our 'nonmarginal' shadow price can be interpreted as if the sulfate plants were less regulated than the two other categories under the individual regulatory system.

Table 3

PROFITS UNDER TWO EMISSIONS TRADING REGIMES

Case 2: Current Total Emissions vs Reduced Emissions

(Standard deviation in parentheses.)

	$\pi^{\max}/\pi^T$	$\Delta\pi$	$\Delta\pi^{mean}$	$\sum_k \sum_i \Delta b_{ki}$	$\Delta\pi / \sum_k \sum_i \Delta b_{ki}$	$NOBS$
			ALL PLANTS			
89	1.31	-7232	-176	331.6	-21800 (SEK/ton)	41
	(0.22)		(170)			
90	1.14	-5658	-138	204.2	-27700 (SEK/ton)	41
	(0.20)		(220)			
			MECHANICAL			
89	1.36	-1229	-112	88.8	-13800	11
	(0.18)		(86.8)			
90	1.11	-1097	-99.7	53.8	-20039	11
	(0.11)		(95.0)			
			SULFATE			
89	1.30	-5384	-234	210.2	-25614	23
	(0.20)		(173)			
90	1.17	-4155	-181	122.1	-34030	23
	(0.25)		(278)			
			SULFITE			
89	1.26	-619	-88.4	32.6	-18987	7
	(0.32)		(204)			
90	1.06	-406	-58.0	28.8	-14097	7
	(0.08)		(88)			

$\sum_k \sum_i \Delta b_{ki} = Total\ change\ in\ emissions\ under\ the\ two\ trading\ regimes$

$\Delta\pi / \sum_k \sum_i \Delta b_{ki} = profit\ increase\ per\ ton\ of\ reduced\ emissions.$

4. Conclusions

In this paper we have developed a framework for calculating the potential gains of a tradeable permit system relative to a system of fixed individual plant regulations. This framework is applied to a data set for the Swedish pulp and paper industry, where current regulation is equivalent to each plant being subject to nontradable emission permits. The first conclusion from the analysis is that the prevailing regulation scheme does not have any impact on total emissions of pollutants relative to an unregulated profit-maximizing outcome. The opportunity cost of the fixed permit system, however, is not negligible, amounting to 1.2 billion SEK in 1989 and 0.4 billion in 1990 as measured by lost profits. The implication is of course that the current permit system is inefficient.

The interesting question is, however, whether the potential efficiency gains of a tradeable permit system would outweigh the potential costs. The costs we are thinking of are various costs to set up and monitor such a market, as well as the transactions cost of trading. The former cost is probably not any higher under a tradeable permit system than under a nontradable system. The latter is a variable cost depending on the number of trades, and a rough guess is that this cost is significantly lower than the potential gain. There might, however, be other costs with a tradeable permit system in this particular case. The first one is that the market would become rather 'thin', i.e., there are few traders. Thus there is a risk of ending up with an imperfect market which does not provide an efficient distribution of the permits. Another possible 'cost' is that the equalization of marginal costs across all the plants in this case may not be an optimal policy. The reason for this may be that the value of the marginal damage varies across locations. If this is the case we have to put a weight on the permit in each location which reflects the environmental impact. Armed with such 'environmental coefficients' this problem can easily be solved with the model presented in this paper.

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Appendix

Table A.1

DESCRIPTIVE STATISTICS, 1989

	MEAN	STD DEV	MINIMUM	MAXIMUM
y=production of pulp, tons	257732.7	189073.7	30720.0	872615.0
b_{BOD}=emmisions of BOD, tons/day	7.90	7.68	0.34	31.0
b_{COD}=emmisions of COD, tons/day	33.20	33.23	0.73	140.0
b_{SS}=emmisions of SS, tons/day	4.86	7.61	0.12	42.0
x_l=input of labor, hours	826589.4	512932.6	106924.7	2267972.0
x_f=input of fibre, m^3	1060928.7	726275.6	82000.0	2543000.0
x_e=input of electricity, kwh	4.14+08	4.11D+08	6.32D+07	1.59D+09
Capital, million of SEK	412.16	293.56	51.28	1368.5
p=price of pulp, SEK/ton	3813.4	626.21	2751.3	4659.8
ω_l=price of labor, SEK/hour	94.40	10.60	65.77	111.9
ω_f=price of fibre, SEK/m^3	355.81	56.18	224.20	450.68
ω_e=price of electricity, SEK/kwh	0.193	0.032	0.118	0.263
π=observed short run profit, SEK	4.91D+08	5.12D+08	-2.87D+07	2.69D+09
NOBS=41				

Table A.2

DESCRIPTIVE STATISTICS, 1990

	MEAN	STD DEV	MINIMUM	MAXIMUM
y	251116.5	175917.8	29199.0	855076.0
b_{BOD}	6.88	6.31	0.32	28.00
b_{COD}	29.18	27.73	0.73	120.00
b_{SS}	4.64	7.22	0.15	36.00
x_l	808736.2	497891.2	95932.7	2201970.0
x_f	1011433.1	687839.3	75000.0	2255600.0
x_e	4.03D08	4.07D+08	6.03D+07	1.51D+09
Capital	407.49	287.12	51.32	1325.6
p	3538.1	370.8	2508.5	4001.1
ω_l	105.21305	13.22128	77.80	139.59
ω_f	373.26	63.31	232.76	510.81
ω_e	0.21	0.039	0.139	0.332
π	3.67D+08	4.01D+08	-1.29D+08	2.10D+09
NOBS=41				