

**CHINA'S PAPER INDUSTRY:
GROWTH AND ENVIRONMENTAL POLICY
DURING ECONOMIC REFORM**

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This paper examines the pollution control policies applied in China's paper industry during the period of economic reform from 1982 to 1992. The paper industry is the source of ten percent of China's industrial wastewater emissions and one-fourth of its chemical oxygen demand. It is the largest source of rural environmental pollution. The very small size of China's mills is comparable to that of papermills in many developing countries and this small size itself creates an interesting problem. Modern pollution control technologies were created for much larger and more capital intensive facilities like those in North American and Northern Europe. Therefore, adoption of the best technology is not a simple matter of technology transfer.

We used mill-level production and pollution data to estimate (1) the effect of China's system of pollution control levies on three environmental effluents, and then (2) examined further the effect of this system of levies on the technical efficiency of mill-level production. Our results show that the pollution levies worked for those larger establishments that were the main targets of reform policies in this period. They decreased the production of effluents by causing managers to alter their mix of productive inputs, but the levies were not large enough to induce the purchase of modern pollution control technologies. The levies had an efficiency improving effect on most modern mills and also on those mills that subsequently discontinued operation. Nevertheless, we observed opportunity for further improvements in efficiency, notably through increased labor productivity. This is consistent with the government's recent decision to relax its policy of employment protection for workers in state-owned mills. Although we found no evidence of scale economies in production, we did observe that smaller mills were less efficient. This observation is consistent with the

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government's more recent decision to close the most environmentally offending small mills.

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1. INTRODUCTION

China began its program of economic reforms in 1978. It has enjoyed double-digit annual growth ever since. Agricultural reforms were implemented most aggressively (Lin (1992)). Industrial reforms and industrial growth followed and, as in any rapidly industrializing economy, so did industrial pollution. Indeed, many see the environment as a casualty of two decades of booming growth (e.g., Wong (1998)) and the environment has become central to national policy. Premier Zhu Rongji, in the Government Report to the National People's Congress on March 5, 1999, identified sustainable development as one of two fundamental strategies for the 21st Century. President Jiang Zemin, stressed the importance of environmental protection at the annual workshop on Population, Resource and Environment on March 13, 1999 when he announced that any enterprise not in environmental compliance by year 2000 would be closed. China has the tools and the means to accomplish these objectives. Its system of pollution levies, for example, is the most ambitious application of a market-based regulatory instrument in the developing world.

The government's position on the competing challenges of environment and development is clear. It desires environmental protection but it aggressively seeks growth. This raises the two standard questions that have always been central to environmental policy anywhere in the world: 1) can economic instruments decrease pollution, and 2) is pollution policy a constraint on growth? Our objective is to address both questions as they apply to China's paper industry.

The paper industry shares many characteristics of China's full manufacturing sector, e.g., increasing financial autonomy for individual mills yet great variation in local government influence, continued government control of certain inputs yet increasing market allocation of final products, the emergence and growth of smaller and more autonomous mills, and, of course, double digit annual growth since 1982; but paper is more important than many other industries for questions of environmental policy. In fact, we expect that the rapidly changing structure of the paper industry may have its own uncertain effect on pollution as larger capacity mills may be associated with declines in effluent discharge, while the expanding number of small mills may be associated with an increase in pollution. The paper industry is the source of ten percent of China's industrial wastewater emissions and one-fourth of its chemical oxygen demand (Huang and Bai (1992)). It is the largest source of rural environmental pollution (State Council (1996)).

We will address the first question - about economic instruments as deterrents to

pollution - with a direct estimation of the effect of China's system of pollution levies on the levels of individual firm's environmental effluents. The second question - about pollution control and economic growth - is more difficult. We will follow a two-step process, first estimating frontier production functions in order to obtain firm- and time-specific measures of technical efficiency (Cornwell *et al.* (1990), Kumbhaker (1990)), and then assessing the determinants of these efficiency measures - with special attention on the affect of China's system of pollution levies.

The data for our analysis are an unusual panel of complete production and effluent data for 34 mills in two representative provinces, Fujian and Yunnan, for the period 1982-1994. This period incorporates most of the gradual industrial reform prior to the government's decisions in 1997 to allow unprofitable mills to close and profitable mills to release surplus labor. Our mills also include the full range of papermaking technologies found in China. They are all state-owned or collectively managed mills but these two categories of mills have been the main targets of the government's industrial reforms and also of its pollution control policies.¹

The results for our first inquiry suggest that the system of pollution levies works. The levies decrease the production of environmental effluents. Furthermore, increasing the levies would reinforce their favorable impact. For the second question, we will find no evidence that the levies alter production efficiency for most classes of mills. [This observation is similar to US experience (Jaffe *et al.* (1995))]. Yet we will also observe ample remaining opportunity to increase efficiency through improved labor productivity. This second observation is consistent with the government's recent decision to allow mills to release surplus labor. In addition, our regressions indicate that smaller mills that are more reliant on non-wood fiber inputs are least efficient. This observation would be consistent with a second recent government decision to close the most environmentally-offending small mills.

2. BACKGROUND: MARKET REFORM AND THE PAPER INDUSTRY

2.1. The General Experience of China's Manufacturing Sector

China's agricultural and forestry reforms began with widespread introduction of the household responsibility system in 1978 and resulted in rapid modification of the system of agricultural collectives (Lin (1992), Yin and Hyde (1999)). Industrial reform began later, in 1984, and proceeded more gradually. The results, however, have been no less impressive.

¹ In the course of twenty years of industrial reform many small private mills (known as township and village enterprises or TVEs), have begun production. They became a primary concern of pollution policy in the 1990s, but most of them did not exist in 1978.

Three broad classes of reforms characterize the changes in industrial policy:

- gradual improvements in firm-level autonomy in the selection of inputs and input mixes (a “manager responsibility system”),
- reform in product distribution (a “dual track” of both centrally allocated and market allocated production, with firms permitted to distribute increasing shares of their output directly to the market), and
- urban reform (which permitted a private manufacturing sector to emerge).

By 1991, the central government had begun talking of a market economy and it began allowing the sale of some state-owned firms and foreign investment in others. By 1993, the government began allowing some firms to go out of business. Nevertheless, the government continues to be major actor in the economy, and many unprofitable state-owned firms remain in operation today.

The industrial reforms of the 1980s and early 1990s were accompanied by financial reforms beginning in the mid-1980s. These increased local financial autonomy and reduced the central government’s budgetary support for most firms. Even today, however, firms apply to the central government for budgetary assistance for their largest capital investments.

