Research Reports

China's Paper Industry: Growth and Environmental Policy During Economic Reform

by Jintao Xu[1]

1.0 INTRODUCTION

China began its program of economic reforms in 1978 and 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 China's 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. He announced the aggressive new policy that any enterprise not in environmental compliance by year 2000 would be closed.

The central government's position on the competing challenges of environment and development is pragmatic. It aggressively seeks growth but it also desires environmental protection. Its application of a system of pollution levies is the largest application of a market-based regulatory instrument in the developing world. Two questions have been central to all considerations of environmental policy: how severe is the pollution policy constraint on economic growth, and can economic instruments decrease pollution? The government has been willing to try various instruments for pollution control, and it has been willing to modify policy when the instrument of initial choice proves unsatisfactory. In the paper industry, for example, the government has used both standards and charges, closing small mills and taxing the effluents of larger mills. The relative merit of the two instruments is a topic of continued debate, although government confidence in the effectiveness of economic instruments to control pollution seems to be declining.

Our objective in this paper is to examine the pollution control policies applied for the paper industry. The paper industry is the source of 10 percent of China's industrial wastewater emissions and one-fourth of its chemical oxygen demand. It is the largest source of rural environmental pollution (Huang and Bai 1992).

We cannot examine pollution policy without also examining the industry's pattern of growth because the rapidly changing structure of the paper industry has its own effect on pollution. In general, the industry shares many experiences with the full manufacturing[2] 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 1978. The paper industry is a representative industry in these respects. However, each industry is characterized by its own patterns of input use and its own relationship between output growth and the production of environmental effluents. For the paper industry, some evidence suggests that growth in mill capacity is associated with a decline in effluent discharge, yet the expanding number of small paper mills is associated with an increase in pollution. Therefore, inducing some characteristics of growth in this industry may even be a desirable environmental policy, but the targets of such a policy would have to be identified clearly.

Most of the literature on China's industrial growth tend to be general to the full sector. Li (1997), Jefferson et al. (1996, 1992), and Jefferson and Xu (1994) examined improvements in aggregate performance since the reforms began. Wang et al. (1996) examined mill responsiveness to pollution charges regardless of industry specialization. In general, this literature reports increasing efficiency in factor use over time (Li 1997), convergence of the marginal revenue products of factors (Jefferson and Xu 1994), and the expected emission-reducing performance of pollution charges (Wang et al.). Nevertheless, the evidence remains sparse—and confirmation would be desirable. Jefferson (1990), for example, points out 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.

We addressed the data problem by collecting pollution information in our own survey of 34 paper mills and combining this with mill-level production data from the Council of Light Industries (CLI). The result is panel data for mills of various sizes and production categories from two representative provinces, Fujian and Yunnan, for the period 1982-1994. The mills are all state-owned or managed by collectives. These mill categories have been the main targets of the central government's industrial reforms and also its pollution control policies.[3] The period of our analysis incorporates most of the period of gradual industrial reform prior to the government's very recent decisions to increase the levy and to allow unprofitable mills to close and profitable mills to release surplus labor.

We used a three-stage procedure to estimate the effects of pollution levies on the emissions of environmental pollutants and on production efficiency. The first stage provided estimates of the endogenous factors of production, including those environmental factors targeted by the pollution levy. The second stage applied predicted values from the first stage, together with actual values for the exogenous factors, to estimate the production of conventional paper products. We estimated frontier production functions (Cornwell et al. 1990, Kumbhakar 1990) in order to obtain firm- and time-specific measures of technical efficiency. The third stage assessed the relationships between the mill-level efficiency scores taken from the second stage and other influential factors—with special attention to the affect of China's pollution levy on efficiency.

The first stage results showed that the system of pollution levies works. Pollution levies decreased the production of environmental effluents—and increasing the levies reinforced their favorable effect. We found no consistent evidence that the pollution levies decreased economic efficiency for most classes of mills, which is more or less consistent with the US experiences (Jafe et al. 1995) and should partially relieve the government's concerns when imposing environmental regulations to its rapidly growing industry. Yet we observed a substantial opportunity to increase efficiency through improved labor productivity. This observation is consistent with the government's recent decision to relax its policy of employment protection for workers in the larger state-owned mills. In addition, increasing returns to productive scale is plausible, and it would be consistent with a second recent government decision to close the most offending small mills.

2.0 BACKGROUND: MARKET REFORM AND CHINA'S PAPER INDUSTRY

Unlike China's agricultural and forestry reforms, which 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), China's industrial reforms began later, in 1984, and proceeded more gradually. The results, however, are no less impressive. 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 an increasing share of final output directly to the market), and
- urban reform—which permitted a private manufacturing sector to emerge.

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

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

The overall impact of combined industrial and financial reforms has been growth in the manufacturing sector at an average annual rate of 15 percent since 1978. The early years, until 1985, were characterized by output growth from more efficient use of inputs. Since 1985, more of the sector's growth has been due to the expanding consumption of inputs (Li 1997).

The government began addressing the problem of unprofitable mills in 1993 as a new move to maintain its commitment to growth. It now endorses external investment in some and allows others to go out of business. It also allows managers to release redundant labor.

