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

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(ABSTRACT)

This dissertation examines the performance of China's pulp and paper industry under environmental regulations, and reflects on the implementation of the regulations, and especially on market-based instruments. The dissertation includes two empirical chapters: one uses a frontier production function model to examine the impact of China's environmental policy on paper mills' environmental as well as efficiency performance; the other derives shadow prices for pollutants for the same group of mills, based on a distance function model, to examine the efficiency performance of current pollution control policy and the degree of regional variation in the policy enforcement. The basic conclusion from the first empirical chapter is that the economic instrument-pollution levy system-can be an effective tool in inducing polluting mills to abate their pollution, and there is no strong evidence that the instrument adversely affected the mills' efficiency performance. The reason that the pollution problem is not lessening over time can be largely attributed to allocative inefficiency and regional disparity in policy enforcement, as is demonstrated by the second empirical chapter. These results should point future policy in the direction of better enforcement and/or the trial of a tradable permit system.

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Chapter 1

Introduction

China's economic reform over two decades is a success, but environmental cost is also enormous. A large share of its river-sheds is close to biological death, due to industrial and non-industrial pollution (Dasgupta, et al, 1997b). Chinese government has been seeking ways to curb the deterioration of the environment. The first legislation addressing water and air pollution was passed in 1979, with a series of acts and regulations followed. A pollution levy system was tried out in 1980 and imposed nationwide in 1982. The rate of levy was later raised by 40% in 1992. Due to lack of evidence that the levy system was effective in inducing polluting firms, especially small polluting firms to adopt pollution abatement practices, the government initiated a nationwide campaigns lately to eliminate those small firms which failed to abate pollution by a given deadline.

The main criticism toward the levy system is that the rate was too low to have any effect and even that there was large variation in the enforcement across locations, partially due to the perceived conflict between pollution control and local economic goals (Qu, 1991). Florig et al. (1995) suggested that the levy's impact must be small because of the way the levy system was designed and implemented, and the insignificance of the levy relative to firms' production costs and pollution abatement costs. Therefore, a change of policy (higher rate, concentration-based levy toward load-based levy, tradable permit, etc.) and direct involvement of central government are warranted.

1.1 Economic Questions

While these criticisms were important for policy discussion, they were largely based on anecdotes or arbitrary assumptions about emissions and cost parameters (Wang and Wheeler, 1999). Recent studies by Wang and Wheeler (1996, 1999) based on provincial and firm level data, found that water pollution has responded significantly to the pollution levy.

Our study intends to bring rigorous empirical evidence to bear on three questions. The first is a continuation of Wang and Wheeler's inquiry into the question of whether or not the levy system was an effective instrument in inducing polluting firms to abate emissions. The second question has to do with how the levy system has affected the economic performance of the firms. The third question has to do with the potentially differential regional pattern of enforcement of the levy system.

1.2 Prior Analyses

Empirical assessments of the effectiveness of China's levy system are sparse, although the levy system is the largest application of a market-based regulatory instrument in the developing world (Wang and Wheeler, 1999). A group of World Bank environmental economists made a unique contribution to the understanding of the levy system. Their work focuses on two related issues: the determinant of differences in enforcement of the pollution levy across regions and the impact of pollution charges on industry's environmental performance. The former is related to the incidence of "endogenous enforcement" of pollution control policy pervasive in developing countries. They found that in China the levy enforcement was sensitive to differences in economic development, public awareness and environmental quality, but less sensitive to plant-specific characteristics (Dasgupta et al. 1997a, Pargal and Wheeler, 1996; Hettige, Huq, Pargal and Wheeler, 1996; Hartmen, Huq and Wheeler, 1996, Wang and Wheeler, 1999). In a separate inquiry, Yun Ping (1997) found that the actual rate of pollution charge was related to the distributional structure of the levy income.

On the issue of policy effectiveness, Dasgupta et al. (1996) constructed an abatement cost function to show that marginal abatement costs in China were much lower than previously supposed. Wang and Wheeler (1996, 1999) used a system of pollution charge response and pollution intensity responses to demonstrate that the level of water pollutant discharges has responded significantly to the pollution levy.