The overall impact of the full set of reforms has been growth in the manufacturing sector at an average annual rate of fifteen percent since 1978. The early years, until 1985, were characterized by output growth from more efficient use of inputs (Li (1997)) and convergence of the marginal revenue products of factors (Jefferson and Xu (1994)). Since 1985, more of the sector’s growth has been due to input expansion (Li (1997)). Nevertheless, the evidence remains sparse - and confirmation would be desirable. Jefferson (1990), for example, points to the paucity of analysis on the performance of key industries. The lack of firm-level and industry-level panel data is one reason. The absence of good pollution data and the locally selective administration of national pollution policy compound the problem for analyses of environmental policies.

2.2. The Paper Industry

China’s industrial reforms made no distinctions for the paper industry. That industry has followed general industrial and finance sector reforms identically. Another component of China’s reforms, trade policy, had a notable effect on the paper industry. The opening of international markets permitted rapid expansion in timber and pulp imports in the early 1980s, and a threefold increase in raw wood imports over the full decade. This created a coastal concentration of papermills that are reliant on wood fiber. It also explains China’s rapid specialization in printing and writing, packaging, and sanitary papers. Newsprint production has grown at a slower six percent annual rate

because international competitors have an advantage in the long fibers required for this technology (CTAPI (1993)).

China's papermaking technology itself is relatively similar across establishments because, until recently, the industry relied on a couple of domestic manufacturers making nearly identical machines for each stage in the papermaking process (CTAPI (1993)). The critical differences in the technology come from the use of two alternative raw materials (wood and non-wood fibers) and from the production of either bleached or unbleached papers. Both differences are important to understanding the industry's pollution. The bleached process, used predominantly in the production of printing and writing paper, consumes more chemical inputs and generally produces greater concentrations of undesirable effluents. The unbleached process, used predominantly for packaging material, is less environmentally intrusive.

Larger capacity mills tend to rely on wood fiber as their principal raw material. Larger capacity also tends to be associated with larger inventories of raw material and larger storage facilities. These usually indicate more water for storage impoundments and more effluents. The pollution control technologies for these operations are well developed.

However, China's industry is dependent on non-wood fibers (largely agricultural residues) at a 3:1 ratio over wood fiber. This suggests a concentration of many smaller operations. In fact, China's rapid agricultural growth since 1978 provided fiber for eight-fold growth in the production of smaller papermills between 1984 and 1992 (CTAPI (1993)). The smaller mills have been rapid innovators, but they remain especially environmentally intrusive. They are dependent on pollution control technologies that are not as effective for non-wood fibers. Non-wood fibers deteriorate more rapidly in storage, leaving a larger volume of untreated residue in the holding ponds and wastewater effluents. Moreover, the black liquor created by the non-wood mills evaporates rapidly and has a low capacity for chemical recovery. Therefore, the control technologies and the "end of pipe" monitoring technologies developed for large North American and European mills are not as effective for these Chinese mills.

A comparison of mill capacity in China with capacity in North America and Europe provides further perspective on the pollution management problem. Papermills in North American and Europe range from several hundred thousand to two million tons of annual capacity. In contrast, the capacity of the largest mill in China is only 250,000 tons and any mill over 30,000 tons is classified as "large". China has more than one thousand state-owned and collective mills, and nine times as many other (private, or township and village enterprise) operations, almost all with capacities under ten thousand tons. China's large number of mills helps to offset their small average capacity. Canada's aggregate capacity, for example, from only 115 mills is 25 percent greater than total Chinese capacity from over 11,000 mills (CTAPI (1993)).

The large number of Chinese mills means that pollution monitoring and enforcement are orders of magnitude more complex than in North America or Europe. The smaller size of China's mills also contributes to its experience with rapid entry and exit from the

industry. This, too, contrasts with the experience of large-capacity, high-fixed-cost, durable and mobile North American and European operations.

2.3. Pollution Control Policy

Pollution control policy is fundamental for our analysis. In 1982 the central government imposed a system of levies on air pollutants, on total wastewater, and on the concentrations of three pollutants contained in wastewater: total suspended solids, chemical oxygen demand, and other solids. The first two are characteristic of the paper industry. The levy rates were reassessed in 1989 and increased in 1992. Wang *et al.* (1996) examined the effect of these charges on the effluents on the general manufacturing sector. They found the expected emission-reducing effect.

Nevertheless, the success of the policy has not been entirely satisfying. The policy instrument is simple. Its administration has been more complex. Local environmental agencies collect the tax and they have the authority to negotiate the revenue actually collected from each mill. Since each county in each of 32 provinces, autonomous regions, and large municipalities has its own environmental agency, what began as a simple uniform system for taxing environmental emissions has become a vast array of negotiated settlements. The environment minister himself criticized the system for its variation in local applications (Qu (1991)). He also suggested that the actual tax may be too low to be effective.

In response, the government added a new environmental policy instrument in 1996. It simply closed 4000 small establishments in fifteen industries; 1000 of these were papermills. The government's current rule is to close all papermills under 5000 tons of annual capacity. It has no other effective means to control effluents from these heaviest-of-all polluters.

3. THEORY AND ANALYTICAL ORGANIZATION

Our two objectives are 1) to measure the effectiveness of the system of environmental levies and 2) to reflect on the effect of this pollution policy instrument on economic growth.

The first objective can be satisfied by directly estimating the effects of various causal factors, including the pollution levies and other inputs, on the levels of environmental outputs.

$$X_{it} = f(X_{-it}, t, \tau_{it}, \Omega_{it}, \varepsilon_{1it}), \quad (1)$$

where X_{it} is a vector of (endogenous) effluents produced by firm i at time t , X_{-it} is a vector of exogenous productive inputs, τ_{it} represents pollution taxes imposed on

firm i at time t , Ω_{it} is a vector of other factors affecting input choices, and ε_{it} is a stochastic error term. A negative sign for τ_{it} indicates the expected effluent-reducing effect of the system of levies.

The second question requires that we build an understanding of how the policy instrument affects production and productive efficiency. Our approach is similar to recent stochastic frontier analyses with panel data (Cornwell *et al.* (1990), Kumbhakar (1990)), which allow intercepts and some coefficients of the production function to vary between firms and over time. Unlike standard production frontier models that assume efficiency measures are stationary, our approach allows us to specify how the pollution levies have affected productive efficiency over time as well as across firms. Intertemporal changes in efficiency are critical for our case since China's reforms have been implemented gradually, and surely adjustments in mill efficiency have accompanied the industry's rapid growth during the period of reform. Fortunately, the error term generated by this approach does not require stringent distributional assumptions (Kumbhakar (1990)).²

The first step is to distinguish endogenous from exogenous factors of production and to obtain predicted values (instruments) for the endogenous factors.