Our production functions demonstrated just how critical the latter policy revision is for the paper industry. State-owned firms typically offer the best benefits—although not necessarily the best wages—and attract many of the best workers. Furthermore, until 1993, these firms had an obligation to hire local labor, as employment was a birthright for children of current employees. This obligation generated excess employment and redundant labor has been a serious drag on efficiency performance.

China's history of reforms made no specific distinctions for the paper industry, hence the later has followed general industrial and finance sector reforms. 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 three-fold increase in raw wood imports over the full decade. This created a coastal concentration of mills that are reliant on wood fiber. It also explains China's rapid specialization in printing and writing, packaging, and production of sanitary papers. Newsprint production has grown at a slower 6 percent annual rate because international competitors have a competitive advantage in the long fibers required for this technology (Almanac of China's Paper Industry 1993).

Following these industrial, financial, and trade reforms, China's modern paper industry features the Kraft pulping technology, producing both bleached and unbleached papers. This technology and two alternative raw materials (wood and non-wood fibers) are important to understanding pollution from the industry. The bleached process, used predominantly in the production of printing and writing paper, requires more additional chemicals and produces greater concentrations of undesirable effluents. The unbleached process, used predominantly for packaging material, is less environmentally intrusive.

Paper produced from wood fiber is associated with larger capacity mills—which require larger inventories of raw materials and larger storage facilities. This can mean more water for storage impoundments and more effluents. The pollution control technologies for these operations are well developed. China's industry, however, is dependent on non-wood fibers (largely agricultural residues) at a 3:1 ratio over wood fiber. Rapid agricultural growth since 1978 provided fiber for eight-fold growth in the production of smaller paper mills between 1984 and 1992 (Almanac of China's Paper Industry 1993). These smaller mills have been rapid innovators, but they remain 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 residues in the holding ponds and wastewater effluents of smaller mills. Smaller paper mills have been identified as the largest source of pollution in China's rural environment (State Council1997).

A comparison of mill capacity in China with the capacity in North America and Europe provides further perspective on the pollution management problem. Standard paper mills in North American and Europe have an annual capacity ranging from several hundred thousand to two million tonnes. In contrast, the capacity of the largest mill in China is only 250,000 tonnes and any mill over 30,000 tonnes is considered large. The large number of mills offsets their small average capacity. China has more than 1,000 state-owned and collective mills, and nine times as many other (private or township and village enterprise) operations, almost all with capacities under 10,000 tonnes. In contrast, Canada has only 115 paper mills but its total capacity is 25 percent greater than that of China (Almanac of China's Paper Industry 1993).

The large number of Chinese mills means that pollution monitoring and enforcement are more complex than in North America or Europe. The smaller size of China's mills suggests that entry and exit from the industry has been rapid—which also contrasts with the experience of large-capacity, high-fixed-cost North American and European operations.

This brings us to a final fundamental issue—China's pollution control policy. 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.

The instrument for administering pollution policy is simple. Their administration has been more complex, and that is one reason for the continuing debate about the instrument's effectiveness. 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 the 32 provinces, autonomous regions, and large municipalities has its own environmental agency, what began as a simple uniform system for taxing environmental emissions became a vast array of negotiated settlements. The environmental minister himself criticized the system for its variation in local applications and because the actual tax may often be too low to be effective (Qu 1991).

Finally, the central government added a new environmental policy instrument in 1996. It simply closed 4,000 small firms in 15 industries; 1,000 of these were paper mills. The government's current rule is to close all paper mills with annual capacity under 5,000 tonnes. Its has no other effective means to control effluents from these heaviest polluters.

3.0 THEORY AND ANALYTICAL ORGANIZATION

Our objective was to measure how environmental regulations enacted during China's economic reforms have affected mill-level efficiency in the mills, as well as the level of environmental waste. The method used was similar to recent econometric work with panel data by Cornwell et al. (1990) and Kumbhakar (1990). It was based on an analysis of covariance that assumes that the intercepts and some coefficients of the production function vary between firms and over time. Intertemporal changes in efficiency were critical because China's reforms were implemented gradually and adjustments in mill efficiency have surely 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).[4]

We followed a three-stage estimation procedure. In the first stage, prior to estimating the production function, we obtained predicted values (instruments) for the endogenous inputs in the production process:[5]

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

where X_{it} is a vector of endogenously determined inputs used by firm *i* at time *t*, X_{-it} is a vector of exogenous 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_{1it} is a stochastic error term. In addition to providing instruments for the second stage of our analysis, equation (1) will be important for assessing how input choices and environmental wastes have responded to environmental reforms and, specifically, to China's system of pollution levies.

Labor and durable capital were exogenous variables in our production function. In the period of our 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. The endogenous inputs to paper production included energy, chemicals, and environmental waste. 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.[6]

An extensive literature considers the endogeneity of pollution levies (Pargal and Wheeler 1996; Laplante and Rilstone 1996; Deily and Gray 1991, 1996; Dion et al. 1998). It observes that enforcement is sensitive to differences in regional economic development, public awareness, and environmental quality, but less sensitive to plant characteristics. These findings are reasonable because efficient pollution fees are related to regional preferences and assimilative capacity. This means they would be endogenous to the enforcement agency. They are exogenous, however, from the perspective of the firm and that is why the literature on endogeneity observes that fees are less sensitive to plant characteristics. Following this reasoning, we treated the pollution levy as exogenous for our firms.