The issue of efficiency and productivity improvement for China's public-owned industries has been an important topic in development economics literature. Jeffereson, Rawski, Zheng and Xu's research has a central role in literature. Jeffereson and Xu

(1994) showed that market-oriented reform had led to the convergence of factor returns across industrial enterprises in China, an indication of increased economic efficiency. Jeffereson, Rawski and Zheng (1996), and Li (1997) both found evidence of productivity growth in Chinese public-owned industry in 1980's and early 1990's.

However, there is no literature that combines an examination of environmental performance with an examination of efficiency performance for Chinese firms. Jaffe et al. (1995) examined the literature on the impact of environmental regulation on U.S. manufacturing competitiveness. They found that there was little evidence to support the hypothesis that environmental regulations had had a large adverse effect on competitiveness. This dissertation research is the first attempt to examine the two related issues in China simultaneously within the same analytical framework.

1.3 Our Approach and Research Questions

This dissertation examines the performance of China's pulp and paper industry under environmental regulations, and reflects on the implementation of the regulations, especially market-based instrument. The study is based on a panel of 34 state and collective mills from two of China's southern provinces, Fujian and Yunnan. The data covers a period from 1982, the year the pollution levy was formally implemented on national scale, to 1992, the year that the level of pollution charge was raised based on revised estimate of the average abatement cost. The dissertation includes two empirical chapters:

The first empirical chapter (Chapter 2) examines the impact of the levy system a) on the paper mills' pollution control behavior and b) on their efficiency performance. This chapter is based on a stochastic frontier production model. The study adopts a three-step estimation approach. The first step provides predicted values for endogenous inputs (including pollutants). It also serves as a vehicle to examine the relationship between pollution levy and pollutant discharges. The second step uses the predicted values of endogenous inputs as well as the actual values of exogenous inputs to estimate a frontier production function using analysis of covariance estimation approach. Firm- and time-specific efficiency measures were derived based on the estimates of the function. The third step examines the relationship between firms' efficiency performance and other influential factors, especially the pollution levy intensity variable.

The purpose of the second empirical chapter (Chapter 3) is still to examine the effectiveness of current pollution control policy, but from a different perspective. It adopts a totally different approach, a distance function model with linear programming estimation, to derive two types of shadow prices. One, called the revenue-based shadow price, represents the opportunity cost of firms for a unit reduction of pollutant emission in terms of foregone revenue. The other, called the output-based shadow price, represents opportunity cost of firms for a unit reduction pollutant emission in terms of foregone physical output. The revenue-based shadow prices can be used to examine the allocative efficiency in pollution abatement under current policy. The small variation and convergence of these shadow prices would indicate that current policy is leading to an efficient allocation of resources in pollution control. Changes in the level of output-based shadow prices will be used to indicate the change of level of pollution discharges.

A lack of empirical evidences on the effectiveness of pollution levy system is causing the central government to consider several lines of policy renovation. The first is forceful closure of small polluting mills, the second is raising the rate of pollution charges, the third is an experiment with tradable permits, and the fourth is centralizing the pollution control administration. Forceful closure of small mills has to be based on the evidence that these mills were inefficient and that they failed to react to current levy system. Raising pollution charge rate should be supported by the revised estimation of marginal abatement cost. Tradable permit should address the issue of differential abatement cost. Centralization of the environmental administration should be based on the fact that there were large variation in the local enforcement of pollution control policy. Our research in the two empirical chapters at least partially provides evidence for these policy revisions.

The final chapter of this dissertation reviews the empirical findings, considers their broader applications and limitations, and recommends areas for further research efforts.

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Chapter 2

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

2.1 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 chapter is to examine the pollution control policies applied for the paper industry. 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 (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 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 papermills 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 tends 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), convergence of the marginal revenue products of factors (Jefferson and Xu), 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 papermills and combining this with mill-level production data from the Council of Light Industries. The result is panel data for mills of various size and production categories from two representative provinces, Fujian and Yunnan, for the period 1982-1994. Our 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.[1] 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 will use a three-stage procedure to estimate the effects of pollution levies on the emissions of environmental pollutants and on production efficiency. The first stage provides estimates of the endogenous factors of production, including those environmental factors targeted by the pollution levy. The second stage applies predicted values from the first stage, together with actual values for the exogenous factors, to estimate the production of conventional paper products. We will estimate frontier production functions (Cornwell *et al*. 1990, Kumbhakar 1990) in order to obtain firm- and time-specific measures of technical efficiency. The third stage assesses 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 will show that the system of pollution levies works. Pollution levies decrease the production of environmental effluents—and increasing the levies reinforces their favorable effect. We will find no consistent evidence that the pollution levies decrease economic efficiency for most classes of mills, which is similar