Labor and durable capital are exogenous. In most of our period of analysis and for state-owned firms, the government, not the firms' managers, made the decisions about these inputs as part of its overall labor and financial-budgetary policies. Energy, chemicals, and environmental emissions are endogenous. The inclusion of emissions as negative inputs to production is standard within the environmental regulation literature whenever abatement inputs are unobserved (e.g., Baumol and Oates (1988)). Higher levels of emission are consistent with lower levels of abatement inputs. Since substitution between abatement and non-abatement inputs affects output, measures of emissions serve as instruments for the endogenous abatement decisions of the firm.³

An extensive literature discusses pollution levies (Pargal and Wheeler (1996), Laplante and Rilstone (1996), Deily and Gray (1991, 1996), Dion *et al.* (1998)). Its

² The large papermills in Europe and North America normally operate in excess of 96 percent of their capacity. This is characteristic of high fixed cost operations and plant size is the key explanatory variable for productive output. These characteristics mean that a linear input-output approach typically describes the most reliable models of their production (e.g., Buongiorno and Gillis (1987), Yin (1998)). The smaller scale and greater variability in scale in China's papermills is more conducive to econometric specification.

Our approach also contrasts with many other assessments of the instruments of pollution policy because we have the input data to model the full production process. Some of the best economic literature on pollution control has been restricted to regressions of effluent levels on pollution policy and other decision variables because input data were unavailable (e.g., Baumol and Oates (1986)).

³ The alternative would be to estimate the joint production of both a market output and the environmental waste using both abatement and non-abatement inputs and, then, to develop predictive equations for both emissions and inputs. This approach requires abatement input data - which were unavailable to us.

fundamental observation is that enforcement is sensitive to differences in regional economic development, public awareness, and environmental quality, but less sensitive to specific firm characteristics. The reasoning behind this observation is that efficient pollution fees are related to regional preferences and assimilative capacities. This means the fees would be endogenous to the regional enforcement agency. They are exogenous, however, from the perspective of each firm - which is consistent with another observation of this literature that fees are less sensitive to the firm's characteristics. We will follow this reasoning and treat the pollution levy as exogenous for our firms. The level of chemical inputs is also an endogenous decision of the mill manager, and an instrument for it can be determined in the same manner as the emission instruments.⁴

The second step applies the predicted values from Equation (1), together with independent observations on the exogenous inputs, to estimate a time series, cross-section production function of the form,

$$Q_{it} = g(\hat{X}_{it}, X_{-it}, \hat{W}_{it}; \beta, \varepsilon_{2it}), \quad (2)$$

where Q_{it} measures output, \hat{X}_{it} is a vector of predicted endogenous inputs, X_{-it} , remains a vector of exogenous inputs, \hat{W}_{it} is a vector of predicted endogenous environmental wastes, and β is a vector of parameters to estimate. (Equation (2) separates environmental wastes from other endogenous inputs only for emphasis and clarity in subsequent discussion.) The use of Equation (1) to obtain a predicted vector of endogenous variables in Equation (2) is consistent with two-stage least squares estimation for the production function. Predicted values are exogenous by definition in such a regression.

The third step is to extract efficiency scores from Equation (2) and to examine the effect of the system of pollution levies on those measures of efficiency. Has the levy encouraged improvements in efficiency and, therefore, in growth? Or has it been a deterrent to growth? This question is the subject of debate within China today, and also within the general literature of environmental regulation - especially in conceptual work that compares pollution control innovations induced by price or quantity instruments

⁴ Although we have good reason to believe that pollution levies in (1) are exogenous from the perspective of the firm, we performed a rigorous test, *ex post* to estimation, to confirm this. The test involved first constructing estimated residuals from the estimated version of Equation (1), and then regressing these residuals on the (presumed) exogenous variables in the equation, which included the pollution levies. None of these exogenous variables were significant in the residual regression. Moreover, the estimated coefficient on the pollution tax variable had a p-value greater than 0.50 for each type of waste emission. This confirms that the tax intensity variable can be treated as exogenous, and that the estimates of Equation (1), and of Equations (2)-(8) below that are based on Equation (1), are all consistent. The rationale for this test can be found in Draper and Smith (1981).

(Baumol and Oates (1988)).

We might anticipate that the effect of the levy has varied over time (with the progress of China's reforms) as well as across classes of firms. Therefore, we will disaggregate our eventual empirical evidence in order to examine differences between classes of firms and over time.

We can estimate a time- and firm-specific efficiency term by introducing a "fixed effect" into the production function.

$$Q_{it} = \alpha_{it} + \tilde{g}(\hat{X}_{it}, X_{-it}, \hat{W}_{it}; \beta, \varepsilon_{2it}), \quad (3)$$

where α_{it} is an unobservable efficiency scale (i.e., the fixed effect) that varies over time and across firms. Firms that are relatively inefficient and "further" from the frontier have efficiency scales that are lower in magnitude than firms that are relatively more efficient and "closer" to the frontier. The conventional specification of α_{it} is

$$\alpha_{it} = \gamma_{0it} + \gamma_{1it}t + \gamma_{2it}t^2, \quad (4)$$

where the γ s are parameters to estimate (e.g., Cornwell *et al.* (1990), Kumbhakar (1990)).

The parameter α_{it} is embedded in the error term in Equation (3) and cannot be observed directly. We can obtain a consistent estimate for it following a procedure recommended by Cornwell *et al.* (1990). The first step is to develop estimates for the two RHS terms in Equation (3). The estimate for \tilde{g} can be obtained by regressing Q on the appropriate functional specification for \tilde{g} , while the estimate for α_{it} can be obtained by regressing the residual of this regression (i.e., $Q_i - \hat{\beta}Z_{it}$) on the RHS of Equation (4). That is,

$$\hat{Q}_i - \hat{\beta}Z_i = \gamma_{0it} + \gamma_{1it}t + \gamma_{2it}t^2 + \eta, \quad (5)$$

where Z_{it} is a new vector that summarizes all explanatory variables in \tilde{g} and η is a white noise error term. The final step applies the fitted values from the RHS of Equation (5) to recover an estimate of firm- and time-specific efficiency,

$$\hat{\alpha}_{it} = \hat{\gamma}_{0it} + \hat{\gamma}_{1it}t + \hat{\gamma}_{2it}t^2, \quad (6)$$

where the $\hat{\gamma}$'s are estimated parameters from Equation (5).

Since a firm that produces on the frontier of efficient production would have the highest predicted efficiency score,

$$\mu_{\max} = \max(\hat{\alpha}_{it}),$$

then the distance between that firm and any other firm is a measure of the relative *inefficiency* of the firm that is not on the frontier. In other words,

$$\mu_{it} = \mu_{\max} - \hat{\alpha}_{it} \quad (7)$$

is the difference between the first firm's predicted efficiency parameter and the maximum efficiency score.

Finally, by regressing this inefficiency score μ_{it} on pollution control policies and other important determinants of efficiency, we can examine how the efficiencies of different classes of firms change in response to these factors.