In the second stage, we applied predicted inputs from the first stage to estimate a time series, cross-section production function of the form,

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

where Q_{it} measures output, $\hat{X}_{it}$ is a vector of predicted endogenous inputs, $\hat{W}_{it}$ is a vector of predicted environmental wastes, and β is a vector of parameters to estimate. Equation (2) separates environmental wastes from other endogenous inputs estimated in

Equation (1) only for emphasis and clarity in subsequent discussion.

In the third stage, we examined technical efficiency scores for different classes of firms. Efficiency scores can be predicted from the results of equations (1) and (2), and hypothesis tests can be performed on the efficiency scores to determine how they differ by classes of firms, how efficiency changes over time (and therefore, with the progress of China's reform policies), and how effective the pollution levy has been in encouraging improvements in efficiency. This last 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 (Oates et al. 1993).

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

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

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

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

where t is time (e.g., Cornwell et al. 1990, Kumbhakar 1990). In sum, technical efficiency depends on the class of firm and it follows a certain path of change over time.

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 three-step procedure recommended by Cornwell et al. (1990). The first step is to develop estimates for the two RHS terms in equation (3). An estimate for $\tilde{\tilde{\Gamma}}$ can be obtained by regressing Q on the appropriate functional specification for $\tilde{\tilde{\Gamma}}$. The residual of this regression (i.e., $Q_i - \hat{\beta} Z_{it}$), regressed on the RHS of equation (4), provides an estimate for γ 's. That is,

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

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

$$Q_{it} = \alpha_{it} + \tilde{\tilde{\Gamma}}(\hat{X}_{it}, X_{-it}, \hat{W}_{it}; \beta, \varepsilon_{2it}), \qquad (6)$$

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

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

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.

4.0 DATA

4.1 Production Data

The sources of our production data were the annual paper industry statistics and annual information briefs compiled by the Council of Light Industries (CLI, formerly the Ministry of Light Industries). These statistics and briefs report production 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 90 percent of China's papermaking capacity in the early 1980s. They comprise about 50 percent of the national capacity today.

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

Output weighted by 1980 prices was our summary measure of all production. Otherwise, we concentrated on physical measures because the personnel at CLI expect the physical data to be more reliable than price or cost data. The measure of capital was problematic because, for much of our 1982-1992 period of analysis, the government has not required state-owned firms to pay many capital costs. Our choice for a measure of capital was net capital stock. In China's accounting terminology, this was capital stock net of depreciation but unadjusted for inflation.[7]

4.2 Pollution Data

The sources of our pollution data were the firm-level accounts collected by local environmental agencies. These data 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 tonnes, and chemical oxygen demand in tonnes) from county offices in two southern provinces, Fujian and Yunnan. These provinces were selected partially because of the willingness of their environmental officials to assist us. The county agencies confirmed the reliability of these data with periodic random checks at each mill.[8] We reconfirmed any doubtful pollution data with mill managers themselves and with records kept at the mills.

Fujian is an industrial and coastal province. Among China's 32 provinces, it ranks in the mid-upper level in paper production. It also represents the advanced portion of China's paper industry that has been subject to a broader and longer exposure to government intervention because of its importance to the 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 40 percent of provincial production. This means that majority of the 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 paper mills but a couple of medium-sized operations. It is an average province in terms of its important resource inputs. Wood fiber-based production accounts for about 20 percent of the provincial total, a share that approaches the national average. Most mills in Yunnan, and the rest of the country, utilize agricultural residues and other locally available non-wood fiber resources.

We began with a complete survey of all the mills originally under CLI supervision. These included approximately 50 mills in Fujian and 40 mills in Yunnan. Some mills that were active in 1982 when the pollution levy was first implemented had become inactive by the time data were collected; some active mills provided only incomplete pollution data. We surveyed 17 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. A Chow test justified combining our production and pollution data from the two provinces.[9]

The CLI production data were complete between 1982 and 1992. The Fujian pollution data covered seven of 11 years in this period. However, the Yunnan pollution data, were complete only after 1986, hence, we applied a procedure recommended by Griliches (1986) to estimate the missing pollution data from 1982-1985. In this procedure, the 1986-1992 data were used to regress 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, were combined to predict the missing observations on emission levels.

4.3 The Pollution Levy

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.[10] The fee is charged if a pollutant exceeds a set minimum standard. If a factory discharges several pollutants, the levy is 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 a higher rate. Some do but, in fact, many charge at lower rates. In addition, local agencies also have the authority to return up to 80 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 these allowed us to examine how effluent levels, production of conventional outputs, and efficiency all change with respect to different levels of the levy rate.