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[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.

to the US experiences (Jaffe et al., 1995) and should partially relieve the government's concern when imposing environmental regulations to its rapid growing industry. Yet we will observe 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.

2.2 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 begun talking of a market economy and it began allowing the reform of many state-owned firms, including the sale of some state-owned firms and foreign investment in others. Nevertheless, the government continues to be 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 fifteen 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 new means of maintaining 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 will demonstrate 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. We can anticipate that this obligation generated excess employment and that redundant labor has been a serious drag on efficiency performance.

China's history of reforms made no specific distinctions for the paper industry and 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 mills 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 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 material 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 papermills 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 residue in the holding ponds and wastewater effluents of smaller mills. Smaller papermills have been identified as the largest source of pollution in China's rural environment (State Council, 1997).

A comparison of mill capacity in China with capacity in North America and Europe provides further perspective on the pollution management problem. Standard 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 considered large. The large number of mills offsets their small average capacity. 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. In contrast, all of Canada has only 115 paper mills but total Canadian capacity is 25 percent greater than total Chinese capacity (Almanac of China's Paper Industry 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 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 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 4000 small firms in fifteen industries; 1000 of these were papermills. The government's current rule is to close all papermills under 5000 tons of annual capacity. Its has no other effective means to control effluents from these heaviest-of-all polluters.

2.3 Theory and Analytical Organization

Our objective is 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 we will adopt is similar to recent econometric work with panel data by Cornwell *et al.* (1990) and Kumbhakar (1990). It is based on an analysis of covariance that assumes the intercepts and some coefficients of the production function vary between firms and over time. Intertemporal changes in efficiency are critical for our case since China's reforms have been 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).[2]

We will follow a three-stage estimation procedure. In the first stage, prior to estimating the production function, we will obtain predicted values (instruments) for the endogenous inputs in the production process:[3]

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

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, eq. (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 are 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 include 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

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[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] 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.

and non-abatement inputs affects output, measures of emissions serve as instruments for the endogenous abatement decisions of the firm.[4]

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 will treat the pollution levy as exogenous for our firms.

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

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

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. [Eq. (2) separates environmental wastes from other endogenous inputs estimated in eq. (1) only for emphasis and clarity in subsequent discussion.

In the third stage, we will examine technical efficiency scores for different classes of firms. Efficiency scores can be predicted from the results of eqs. (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

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[4] 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 unavailable to us.

conceptual work that compares pollution control innovations induced by price or quantity instruments (Baumol and Oates 1988).

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

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

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

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

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 eq. (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 eq. (3). An estimate for $\tilde{\Gamma}$ can be obtained by regressing Q on the appropriate functional specification for $\tilde{\Gamma}$. The residual of this regression (*i.e.*, $Q_i - \hat{\beta}Z_{it}$), regressed on the RHS of eq. (4), provides an estimate for γ's. That is,

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

where Z_{it} is a new vector that summarizes all explanatory variables in $\tilde{\Gamma}$ 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,

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

where the $\hat{\gamma}$'s are estimated parameters from eq. (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,

$$\mu_{it} = \mu_{\max} - \hat{\alpha}_{it} \tag{7}$$

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.

2.4 Data

2.4.1 Production Data

The sources of our production data are 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 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 (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 will be our summary measure of all production. Otherwise, we will concentrate on physical measures because personnel at CLI expect the physical data are more reliable than price or cost data. The measure of capital is 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 is net capital stock. In China's accounting terminology, this is capital stock net of depreciation but unadjusted for inflation.[5]

2.4.2 Pollution Data

The sources for our pollution data are 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 tons, and chemical oxygen demand in tons) from county offices in two southern provinces, Fujian and Yunnan. These provinces were selected partially because environmental officials were willing to assist us. The county agencies confirm the reliability of these data with periodic random checks at each mill.[6] And where doubt remained, we reconfirmed the pollution data with mill managers themselves and with records kept at the mills.