4. DATA

4.1. Production Data

The Council of Light Industries (CLI, formerly the Ministry of Light Industries) compiles production data and financial information for about 1100 mills in 32 provinces, autonomous districts, and large municipalities - essentially all the mills under the jurisdiction of the central government. These mills accounted for approximately ninety percent of China's papermaking capacity in the early 1980s. They comprise about fifty percent of national capacity today.

The CLI data include sales income, output value (in both current and 1980 prices), profits and tax payments, physical outputs by product and grade, pulp production by grade, material inputs (including five measures of capital stock or annual investments in durable capital).

Our summary measure of all production will be output weighted by 1980 prices. Otherwise, we will concentrate on physical measures because personnel at CLI recommended that those data are more reliable than price or cost data. The measure of capital is problematic. For much of our 1982-1992 period of analysis, the government did not require state-owned firms to pay most capital costs. Our measure of capital is net capital stock. In China's accounting terminology, this is capital stock net of depreciation but unadjusted for inflation.⁵

⁵ Jefferson, Rawski and Zheng (1996) review this problem. They too prefer to use net capital stock for their production analysis but they add a term, the ratio of net capital to original capital, to adjust for inflation. We remain uncertain as to what is the best reformulation. Therefore, we replaced our measure of capital with a measure of investment and re-ran our basic production regression. There are no fundamental differences between the two equations, and both measures of capital perform as expected.

4.2. Pollution Data and the Pollution Levy

County environmental agencies collect firm-level accounts that include pollution data. These accounts are dispersed in offices around the country. We arranged a firm-level survey of the three important classes of papermill emissions (wastewater measured in cubic meters, total suspended solids in tons, and chemical oxygen demand in tons) from county offices in two southern provinces, Fujian and Yunnan. The willingness of the environmental officials in Fujian and Yunnan to assist us may be an indication of their confidence in their data. (Officials in some provinces with poorer data were less willing to provide assistance.) The county agencies confirm the reliability of these data for their own purposes with periodic random checks at each mill, and they penalize misreporting with fines or higher charges. We reconfirmed the pollution data ourselves in our own discussions with mill managers and with our own reviews of additional records kept at the mills.⁶

We began with a complete survey of all the mills originally under CLI supervision, approximately fifty mills in Fujian and forty mills in Yunnan. Some mills that were active in 1982 when the pollution levy was first implemented had become inactive by the time we collected our data, and some active mills provided only incomplete pollution data. We finished with seventeen mills in each province (generally no more than one per county) for which we could match annual pollution data with annual production data from CLI.

The CLI production data are complete between 1982 and 1992. Our Fujian pollution data cover seven of eleven years in this period. Our Yunnan pollution data, however, are complete only after 1986. Therefore, we applied a procedure recommended by Griliches (1986) to estimate the missing pollution data for Yunnan's mills in 1982 and 1985. This procedure begins with the 1986-1992 data, and regresses emission levels on productive inputs for those years. The estimated input coefficients from this first stage, plus the actual input data for 1982 and 1985, combine to predict the missing observations on emission levels.

The pollution levy requires separate consideration. The official water pollution regulation stipulates a graduated fee on total wastewater effluents plus a flat fee per concentration unit of total suspended solids, chemical oxygen demand, or other solids. The fee is charged if a pollutant exceeds a set minimum standard. Mills that discharge several pollutants are charged on the worst case - defined as wastewater plus the pollutant on which the estimated total levy is highest among all effluents.

Local environmental agencies have the authority to charge at a higher rate. Some do but, in fact, many charge at lower rates. In addition, local agencies also have the

⁶ In our experience, "doctored" records usually reveal themselves through the existence of some inconsistent records, for example strange proportions for one input, or absent entries for others. None of our mills' records demonstrated these deficiencies.

authority to return up to eighty percent of the total levy to assist the firms in purchasing pollution control equipment. The result is great variation across firms and counties in the effective rates of pollution charges. Variable rates may be inequitable, but they are an advantage for our analysis because they allow us to examine how effluent levels, the production of conventional outputs, and efficiency all change with respect to different levels of the tax rate.

Perhaps the best measure of the effective tax rate would be a ratio of the firm's net taxes (after any reimbursement from the county environmental agency) to the basic liability assessed according to the central government's pollution regulations. An increase in this ratio would be the equivalent of an increase in the tax on pollution. We calculated the denominator of this ratio from the central government's pollution tax tables and our firm-level pollution data. For the numerator we relied on measures of gross payments (after the county agency adjusted the central government's rates but before it returned any share of the levy to the firm). The result is an imperfect measure of the final effective tax rate for each firm, but we will find that even this measure demonstrates that pollution levies are a disincentive to pollute and that higher tax rates (a larger ratio) are even greater disincentives.

4.3. Fujian and Yunnan

We have complete data on 34 mills for seven years in the period 1982-1992, a total of 352 observations. These data are complete for conventional inputs, four different effluents, and the pollution levy. Complete production and effluent data at the establishment level are unusual in the economics literature - and this is an important feature of this paper. They permit the theoretically sound approach of estimating pollution control behavior from observations of the full production function. The variation in our observations of the pollution levy is also an advantage. It will give us more confidence that our regressions reliably demonstrate the effect of higher and lower rates for the levy.

But what about our restriction to evidence from two provinces? Are Fujian and Yunnan representative of China's paper industry in general? The most reliable evidence would come from a comparison of full Fujian-Yunnan production functions with the all-China production function. The lack of easy access to pollution data for all Chinese mills prevents this. Collecting effluent data for the remaining mills would be an enormous task. Indeed, this is the reason our sample is limited.

Alternatively, let's consider the industry and its comparative technologies for these two provinces. Fujian is an industrial and coastal province that, among China's 32 provinces, ranks in the mid-upper level in paper production. It represents the advanced portion of China's paper industry, the portion that has been subject to a broader and longer exposure to government intervention because of its importance to national supply. China's largest newsprint and its largest sack and kraft mills are all in Fujian. These and other wood fiber processing mills account for about forty percent of provincial

production - in comparison with the national average of 33 percent wood fiber. This means that the majority of mills in Fujian still use non-wood fibers - and that mills in Fujian, on the whole, provide a complete image of China's paper industry.

Yunnan is an inland province with no large papermills but a couple of medium-sized operations. Wood fiber-based production accounts for about twenty percent of the provincial total, a share that also approaches the national average, although from below.

For further perspective, we reflected on knowledge that the machinery for the papermaking technology itself was similar across firms and the only differences in scale should be reflected in different numbers of machines within any given papermaking establishment. Therefore, the important differences in papermaking technology should be captured in a measure of labor productivity.