Perhaps the best measure of the effective levy rate for any firm would be a ratio of the firm's net levies (after any reimbursement from the county's environmental agency) to the basic liability assessed according to the central government's pollution levy regulations. An increase in this ratio would be the equivalent of an increase in the levy on pollution. We calculated the denominator of this ratio from the central government's pollution levy tables and our firm-level pollution data. For the numerator we could only obtain 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 was an imperfect measure of the final effective levy rate for each firm, but we found out later that even this measure demonstrates that pollution levies are a disincentive to pollute and that higher levy rates (a larger ratio) are greater disincentives.

4.4 Are Fujian and Yunnan Representative?

Do data from Fujian and Yunnan characterize only those two provinces, or are they representative of production and pollution data for China in general? The most reliable comparison of these two provinces with all-China would be a comparison of the full Fujian-Yunnan production function with the all-China production function. Our lack of pollution data for all-China prevents this. Collecting effluent data for the rest of China's mills would also be an enormous task, hence, the limited sample.

Alternatively, we can compare Fujian and Yunnan's mills with mills from other provinces in terms of both their labor productivity and the physical productivity of their basic raw material inputs. Fujian's labor productivity is above the mean for all provinces but within a standard deviation of the mean for each year in our sample. Yunnan's labor productivity is below the mean but growing toward it, and it is always within a standard deviation of that mean. The average physical productivities of Fujian's and Yunnan's mills also fall within a standard deviation of the all-province mean for each of four major raw material inputs: unbleached chemical woodpulp, unbleached wood, imported pulp, and unbleached straw. (As expected, the average physical productivity of Fujian's mills exceeds the average physical productivity of Yunnan's mills for all four.)[11] These evidences are the bases of this study's argument that Fujian's and Yunnan's mills are representative of the production and pollution data for China in general.

5.0 EMPIRICAL RESULTS

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

The first stage of our empirical analysis was to estimate the endogenous inputs to production. The results from this stage became inputs for the assessment of the production function in the second stage. The first stage results were also the source of observations on the effects of environmental policy and economic reform on managers' decisions, especially the decision to pollute. Pollution is a component of these first two stages because mill managers have some control over the levels of effluents discharged from their mills and because we recall the convention to treat effluents as negative inputs to production.

Managerial decisions in state-owned and collective firms have been limited to decisions about variable inputs, essentially chemicals (*ALK* for alkali, the most important chemical) and energy (*E*), water, fiber, and unidentified abatement inputs. In our production analysis, the levels of discharge or concentration for wastewater (*WW*), total suspended solids (*TSS*), and chemical oxygen demand (*COD*) were instruments for decisions about abatement effort. This made five dependent variables and five regressions, each of which was 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" were output prices (*P*), time (*t*), and the basic production technologies associated with each mill. The time variable accounted for the overall effect of China's gradual industrial, financial, and trade reforms on pollution. Dummy variables distinguished bleach-using production processes (*BD*), and mills that are wholly reliant on either wood (*WD*) or non-wood (*NWD*) fibers. Another dummy variable distinguished mills in Fujian (*FD*) from mills in Yunnan.

The resulting regressions are of the form:

$$\ln X_{it} = \delta_0 + \delta_1 \ln K_{it} + \delta_2 \ln L_{it} + \delta_3 \ln TXR_{it} + \delta_4 \ln P_{it} + \delta_5 t + \delta_6 BD_i + \delta_7 WD_i + \delta_8 NWD_i + \delta_9 FD_i + \varepsilon_{1it} \quad (8)$$

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 1 reports the OLS coefficients for the three effluent regressions. The equation fits are satisfactory and most coefficients satisfy expectations.

Increasing amounts of either capital or labor increase the levels of all three effluents. (Four of six coefficients are statistically significant.) We recall that the levels of capital and labor are determined by central authority. Mill managers had little discretion over them in the period of our analysis. We might anticipate that increases in these two inputs 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. The labor variable is an important special case.)

Table 1. Effluent decisions[1]

Variable	Wastewater	TSS	COD
Constant	-0.6407 (-0.5132)	0.5808 (0.3353)	-2.8698 (-1.5705)
ln (capital)	0.1772 (1.6152)	0.0255 (0.1678)	0.2983 * (1.8582)
ln (labor)	1.0978 *** (7.4293)	1.4763 *** (7.2055)	1.0461 *** (4.8393)
ln (tax rate)	-0.2731 *** (-5.0255)	-0.4498 *** (-5.9668)	-0.6205*** (-7.8022)
ln (price)	-0.1587 (-0.9455)	-0.6629 *** (-2.8467)	-0.0835 (-0.3400)

T	0.0633 (1.3960)	0.1983 *** (3.1517)	0.1252 * (1.8869)
Dummies			
Bleach	0.2103 (1.2833)	-0.4681** (-2.0591)	0.3201 (1.3346)
Wood fiber	-0.1295 (-0.6803)	-0.1659 (-0.6283)	0.0491 (0.1764)
Non-wood fiber	-0.8112 *** (-3.4672)	0.1099 (0.3387)	-0.2474 (-0.7226)
Fujian	0.5024 *** (3.3622)	-0.1072 (-0.5172)	-0.7344 *** (-3.3575)
F(9,914)	60.08	32.3	31.65

[1] Numbers in parenthesis are t-statistics. ***, **, * indicate significance at the 1, 5, and 10 percent levels, respectively.