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. 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. It is an average province in terms of its important resource inputs. Wood fiber-based production accounts for about twenty percent of the provincial total, a

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[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.

[6] 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.

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, 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. A Chow test justified combining our production and pollution data from the two provinces.[7]

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.

2.4.3 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[8]. 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

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[7] 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.

[8] 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.

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 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 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 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 is an imperfect measure of the final effective levy rate for each firm, but we will find that even this measure demonstrates that pollution levies are a disincentive to pollute and that higher levy rates (a larger ratio) are greater disincentives.

2.4.4 Are Fujian and Yunnan Representative?

Our data are now complete, but are they 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 our 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 be an enormous task. Indeed, this is the reason our sample is limited.

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.)[9] We will base an argument that Fujian's and Yunnan's mills are representative on this evidence.

2.5 Empirical Results

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

The first stage of our empirical analysis is an estimate of the endogenous inputs to production. The results from this stage will become inputs for the second stage assessment of the production function itself. The first stage results will also be 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*) will be instruments for decisions about abatement effort. This makes five dependent variables and five regressions, each of which is a function of the firm's exogenous inputs; capital (*K*), labor

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[9] Tables and statistics available from the author.

(*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:

$$\begin{aligned}\ln X_{it} &= \delta_0 + \delta_1 \ln K_{it} + \delta_2 \ln L_{it} + \delta_3 \ln TXR_{it} + \delta_4 \ln P_{it} \\ &+ \delta_5 t + \delta_6 BD_i + \delta_7 WD_i + \delta_8 NWD_i + \delta_9 FD_i + \varepsilon_{1it}\end{aligned} \tag{8}$$

where the δs 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 2.1 reports the OLS coefficients for the three effluent regressions. The equation fits are satisfactory and we can see that 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. We will see that the labor variable is an important special case.)

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

Table 2.1: Effluent Decisions[1]

Variable	Wastewater	TSS	COD
Constant	-0.6407	0.5808	-2.8698
	(-0.5132)	(0.3353)	(-1.5705)
ln (capital)	0.1772	0.0255	0.2983 *
	(1.6152)	(0.1678)	(1.8582)
ln (labor)	1.0978 ***	1.4763 ***	1.0461 ***
	(7.4293)	(7.2055)	(4.8393)
ln (tax rate)	-0.2731 ***	-0.4498 ***	-0.6205***
	(-5.0255)	(-5.9668)	(-7.8022)
ln (price)	-0.1587	-0.6629 ***	-0.0835
	(-0.9455)	(-2.8467)	(-0.3400)
t	0.0633	0.1983 ***	0.1252 *
	(1.3960)	(3.1517)	(1.8869)
dummies			
bleach	0.2103	-0.4681**	0.3201
	(1.2833)	(-2.0591)	(1.3346)
wood fiber	-0.1295	-0.1659	0.0491
	(-0.6803)	(-0.6283)	(0.1764)
non-wood fib	-0.8112 ***	0.1099	-0.2474
	(-3.4672)	(0.3387)	(-0.7226)
Fujian	0.5024 ***	-0.1072	-0.7344 ***
	(3.3622)	(-0.5172)	(-3.3575)
F(9,194)	60.08	32.3	31.65

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

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 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 their COD emissions to be greater. They are, but 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 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 opposite, 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 yet additional support for the contention that there is no widespread use of the pollution control technologies 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 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. We know that China's general economic reforms led to increases in the conventional outputs of industrial production. Our evidence supports the argument 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, first establishing a variably administered system of pollution levies, and then increasing these levies. The levies are a statistically significant disincentive to pollute for firms in China's paper industry. Our evidence 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[10]. 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 1997). 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.

2.5.2 The Production Function

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

We will use a restricted translog specification of production 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 concave form of the function.

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

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[10] 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 in China. 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 make the reduction of waste emissions possible. This may cause the reduction of conventional output due to productive inputs being transferred to the abatement process.