Table 1 reports labor productivity in the paper industry for all of China and for Fujian and Yunnan. Productivity increased steadily for all-China and for both Fujian and Yunnan throughout all years for which we have complete data. Productivity increased sharply in 1990, as mill managers began to exercise a new option to release contract labor in response to a general economic downturn.⁷

Table 1. Labor Productivity (tons/employee-year)

Region	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
All China											
Maximum	29060	31553	32315	33881	65773	43815	36722	38512	35476	69590	68741
Minimum	2658	3149	4649	5455	1552	7804	6790	8351	7216	2250	13566
Mean	9626	10432	11434	12595	14456	15444	14975	15980	16453	29080	29752
Standard Dev	5476	5406	5307	5487	11117	7898	5722	6589	6639	13651	13813
<i>Fujian</i>	12031	12171	12772	10068	15651	16052	16263	16645	17484	40782	40971
<i>Yunnan</i>	6635	7056	7659	9365	10619	11791	12831	14036	13390	27384	27453

In all years, including 1990 and 1991, productivity in Fujian, where wages are higher, exceeds the national mean while productivity in Yunnan, where wages are lower, is less than the national mean. Yet, in all years, both Fujian and Yunnan are within a standard deviation of the national average. We will base an argument that Fujian's and Yunnan's mills are representative on this evidence, and also on a Chow test that did not reject the hypothesis that the production observations from the two provinces are themselves

⁷ The policy distinguished between permanent and contract labor. Managers had discretion to release contract labor, but they only began to exercise the option during the downturn of 1990.

similar.⁸

The national data for many other comparisons are incomplete. However, we were able to estimate average physical productivities for three key inputs: wood fiber, the alkali chemical, and electricity. In all three cases, the average physical productivity was greater in Fujian than Yunnan, but both provinces were within a standard deviation of the all China mean. These observations are consistent with our labor productivity evidence. They add confidence to our conclusion that the mills of Fujian and Yunnan are representative.

5. EMPIRICAL RESULTS

5.1. Environmental Policy, Economic Reform, and the Decision to Pollute

Our first objective was to inquire of the effectiveness of the pollution levy in reducing environmental effluents. Our first set of regressions addresses this objective and it also provides estimates (instruments) for the endogenous inputs to the production function used in subsequent analysis.

The important measures of pollutants are the levels of discharge or concentration for wastewater (*WW*), total suspended solids (*TSS*), and chemical oxygen demand (*COD*). All three are also instruments for managerial decisions about water, fiber, and effluent abatement. In addition, managers in state-owned and collective mills had authority to make decisions about variable inputs other than labor - essentially chemicals (*ALK* for alkali, the most important chemical) and energy (*E*).

This makes five dependent variables and five regressions, each of which is a function of the firm's exogenous inputs; capital (*K*), labor (*L*), and the pollution levy rate (*TXR*); and other factors that could affect managerial decisions. These "other factors" are output prices (*P*), time (*t*), and the basic production technologies associated with each mill. The time variable accounts for the overall effect of China's gradual industrial, financial, and trade reforms on pollution. Dummy variables distinguish bleach-using production processes (*BD*), and mills that are wholly reliant on either wood (*WD*) or non-wood (*NWD*) fibers. Another dummy variable distinguishes mills in Fujian (*FD*) from mills in Yunnan.

The resulting regressions are of the form:

⁸ We compared the OLS version of frontier functions for the two provinces. The Chow $F(7, 150)$ is 0.3185 while the critical value for 95 percent confidence is 2.01. Therefore, we cannot reject the hypothesis that the last seven slopes for regular production inputs and mill characteristics are similar for the two separate provincial estimations.

$$\ln X_{it} = \delta_0 + \delta_1 \ln K_{it} + \delta_2 \ln L_{it} + \delta_3 \ln TXR_{it} + \delta_4 \ln P_{it} + \delta_5 t + \delta_6 BD_i + \delta_7 WD_i + \delta_8 NWD_i + \delta_9 FD_i + \varepsilon_{it} \quad (8)$$

where the δ s are parameters and the X_i are any of five endogenous inputs to production. An appendix table contains a complete list of all variables and their units of measure.

Table 2 reports the OLS coefficients for the three effluent regressions. The equation fits are satisfactory and most coefficients satisfy expectations. We examined these regressions (and the two regressions for predicting endogenous factors of production) for heteroskedasticity of unknown form following White's method (Green (1997)). Heteroskedasticity in the errors might be expected due to differences in firm size, for example. We detected heteroskedasticity in the wastewater regression (only), and therefore, we estimated a White robust regression in order to draw valid inferences for that effluent. Table 2 reports this regression as well.

Table 2. Effluent Decisions¹⁾

Variable	WW	Robust WW	TSS	COD
Constant	-0.736 (-0.593)	-0.736 (-0.586)	0.665 (0.384)	-2.881* (-1.576)
ln(capital)	0.195* (1.791)	0.195* (1.665)	0.042 (0.273)	0.299** (1.862)
ln(labor)	1.107*** (7.553)	1.107*** (6.109)	1.490*** (7.280)	1.046*** (4.842)
ln(tax rate)	-0.283*** (-5.246)	-0.283*** (-5.655)	-0.449*** (-5.957)	-0.620*** (-7.790)
ln(price)	-0.170 (-1.021)	-0.170 (-0.957)	-0.697*** (-2.995)	-0.083 (-0.336)
<i>T</i>	0.054 (1.202)	0.054 (1.103)	0.189*** (3.001)	0.125** (1.885)
<i>Dummies</i>				
bleach	0.216 (1.330)	0.216 (1.197)	-0.461** (-2.030)	0.318 (1.325)

Table 2. (Continued)

Variable	WW	Robust WW	TSS	COD
wood fiber	-0.162 (-0.856)	-0.162 (-0.966)	-0.196 (-0.743)	0.047 (0.168)
non-wood fiber	-0.787*** (-3.388)	-0.787*** (-3.976)	0.138 (0.425)	-0.247 (-0.721)
Fujian	0.470*** (3.166)	0.470*** (2.966)	-0.170 (-0.820)	-0.736*** (-3.363)
F(9,194)	62.20	66.15	33.33	31.64

Note: ¹⁾ Numbers in parenthesis are *t*-statistics. ²⁾ *(** , ***) indicates significance at 10% (5%, 1%) level.

Increasing amounts of either capital or labor increase the levels of all three effluents. (Four of six coefficients are statistically significant.) We recall that mill managers had little discretion over these inputs in the period of our analysis. We might anticipate that increases in capital and labor are associated with increased production, and that total production of the conventional output and total effluents are directly related. (Our production function in the second stage supports this logic for capital. We will see that the labor variable is an important special case.)

The key observation for our first objective is that the pollution tax is a disincentive to pollute. Furthermore, increases in the tax rate cause statistically significant decreases in the levels of all three pollutants.