The pollution levy is a disincentive to pollute, and increases in the levy rate cause statistically significant decreases in the levels of all three pollutants.

Higher output prices should be an incentive for production. Since we expect pollution to increase with production, we also expect higher prices to increase the flow of environmental effluents. The contrary (negative) sign may reflect the opposite—adoption of better pollution control technologies and increasing recovery and re-use of some environmental wastes as prices increase. The statistical insignificance of the price terms leaves us uncertain regarding which argument dominates. However, statistical insignificance is not surprising if we recall that a substantial share of mill production was centrally allocated for most of the period of our analysis. Mill managers had discretion over some input decisions but the central government only gradually introduced a "dual track" of both centrally allocated and market allocated distribution of the final industrial products.

Time had a positive (and generally significant) relationship to pollution that we anticipated if it reflected growth in conventional outputs without corresponding improvements in pollution control technologies.

Bleach pulping processes use more chemicals than other production processes. While their COD emissions are greater, the effect is not statistically significant. Firms that are entirely reliant on wood fiber 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 indicates that probably 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 further indicates that the 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 further shows that there is no widespread use of pollution control technologies to this class of firms. In fact, we know that large firms practice flushing to address their problems with other effluents, a practice that increases wastewater effluents. The signs and significance of the Fujian dummy confirm this behavior.

The policy conclusions that emerge 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. China's general economic reforms led to increases in the conventional outputs of industrial production. The study shows that the 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, by first establishing a system of pollution levies, and then increasing these levies. The levies are a statistically significant disincentive for firms in China's paper industry to pollute the environment. The evidence in this study should remove any doubt about that question. But apparently the levies are not high enough to be an incentive for firms to adopt advanced pollution control technologies.[12] As the economy has continued to grow and as environmental quality has continued to deteriorate, the production of environmental pollutants has become an increasingly 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 toward a uniform centralized system. Perhaps it should increase the levy as well.

5.2 The Production Function

The second stage of our analysis was an assessment of the frontier production function. The estimated first-stage dependent variables were inputs to this function. The firm- and time-specific measures of efficiency that emerge from it became the data for our third stage assessment of the determinants of efficiency. Our observation of a negative marginal contribution for labor was a second interesting conclusion. This unusual result, its impact on pollution, and the government's policy response was closely examined.

We used a restricted translog specification of production in which there were no cross-effects for pollutants with pollutants. The restricted form eliminated the possibility that the pollutants (as negative inputs) might destroy the concave form 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 were capital, labor, and the two endogenous conventional inputs, energy and chemicals, estimated in the first stage. The next three were the negative environmental inputs, wastewater, TSS, and COD, which were also estimated as endogenous inputs in the first stage. The three dummy variables identified were all-wood, all non-wood, and bleach production processes. α_{it} was the efficiency scale for the i-th firm. The β_j, β_{jk}, and ϕ_j were parameters.

A second appendix table reports the estimated parameters. The equation statistics are satisfactory. All first-order coefficients except that on the energy input satisfy expectations (and the energy coefficient is insignificant). The second-order and cross effects are highly significant (with only one exception). These latter results 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 2 in the text summarizes the output and substitution elasticities calculated from these coefficients. The negative output elasticity for labor is the most interesting observation as it indicates that the marginal product of labor is negative. The last worker crowds productive earlier workers and actually causes total output to be less than it would have been if the last worker had not been hired.[13] This unusual result is more reasonable than it first seems. Employment has been a birthright for children of employees of state-owned firms. Before the recent trend to "privatization", collective-owned firms also followed a policy of employment security. After 50 years of state ownership, this policy has created excess employment in many firms. The problem became so great by the 1980s that mill managers commonly instructed some employees to stay home. Yet these unproductive workers continued to be paid. These managerial decisions are only consistent with an observation that marginal workers contributed negatively to a firm's total product.

Table 2. Production elasticities

Variable	Output elasticity	Alllen partial elasticities of substitutions					
		K	L	E	ALK	WW	TSS
Capital	0.8432						
Labor	-0.5906	0.9275					
Energy	2.7823	0.6937	0.9161				
Alkali	-2.2395	0.8375	0.8524	0.9386			
Wastewater	0.2983	0.2848	0.7205	0.8534	0.9159		
TSS	3.4708	0.2848	0.7205	0.8534	0.9159	0.6628	
COD	-5.7197	0.2848	0.7205	0.8534	0.9159	0.6628	0.6628

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 this constraint to growth and initiated a major policy change in 1995. Managers now have the authority to release excess workers, although they continue to pay a minimum monthly stipend to these released workers. Seventeen million workers, or more than one of every five from state-owned firms, were expected to be 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 observation. For example, the output elasticities show that the next unit of capital would be more productive than the last unit of labor. The positive substitution elasticities indicate that all inputs are substitutes with each other.[14] They show that it takes more labor than capital to substitute for another unit of the conventional energy and chemical inputs and still produce 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. 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, it is anticipated that China's new policy allowing managers to release excess workers will yield a double dividend by improving efficiency and maintaining growth (the policy objective), and also by 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 the managers' decisions to use purchased alkali excessively because of its very low relative price and budget effects. Alkali is used to separate useful fiber from residual raw material. Its over-use may allow managers to focus on what they perceive to be more costly components of the production process.[15]

Where pollution control is enforced, mills recover and re-use 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 over-use of the alkali input and the low incentive effect of COD levies on the adoption of pollution control technologies by bleach process mills.