The first four inputs are capital, labor, and the two endogenous conventional inputs, energy and chemicals, estimated in the first stage. The next three are the negative environmental inputs; wastewater, TSS, and COD; which were also estimated as endogenous inputs in the first stage. 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. 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 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 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 2.2: Production Elasticities

	Output	Allen partial elasticities of substitution					
Variable	Elasticity	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			
wastwater	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

Table 2.2 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 productive earlier workers and actually causes total output to be less than it would have been if the last worker had not been hired.[11] This unusual result is more reasonable than it first seems. We reported that employment has been a birthright for children of employees of state-owned firms. (Before the recent trend to "privatization", collective-

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[11] Various estimates of production with alternative functional forms all yield similar negative and significant marginal products of labor.

owned firms also followed a policy of employment security.) After fifty 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 managers continued to pay these unproductive workers. These decisions are only consistent with an observation that marginal workers contributed negatively to a firm's total product.

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 with 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 released workers even under the new policy. 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 2.2 demonstrate the effect of this unusual 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 with each other.[12] 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, we anticipate that

China's new 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.[13]

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.

The much larger capacity papermills 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.[14] 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.

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[12] 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).

[13] This would be similar to the overuse of pesticides and fertilizer by many American farmers (Carlson and Wetzstein 1993).

[14] An intitial estimation with a Cobb-Douglas specification did show increasing returns to scale. Results available from the author.

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 eqs. (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 too is consistent with our first- and second-stage regressions, if not with our initial expectations.

2.5.3 The Determinants of Productive Efficiency

The final stage of our analysis examines 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 are particularly interested in whether the pollution levies also have an affect on technical efficiency. Table 2.3 shows the results of our regression analysis where the observations on the dependent variable are the declining mill-level inefficiency scores taken from appendices 2.3 and 2.4. The first column of table 2.3 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 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.

Table 2.3: Efficiency Analysis by Mill Categories[1]

Variable	Full Sample	Large	Small	Woodfiber	Nonwoodfiber
Constant	3.616***	-1.6061	7.0011***	3.2840**	3.0581***
	(4.2999)	(-1.1599)	(5.6284)	(2.2300)	(2.7075)
ln (Net Capital Ratio)	1.1698***	0.0972	1.6054***	2.4308***	0.3199
	(2.4918)	(0.1156)	(2.9316)	(3.0219)	(0.5628)
ln (Engineer Ratio)	-1.1347***	-2.5061***	-0.3168	-1.3293***	-1.2792***
	(-5.0110)	(-5.8016)	(-1.1374)	(-3.7020)	(-4.0377))
ln (Electricity Ratio)	-1.4287***	-1.5327***	-0.7518	-2.3063*	-0.9948
	(-2.5749)	(-2.6439)	(-0.4081)	(-1.9005)	(-1.6377)
ln (Levy Intensity)	-0.0002	-0.0814	0.0769	-0.4785**	0.4297**
	(-0.0014)	(-0.3377)	(-0.5196)	(-2.5245)	(2.3734)
	F(4,233)=9.442	F(4,93)=8.92	F(4,135)=2.69	F(4,107)=10.17	F(4,121)=4.76
Variable	Bleach	Nonbleach	Fujian	Yunnan	
Constant	3.7014***	4.8140***	5.861***	2.5460**	
	(3.4496)	(3.3856)	(3.4634)	(2.3202)	
ln (Net Capital Ratio)	0.5069	1.9385**	4.1801***	0.7022	
	(0.9111)	(2.2955)	(3.8446)	(1.5533)	
ln (Engineer Ratio)	-1.2445***	-0.9203**	-0.8039*	-1.4895***	
	(-4.5384)	(-2.3770)	(-1.8864)	(-5.2304)	
ln (Electricity Ratio)	-3.6344***	-1.0527	-3.6528**	-1.0356**	
	(-3.1976)	(-1.6272)	(-2.3324)	(-1.9611)	
ln (Levy Intensity)	0.1552	-0.0736	-0.8085***	0.7388***	
	(0.8902)	(-0.3830)	(-4.5996)	(4.6498)	
	F(4,142)=8.43	F(4,86)=3.10	F(4,114)=14.05	F(4,114)=11.24	

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

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. Moreover, it is expected that the instrument bring about Pareto improvement to the modern sector. In fact, the government is acting as if it has the same perception. It is experimenting with tradable permits, a more complex economic instrument for pollution control.