The anticipated effect of market prices is unclear. Newsprint production was (and still is) under a “dual track” of both quotas and market production. The manufacture of other paper products was an early beneficiary of reforms in market access. Therefore, higher prices should be an incentive for production for most of the industry. Since pollution follows production, we might expect higher prices to increase the flow of environmental effluents. On the other hand, higher prices may permit the adoption of better pollution control technologies and increasing recovery and re-use of some environmental wastes. The general statistical insignificance of the price terms leaves us uncertain about the assessment of these factors.

Time has the positive (and generally significant) relationship to pollution that we would anticipate if it reflects growth in conventional outputs without corresponding improvements in pollution control technologies.

Bleach pulping processes use more chemicals than other production processes. Therefore, we expect COD emissions to be greater for this process. They generally are, but the effect is not statistically significant.⁹ Firms that are entirely reliant on wood fiber

⁹ The significant positive bleach term in the TSS regression was unexpected. We inquired further.

might pollute less because the pollution control technologies available to them are more advanced. In fact, the regressions show that these firms do produce less wastewater and lower levels of TSS, but these effects are also not statistically significant. This probably indicates that their adoption of pollution control technologies is not widespread. Firms wholly dependent on non-wood fibers should be heavier polluters because their pollution control technologies are less advanced. Our evidence does not support this expectation either - which is further evidence that their opposites, wood-using mills, have not adopted the available technological advantages. The Fujian dummy indicates a region in which larger wood-using firms play a larger role in production. The significant positive sign on wastewater production in Fujian is additional support for the contention that there is no widespread use of the pollution control technologies that are available to this class of firms. In fact, we know that flushing is one means large mills use to address problems with other effluents. Of course, this increases wastewater effluents. The signs and significance of the Fujian dummy confirm this behavior.

The policy conclusions emerging from these observations are entirely consistent with economic theory, with China's history of economic reforms, and also with the central government's more recent revisions of its pollution control policies and administration. We know that China's general economic reforms led to increases in the conventional outputs of industrial production. Our evidence supports the argument that increases in production came at an increasing cost in terms of environmental quality. As environmental quality deteriorated, the government has directed more attention to it, first establishing a variably administered system of pollution levies, and then increasing these levies. The levies are a statistically significant disincentive to pollute. But apparently the levies are not high enough to be an incentive for firms to adopt advanced pollution control technologies.

This observation concurs with the general criticisms of the levy system. China's environmental authority favors the end-of-pipe facilities for pollution control, but the required investment is a financial burden for many small mills. Hence, where there is effort to reduce pollution, it occurs more often within the production process itself. That is, it occurs in the form of more efficient use of materials other internal production adjustments. This strategy may cause a reduction in conventional outputs as productive inputs are transferred to the abatement process and it raises the question of our second objective in this paper, the question of tradeoffs between pollution and growth, or pollution controls and efficient production.

As the economy has continued to grow and as environmental quality has continued to deteriorate, the production of environmental pollutants has become an increasingly

Fourteen of 21 bleach mills in our sample use non-wood fibers. Engineers at the State Environmental Protection Agency told us that bleach mills, as producers of higher quality paper, are selective in their choices among non-wood fibers. They predict that this selective choice results in raw material inputs that produce lower levels of total suspended solids.

important issue. For sure, paper industry emissions have continued to increase, and both the low levels of the pollution levies and their uneven administration have become more troublesome. In 1997 (after the 1982-1992 period of our data) the government announced a more aggressive regulatory stance - equating "ecological conservation" with pollution control and closing the smallest mills (State Council). It also began the process of moving away from decentralized administration of the pollution levy and toward a uniform centralized system. Perhaps it should increase the levy as well.

5.2. The Effect of Environmental Policy on Efficient Production

The production function: There are two steps to examining the question of environmental policy and economic efficiency. The first is to estimate the full production frontier and the second is to examine the sources of departure from operations on this efficient frontier. A thorough review will show that our production function satisfies most reasonable expectations. Therefore, it is an appropriate basis from which to examine departures from efficiency. However, this function does reveal one unusual intermediate observation, the marginal product of labor is negative! This important observation, its impact on pollution, and the government's policy response, all bear closer examination.

For the production specification, we will use a restricted translog form in which there are no cross-effects for pollutants with pollutants. The restricted form eliminates the possibility that the pollutants (as negative inputs) might destroy the concavity of the function.

$$\ln Q_{it} = \alpha_{it} + \sum_{j=1}^7 \beta_j \ln Z_{j,it} + \frac{1}{2} \left[\sum_{j=1}^4 \sum_{k=1}^4 \beta_{jk} \ln Z_{j,it} \ln Z_{k,it} \right] + \sum_{j=8}^{10} \phi_j D_{j,it} + \varepsilon_{2it} . \quad (9)$$

The first four inputs are capital, labor, and the two endogenous conventional inputs, energy and chemicals, estimated in the prior regressions. The next three are the negative environmental inputs; WW, TSS, and COD; which were also estimated as endogenous inputs in prior regressions. The three dummy variables identify all-wood, all non-wood, and bleach production processes, α_{it} is the efficiency scale for the i -th firm, and the β_j , β_{jk} , and ϕ_j are parameters.

A second appendix table reports the estimated parameters. The equation statistics are satisfactory, all first-order coefficients except that on energy satisfy expectations (and the energy coefficient is insignificant). The second-order and cross effects are highly significant (with only one exception). These support our selection of a translog form. The significance of all capital-related coefficients is consistent with a high fixed cost, capacity-driven, industry.

Table 3 in the text summarizes the output and substitution elasticities calculated from these coefficients. The negative output elasticity for labor is our most interesting

observation. It tells us that the marginal product of labor is negative. The last worker crowds more productive workers and actually causes total output to be less than it would have been if the last worker had not been employed.¹⁰ This unusual result is more reasonable than it first seems. Employment was a birthright for children of employees of state-owned firms. (Before the recent trend to privatization, collective firms also followed a policy of employment security.) After fifty years of state ownership, this policy created excess employment in many firms. The problem became so great by the 1980s that mill managers commonly instructed some unproductive employees to stay home - while continuing to pay them. These decisions confirm our observation that marginal workers contributed negatively to a firm's total product.

Table 3. Production Elasticities

Variable	Output Elasticity	Allen Partial Elasticities of Substitution					
		K	L	E	ALK	WW	TSS
Capital	0.843						
Labor	-0.591	0.928					
Energy	2.782	0.694	0.916				
Alkali	-2.240	0.838	0.852	0.939			
Wastewater	0.298	0.285	0.721	0.853	0.916		
TSS	3.471	0.285	0.721	0.853	0.916	0.663	
COD	-5.720	0.285	0.721	0.853	0.916	0.663	0.663

The negative marginal productivity may not be true for all state-owned and collective firms, but it is not restricted to paper producers in Fujian and Yunnan, or even to the paper industry in general. Excess employment (if not negative marginal productivity) has been a national problem. The central government recognized its constraint on growth and permitted limited hiring discretion with contract laborers by 1990. All workers became contract laborers in a major policy change introduced in 1995. Employment birthrights no longer exist. Managers now have the authority to release excess workers, although they continue to pay a minimum monthly stipend to released workers even under the new policy. Seventeen million workers, or more than one of every five from state-owned firms, were removed from the payrolls of state-owned companies between 1995 and the end of 1998 (Wilhelm (1999), Saywell (1999)).