The much larger capacity paper mills in more developed countries should raise curiosity regarding potential scale effects in China's mills. Normally, the sum of the output elasticities tells us about scale effects.[16] Our output elasticities are an underestimate 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, 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 to scale. 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.

Indeed, this raises the possibility of increasing return to scale (IRS) as a new question. IRS would suggest 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 first stage results 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 and bleach technology mills, 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 stages 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 is also consistent with our first- and second-stage regressions, if not with our initial expectations.

5.3 The Determinants of Productive Efficiency

The final stage of our analysis examined the determinants of change in productive efficiency. Improvements in productive efficiency might come from better quality capital or labor, or from improved energy inputs. We were particularly interested in whether the pollution levies also had an affect on technical efficiency. Table 3 shows the results of our regression analysis where the observations on the dependent variable are the declining mill-level inefficiency scores taken from Appendices 3 and 4. The first column of Table 3 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 original 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 the 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 same for all mill categories as they are for the full sample 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 the first stage) that higher levies decrease pollution, but will 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 in 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.

If increases in the levy decrease pollution but do 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. In fact, the government seems to have the same perception. It is experimenting with tradable permits, a more complex economic instrument for pollution control.[17]

Regarding the smaller, non-wood-fiber mills, which are the greatest polluters of the rural environment, enforcing pollution control responsibilities has proven to be 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.

Table 3. Efficiency analysis by mill categories

6.0 CONCLUSIONS

Three major conclusions emerge from our assessment of paper mills 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 levies decreased environmental emissions, and higher levies decreased emissions even more. Economic incentives worked. There is evidence, however, that the levies have not been high enough to induce even the most modern mills to adopt modern pollution control technologies. Therefore, we would hypothesize that higher pollution levies would be more effective yet. It is unclear how high the levies would have to be raised to induce technological improvements. This depends on the individual pollutants and their abatement costs. A nationwide survey in late 1980s on mill level abatement cost suggested that the levy should be doubled (NEPA 1996).

Second, the production function for paper generally demonstrates the anticipated positive relationship between conventional paper products and environmental emissions. It also demonstrates an unusual negative marginal product for labor and it raises the possibility of increasing returns to scale.

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.

The possibility of increasing returns to scale requires 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.

Third, the pollution levy has differential effects on the productive efficiency of different categories of mills. It increases productive efficiency in the most technologically advanced mills, but correlates with greater distances from the production frontier for the class of small mills that rely on non-wood fibers. The first provides further argument that increasing the levy would induce more adoption of modern pollution control technologies by those mills capable of using the technology. The pollution levy brings about Pareto improvement in the modern sector due to decreased emissions and enhanced efficiency. The second class of mills are comparable to the rapidly growing and most environmentally intrusive of private (or township and village enterprise) mills that were not in our sample. Either taxing or regulating the multitude of these small mills poses an exceptionally difficult administrative problem. Evidence from this study supports the government's decision to close 4,000 of them.

[1] I would like to thank David Newman, Runsheng Yin and Knox Lovell for their comments at the Productivity Workshop in Athens, Georgia, in November 1998; Zhong Ma, Shiqiu Zhang, Benoit Laplante, Jikun Huang, Bill Barron, Stein Hansen and David Glover for their comments at the biennial EEPSEA meetings in Singapore in November 1998 and May 1999; Tommy Hu Tao and Wendong Tao for their assistance in data collection; and Liya Li for her help with data entry and editing. Back

[2] The full manufacturing sector would include such industries as textile, iron and steel, pulp and paper, automobile, etc. Back

[3] In the course of 20 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. Back

[4] The large paper mills 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 paper mills 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). Back

[5] This is similar to a 2SLS approach where predicted values of endogenous variables are obtained prior to estimating the

production function. Kumbhakar (1990) discusses the problems of endogenous inputs and their consequences for estimations of the production frontier. Back

6 The alternative would be to estimate, first, 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 not available. Back

7 Jefferson, Rawski and Zheng (1996) reviewed this problem. They too prefer to use net capital stock for 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. Back

8 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 other provinces with poorer data were less willing to provide assistance. Back

9 The Chow-test compared the OLS version of frontier functions for the two provinces with data from 1986-1992, the years in which our data are complete. Comparing the Chow $F(7, 150)=0.3185$ with the critical value of 2.01 from the F table at the 95% confidence level, we cannot reject the hypothesis that the last seven slopes for regular production inputs and mill characteristics are equal for two separate estimations. Back