The other elasticities in Table 2 demonstrate the effect of this unusual labor

¹⁰ Various estimates of production with alternative functional forms all yielded similar negative and significant marginal products of labor.

observation. The output elasticities show that the next unit of capital, for example, would be more productive than the last unit of labor. The positive substitution elasticities indicate that all inputs are substitutes for each other.¹¹ They show that it takes more labor than capital to substitute for another unit of the conventional energy and chemical inputs while still producing the same level of conventional product. This means that capital is more productive than labor at the margin - which is what we would expect for a process that employs excess labor. Furthermore, the effluent substitution elasticities show that (at the margin) it takes three times as much labor as capital to reduce effluents by one unit. Effluent production is largely a function of capital management, but excess labor also contributes to these results. If mill managers could have transferred resources from labor to capital, the marginal product of labor would have increased, total paper production would have increased, and pollution would have decreased. Therefore, we anticipate that China's more recent policy allowing managers to release excess workers will yield a double dividend, improving efficiency and maintaining growth (the policy objective), but also improving the environment (the unplanned second dividend).

The alkali output elasticity also has an unexpected negative sign - indicating excessive use and a negative marginal product. It may be unimportant because the first-order alkali coefficient in the translog equation is so insignificant. Alternatively, it may be explained by managers' decisions to use purchased alkali excessively because its relative price and its budget effects are so low. Alkali is used to separate useful fiber from residual raw material. Its overuse may allow managers to focus on what they perceive to be more costly components of the production process.¹²

Where pollution control is enforced, mills recover and reuse some alkali and the concentration of COD discharges declines. Where enforcement is weak, less alkali is recovered and the concentration of COD discharges increases. Therefore, the negative output elasticity for COD supports the contentions of overuse of the alkali input and the low incentive effect of COD levies on the adoption of pollution control technologies by bleach process mills.

We have explained our doubts about scale economies in Chinese paper production. Our test for heteroskedasticity in the first regressions seems to confirm these doubts and our production results are further confirmation. The sum of the output elasticities actually tells us to expect decreasing returns to scale. However, our output elasticities are underestimates for two reasons. First, the dummy variable indicators of fiber inputs reflect the positive sign but not the magnitude of the effect of raw material inputs on output. Their positive signs indicate that, if we had the data to calculate the elasticities,

¹¹ The identical elasticities of substitution between any input and all three effluents are due to the restrictions on effluents in our translog function (no second order effluent-effluent terms).

¹² The reasoning is similar to the reasoning of many American farmers for their overuse of pesticides and fertilizers (e.g., Carlson and Wetzstein (1993)).

they would increase our estimate of returns to scale. Second, we would need to remove the labor inefficiency problem to obtain a measure of true technological returns. With efficient employment of labor the labor output elasticity would also be positive. Combining both corrections causes us to doubt the observed decreasing returns to scale. On the other hand, our evidence provides no basis for anticipating increasing returns to scale.

Nevertheless, when the government began addressing the problem of unprofitable mills in 1993, it endorsed some external investment. About the same time a small number of mills began installing paper machines manufactured overseas. The much larger capacity papermills in more developed countries should raise curiosity regarding whether scale effects will emerge from with the use of these new machines. Increasing returns to scale would suggest the opportunity for continued productivity growth simply by increasing mill size. If China's pollution levy affects effluent levels, but not conventional output levels - as our results in Table 2 suggest - then China's paper industry may be able to grow and control pollution simultaneously. This remains a possibility worth further examination.

Finally, our frontier production function is the source of relative inefficiency scores derived according to the procedure of Equations (4)-(7). The third and fourth appendix tables record these scores for each mill in our sample. We expect improvements in efficiency over time (decreasing inefficiency scores), as the industry has grown over the decade of our data, and we expect greater efficiency in the larger mills and mills applying the bleach process, especially in Fujian, because this is the most rapidly growing and most technologically advanced segment of our sample. These expectations are consistent with the results from the first two components of our analysis and the appendix tables of inefficiency scores confirm them. A firm's fiber source (wood or non-wood) does not seem to confer an efficiency advantage. This result too is consistent with the evidence from our prior regressions and our production function, if not with our initial expectations.

The determinants of productive efficiency: Improvements in productive efficiency might come from better quality capital or labor, or from improved energy inputs. We are particularly interested in whether the pollution levies also have an affect on technical efficiency. Table 4 shows the results of our regression analyses where the dependent variables are the declining mill-level inefficiency scores taken from appendices 3 and 4. The first column of Table 4 reports the results for the aggregate of all mills in our sample. Subsequent columns show the results for select categories of mills.

Our measure of capital improvement is the ratio of net capital to original capital. This ratio increases as new capital is added to the stock, and as the original durable capital is removed from service. The positive sign on the capital ratio in the first column of estimates (for the full sample of mills) suggests that the industry's rapid introduction of capital improvements has meant that significant start-up costs associated with new capital have been important for several mills at a time throughout our sample period, and that the elapsed period of our analysis has not been sufficient to capture all efficiency gains due to capital improvements. A longer data series and an industry that was adopting new technologies, but adopting them less rapidly, would be less likely to display this positive effect on inefficiency.

Improvements in labor and shifts to modern energy sources might both improve efficiency (decrease the inefficiency scores). Our measure of improved labor is the ratio of engineers to total employees. Our measure of energy is the ratio of electricity consumption to coal consumption. Increases in each significantly improve efficiency for our full sample of mills.

The capital, labor, and energy effects on efficiency are robust. The signs of the respective coefficients are the full sample of mills and for all specialized categories of mills, and these signs are often significant for mills categorized by mill size, fiber preference, bleach technology, or location.

For this paper, however, we are more interested in the effect of increasing pollution levies on the technical efficiency of our mills. We know (from regressions in Table 2) that higher levies decrease pollution, but do they also cause mills to produce closer to the production frontier or farther away? We can see from the first column of results that the level of the pollution levy has no consistent effect on efficiency. Increasing the levy actually increases technical efficiency for wood-fiber mills and for mills in Fujian. The more modern mills in our sample fall within these two categories. Increasing the levy does correlate with greater distances from the production frontier for mills reliant on non-wood-fiber and for mills in Yunnan. Non-wood-fiber mills are a growing segment of the industry. They, and their emissions, have been more difficult for the government to control. Mills in Yunnan were slower to experience government pollution control policy and this policy has probably not been applied as uniformly, especially for the smaller mills in that province.