10 The levels of emissions are self-reported by the polluting firms and the monitoring team within the local environmental agency conducts random checks for the accuracy of the reporting. Misreporting of emission level may result in penalties to the firm in the forms of fine and/or increased levy rate. Back

11 Tables and statistics available from the author Back

12 This concurs with the general criticisms toward the levy system. The environmental authority in China favors the adoption of the end-of-pipe facility in pollution control, but the investment often is too high a financial burden to a large number of small paper mills. Hence if there is ever any effort in pollution reduction, it is more often happening in-the-process, namely, firms putting more energy in the efficient use of materials and/or making internal adjustment to reduce waste emissions. This may reduce conventional output due to productive inputs being transferred to the abatement process. Back

13 Various estimates of production with alternative functional forms all yield similar negative and significant marginal products of labor. Back

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

15 This would be similar to the over-use of pesticides and fertilizer by many American farmers (Carlson and Wetzstein 1993). Back

16 An initial estimation with a Cobb-Douglas specification did show increasing returns to scale. Results available from the author. Back

17 The impact of a system of tradable permits on the mills in this sample is the topic of another chapter of the dissertation. Back

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Appendices

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dglover@idrc.org.sg | 21 June 2000

APPENDICES

Appendix Table 1. Definitions of variables

Variable	Definition
Dependent Variables	
1. Predicted inputs	
WW	Wastewater emission in 1,000 m^3
COD	Total COD discharge in tonnes
TSS	Total TSS discharge in tonnes
E	Total energy use (standard coal equivalent) in 1,000 tonnes
ALK	Total alkali use in tonnes
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)
T x R	Levy intensity (total levy charged/calculated levy liability)
WD	Wood fiber dummy
NWD	Non-wood 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
	Predicted value of wastewater discharge
	Predicted value of TSS

PWW PTSS PCOD WD NWD BD	Predicted value of COD Wood fiber dummy Non-wood fiber dummy Dummy for bleach process
3. Efficiency analysis t KR LR ER T x R	time Net capital stock/original capital stock Number of engineers/number of employees Amount of electricity used/coal (in standard coal) Levy intensity (total levy charged/calculated levy liability)

Appendix Table 2. Translog production frontier coefficients

Variable	Estimate	Variable	Estimate	Variable	Estimate
ln K	1.3931 * (1.8306)	$(\ln K)^2$	0.0634 *** (31.9319)	(ln L)*(ln E)	0.1958 (1.6175)
ln L	1.7709 (0.7316)	$(\ln L)^2$	0.3128 *** (14.6056)	(ln L)*(ln PALK)	-0.5537 *** (-3.6898)
ln PE	-0.8642 (-0.2167	$(\ln PE)^2$	-0.6315 *** (-8.1703)	(ln E)*(ln PALK)	1.4463 *** (4.0178)
ln PALK	1.1894 (0.2715)	$(\ln PALK)^2$	-0.6949 *** (-6.0175)	WD	3.1642 (0.4707)
ln PWW	0.2983 *** (4.1070)	(ln K) * (ln L)	-0.5079 *** (-18.6838)	NWD	1.3181 (1.0310)
ln PTSS	3.4708 (0.3249)	(ln K) * (ln PE)	0.4991 *** (8.0699)	BD	2.3839 (0.4181)
ln PCOD	-5.7197 (-0.2620)	(ln K)*(ln PALK)	-0.4530 *** (-6.1862)		

Numbers in parenthesis are t-statistics. ***, **, * indicate significance at the 1, 5, and 10 percent levels, respectively.

Appendix Table 3. Efficiency scores for paper mills in Fujian

	Mill 1 (L, W)	Mill 2 (L, B, W)	Mill 3 (L, B, W)	Mill 4	Mill 5 (L, B)	Mill 6 (B)	Mill 7 (L, B)	Mill 8 (L, B)	Mill 9 (W)
1992	0.3545	0	1.8741	3.8470	2.2496	3.2486	2.6949	3.3597	4.9978
1990	2.0034	1.3947	2.6133	4.6727	3.5015	4.8431	3.9566	3.8319	5.3868
1989	3.4832	2.7305	3.4219	5.5884	4.8874	6.3362	5.2009	4.4989	6.0014
1987	4.7940	4.0074	4.2999	6.5940	6.4074	7.7280	6.4276	5.3608	6.8716
1986	5.9356	5.2255	5.2472	7.6896	8.0614	9.0184	7.6368	6.4174	7.9674
1985	6.9082	6.3848	6.2639	8.8752	9.8495	10.2074	8.8286	7.6690	9.2989
1982	7.7117	7.4851	7.3499	10.1507	11.7716	11.2951	10.0028	9.1153	10.8659

	Mill 10 (W)	Mill 11 (W)	Mill 12 (W)	Mill 13 (W)	Mill 14 (L, B)	Mill 15 (L, B, W)	Mill 16 (L, B)	Mill 17 (B)
1992	4.4624	3.5398	5.5262	4.3415	1.8758	2.1132	2.4230	3.5572
1990	5.4544	4.6443	6.5089	5.9855	3.1877	3.4248	3.6692	4.5367
1989	6.4806	5.8066	7.5123	7.4995	4.5522	4.7718	4.9055	5.5652
1987	7.5409	7.0267	8.5362	8.8834	5.9693	6.1543	6.1318	6.6425
1986	8.6354	8.3045	9.5807	10.1374	7.4390	7.5722	7.3482	7.7687
1985	9.7642	9.6402	10.6459	11.2613	8.9614	9.0255	8.5547	8.9437
1982	10.9271	11.0336	11.7316	12.2553	10.5364	10.5143	9.7512	10.1677

Codes: L = large or capacity over 5,000 tonnes annual capacity; B = bleach; W = wood; and NW = non-wood

Appendix Table 4. Efficiency scores for paper mills in Yuman

	Mill 18 (B)	Mill 19 (B)	Mill 20 (L)	Mill 21 (B)	Mill 22 (L, B)	Mill 23 (B)	Mill 24 (B, W)	Mill 25 (L, B, W)	Mill 26 (B, W)
1992	3.1427	3.1039	2.2295	3.4573	2.2915	4.5222	2.2326	3.5675	3.1091
1990	4.2695	4.7167	3.3159	4.3521	3.5110	5.6904	3.3843	4.5691	4.3700
1989	5.4082	6.1972	4.4581	5.3116	4.7036	6.8374	4.5427	5.6657	5.5855
1987	6.5590	7.5454	5.6562	6.3360	5.8694	7.9632	5.7078	6.8570	6.7556
1986	7.7217	8.7613	6.9103	7.4250	7.0083	9.0680	6.8794	8.1433	7.8803
1985	8.8964	9.8450	8.2202	8.5789	8.1203	10.1516	8.0577	9.5244	8.9597
1982	10.0831	10.7964	9.5859	9.7975	9.2054	11.2141	9.2426	11.0003	9.9936

	Mill 27 (B)	Mill 28 (L, W)	Mill 29 (W)	Mill 30 (B)	Mill 31 (L,B,W)	Mill 32 (W)	Mill 33	Mill 34
1992	2.0799	1.9378	4.7398	4.8897	2.1094	4.0728	3.3768	5.7077
1990	3.4161	3.3898	5.7152	5.9939	3.2253	5.0843	4.4509	6.1841
1989	4.7233	4.7402	6.7738	7.0660	4.3590	6.1672	5.5727	6.8993
1987	6.0014	5.9890	7.9155	8.1062	5.5105	7.3216	6.7421	7.8536
1986	7.2504	7.1361	9.1404	9.1145	6.6797	8.5474	7.9591	9.0469
1985	8.4703	8.1816	10.4485	10.0907	7.8666	9.8447	9.2236	10.4791
1982	9.6611	9.1255	11.8398	11.0350	9.0713	11.2134	10.5359	12.1503

Codes: L = large or capacity over 5,000 tonnes annual capacity; B = bleach; W = wood; and NW = non-wood

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Table 3. Efficiency analysis by mill categories[1]

Variable	Full Sample	Large	Small	Wood Fiber	Non-wood Fiber	Bleach	Non-bleach	Fujian	Yunnan
Constant	3.616*** (4.2999)	-1.6061 (-1.1599)	7.0011*** (-1.1599)	3.2840** (2.2300)	3.0581*** (2.7075)	3.7014*** (3.4496)	4.8140*** (3.3856)	5.8610*** (3.4634)	2.5460** (2.3202)
ln (Net Capital Ratio)	1.1698*** (2.49118)	0.0972 (0.1156)	0.0972 (0.1156)	2.4308*** (3.0219)	0.3199 (0.5628)	0.5069 (0.9111)	1.9385** (2.2955)	4.1801*** (3.8446)	0.7022 (1.5533)
ln (Engineer Ratio)	-1.1347*** (-5.0110)	-2.5061*** (-5.8016)	-2.5061*** (-5.8016)	-1.3293*** (-3.7020)	-1.2792*** (-4.0377)	-1.2445*** (-4.5384)	-0.9203** (-2.3770)	-0.8039* (-1.8864)	-1.4895*** (-5.2304)
ln (Electricity Ratio)	-1.4287*** (-2.5749)	-1.5327*** (-2.6439)	-1.5327*** (-2.6439)	-2.3063* (-1.9005)	-0.9948 (-1.6377)	-3.6344 (-3.1976)	-1.0527 (-1.6272)	-3.6528** (-2.3324)	-1.0356** (-1.9611)
ln (Levy Intensity)	-0.0002 (-0.0014)	-0.0814 (-0.3377)	-0.0814 (-0.3377)	-0.4785** (-2.5245)	0.4297** (2.3734)	0.1552 (0.8902)	-0.0736 (-0.3830)	-0.8085*** (-4.5996)	0.7388*** (4.6498)
	F (4,233) = 9.442	F (493) = 8.92	F (4,135) = 2.69	F (4,107) = 10.17	F (4,121) = 4.76	F (4,142) = 8.43	F (486) = 3.10	F (4,114) = 14.05	F (4,114) = 11.24

[1] Numbers in parenthesis are t-statistics. ***, **, * indicate significance at the 1, 5, and 10 percent levels, respectively.

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