Finally, we also examined another set of mills that, since 1992, either have discontinued their pulp operations while continuing to produce paper (13 mills) or have ceased operations altogether (3 mills). The final column of Table 4 reports the determinants of the efficiency scores for these sixteen mills. Three small mills closed because they could not meet environmental standards. We might anticipate that environmental standards and the levy were one reason some other mills discontinued their pulp processing and turned to the market for their pulp inputs. The levy had a significant effect on these mills, actually increasing the efficiency of their performance while they were still operating.

If increasing in the levy decreases pollution but does not deter efficient operation in

modern mills, then we can anticipate that economic instruments will be effective policy tools as the industry continues to modernize. The instrument will probably bring Pareto improvements to the modern sector. In fact, the government is acting as if it shares this perception. It is experimenting with tradable permits, a more complex economic instrument for pollution control.¹³

The smaller, non-wood-fiber mills had their own set of experiences: We indicated that these mills are the greatest polluters of the rural environment. Enforcing pollution control responsibilities on the many dispersed mills in this category has proven a difficult task. If higher pollution levies correlate with greater distances from the production frontier for these mills, then a pollution control standard may be a better alternative. The government's recent decision to simply close the smallest and worst offenders may be the right strategy.

6. CONCLUSIONS

Four major conclusions emerge from our assessment of papermills during the 1982-1994 period of economic reforms. Their policy implications are remarkably consistent with the central government's industrial and environmental policy decisions since 1994 - although in some cases our evidence argues for even more aggressive environmental policy.

First, China's system of pollution control levies decreased environmental emissions, and higher levies decreased emissions even more. Economic incentives worked. The levies worked because they induced adjustments in the use of conventional inputs. However, they were insufficient to encourage even the most modern mills to adopt modern pollution control technologies. Therefore, we would hypothesize that higher pollution levies could be more effective yet. It is unclear what level of levies would induce the adoption of modern pollution control equipment. This depends on the individual pollutants and their abatement costs, and the underlying technologies of China's small mills. A nationwide survey in late 1980s on mill level abatement cost suggested that the levy should be doubled (NEPA (1996)).

Second, the production function generally demonstrates the anticipated positive relationship between conventional paper products and environmental emissions. It also demonstrates an unusual negative marginal product for labor. The government responded to widespread evidence of redundant labor in 1995 and the managers of state-owned mills released one-fifth of their labor force by 1998. Our production function anticipates that the net effects of this policy change will include both increased mill productivity and an improved environment.

¹³ The impact of a system of tradable permits on the mills in this sample is the topic of another chapter of the senior author's dissertation.

Third, while our analysis fails to uncover any evidence of increasing returns to mill scale, two mills in our sample added new machines manufactured abroad at the end of our sample period. Others have purchased more internationally manufactured papermaking machines since then. The much larger scale of international papermills raises the possibility of increasing returns to scale (IRS) as a topic for further examination. Combined with evidence that some effluents decrease with expanding mill production and others have less than unitary output elasticities, IRS would support the government's decision in 1996 to close the most environmentally offending small mills.

Fourth, the pollution levy has differential effects on the productive efficiency of different categories of mills, increasing productive efficiency in the most technologically advanced mills, but correlating with greater distances from the production frontier and less efficient operation for the class of small mills that rely on non-wood fibers. The first provides further support for the argument that increasing the levy would induce greater adoption of modern pollution control technologies by those mills capable of using the technology. The latter class of mills is comparable to the rapidly growing and most environmentally intrusive private (or township and village enterprise) mills that were not in our sample. Either taxing or regulating the multitude of these smaller mills poses an exceptionally difficult administrative problem. Our evidence is further support for the government's decision to close the smallest polluting firms that failed to comply with the environmental standard.

Appendix 1. Definitions of Variables¹⁾

Variable	Definition
Dependent Variables	
1. Predicted Inputs	
WW	Wastewater emission in 1,000 cubic meters
COD	Total COD discharge in tons
TSS	Total TSS discharge in tons
E	Total energy use (standard coal equivalent) in 1,000 tons
ALK	Total alkali use in tons
2. Production Frontier	
VAL	Output evaluated in 1980 prices
3. Efficiency Analysis	
EFF	Inefficiency score
Independent Variables	
1. Predicted Inputs	
FD	Dummy variable for Fujian Province
T	Time
P	Average output price for each mill
K	Capital input (Depreciation + Maintenance fee)
L	Labor (number of employees)
TXR	Levy intensity (total levy charged/calculated levy liability)

Appendix 1. (Continued)

Variable	Definition
WD	Wood fiber dummy
NWD	Nonwood fiber dummy
BD	Dummy for bleach process
2. Production Frontier	
T	Time
T2	Time squared
K	Capital input (depreciation + maintenance fee)
L	Labor (number of employees)
PE	Predicted value of energy
PALK	Predicted value of alkali
PWW	Predicted value of wastewater discharge
PTSS	Predicted value of TSS
PCOD	Predicted value of COD
WD	Wood fiber dummy
NWD	Nonwood fiber dummy
BD	Dummy for bleach process
3. Efficiency Analysis	
T	Time
KR	Net capital stock/original capital stock
LR	Number of engineers/number of employees
ER	Amount of electricity used/coal (in standard coal)
TXR	Levy intensity (total levy charged/calculated levy liability)

Note: ¹⁾ All monetary values in yuan.

Appendix 2. Translog Production Frontier Coefficients

Variable	Estimate	Variable	Estimate	Variable	Estimate
ln K	1.393 [*] (1.831)	(ln K) ²	0.063 ^{***} (31.932)	(ln L)*(ln E)	0.196 (1.618)
ln L	1.771 (0.732)	(ln L) ²	0.313 ^{***} (14.606)	(ln L)*(ln PALK)	-0.554 ^{***} (-3.690)
ln PE	-0.864 (-0.217)	(ln PE) ²	-0.6315 ^{***} (-8.170)	(ln E)*(ln PALK)	1.446 ^{***} (4.018)
ln PALK	1.189 (0.272)	(ln PALK) ²	-0.695 ^{***} (-6.018)	WD	3.164 (0.471)
ln PWW	0.298 ^{***} (4.107)	(ln K)*(ln L)	-0.508 ^{***} (-18.684)	NWD	1.318 (1.031)
ln PTSS	3.471 (0.325)	(ln K)*(ln PE)	0.499 ^{***} (8.070)	BD	2.384 (0.418)
ln PCOD	-5.720 (-0.262)	(ln K)*(ln PALK)	-0.453 ^{***} (-6.186)		

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