Regarding the smaller, non-wood-fiber mills: We previously indicated that these mills are the greatest polluters of the rural environment. Enforcing pollution control responsibilities on the many and 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.

2.6 Conclusions

Three 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 levies decreased environmental emissions, and higher levies decreased emissions even more. Economic incentives worked. There is evidence, however, that the levies have not been great 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, increasing productive efficiency in the most technologically advanced mills, but correlating 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 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. For the Chinese government that strives for environmental protection but also has to be sensitive to economic development, upgrading its paper industry will be a sensible strategy. Our evidence is further support for the government's decision to close the small polluting firms that failed to comply with the environmental standard.

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Appendices

Appendix 2.1: Definitions of Variables *

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)
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	Preducted 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)

* All monetary values in yuan.

Appendix 2.2: 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 PAL	-0.5537 *** (-3.6898)
ln PE	-0.8642 (-0.2167)	(ln PE)^2	-0.6315 *** (-8.1703)	(ln E)*(ln PAL	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 PAL	-0.4530 *** (-6.1862)		

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

Appendix 2.3: Efficiency Scores for Paper Mills in Fujian

	Mill1(L,W)	Mill2(L,B,W)	Mill3(L,B,W)	Mill4	Mill5(L,B)	Mill6(B)	Mill7(L,B)	Mill8(L,B)	Mill9(W)	Mill10(W)	Mill11(W)	Mill12(W)	Mill13(W)	Mill14(L,B)	Mill15(L,B,W	Mill16(L,B)	Mill17(B)
1992	0.3545	0	1.8741	3.847	2.2496	3.2486	2.6949	3.3597	4.9978	4.4624	3.5398	5.5262	4.3415	1.8758	2.1132	2.423	3.5572
1990	2.0034	1.3947	2.6133	4.6727	3.5015	4.8431	3.9566	3.8319	5.3868	5.4544	4.6443	6.5089	5.9855	3.1877	3.4248	3.6692	4.5367
1989	3.4832	2.7305	3.4219	5.5884	4.8874	6.3362	5.2009	4.4989	6.0114	6.4806	5.8066	7.5123	7.4995	4.5522	4.7718	4.9055	5.5652
1987	4.794	4.0074	4.2999	6.594	6.4074	7.728	6.4276	5.3608	6.8716	7.5409	7.0267	8.5362	8.8834	5.9693	6.1543	6.1318	6.6425
1986	5.9356	5.2255	5.2472	7.6896	8.0614	9.0184	7.6368	6.4174	7.9674	8.6354	8.3045	9.5807	10.1374	7.439	7.5722	7.3482	7.7687
1985	6.9082	6.3848	6.2639	8.8752	9.8495	10.2074	8.8286	7.669	9.2989	9.7642	9.6402	10.6459	11.2613	8.9614	9.0255	8.5547	8.9437
1982	7.7117	7.4851	7.3499	10.1507	11.7716	11.2951	10.0028	9.1153	10.8659	10.9271	11.0336	11.7316	12.2553	10.5364	10.5143	9.7512	10.1677

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

Appendix 2.4: Efficiency Scores for Paper Mills in Yunnan

	Mill18(B)	Mill19(B)	Mill20(L)	Mill21(B)	Mill22(L,B)	Mill23(B)	Mill24(B,W)	Mill25(L,B,W	Mill26(B,W)	Mill27(B)	Mill28(L,W)	Mill29(W)	Mill30(B)	Mill31(L,B,W	Mill32(W)	Mill33	Mill34
1992	3.1427	3.1039	2.2295	3.4573	2.2915	4.5222	2.2326	3.5675	3.1091	2.0799	1.9378	4.7398	4.8897	2.1094	4.0728	3.3768	5.7077
1990	4.2695	4.7167	3.3159	4.3521	3.511	5.6904	3.3843	4.5691	4.37	3.4161	3.3898	5.7152	5.9939	3.2253	5.0843	4.4509	6.1841
1989	5.4082	6.1972	4.4581	5.3116	4.7036	6.8374	4.5427	5.6657	5.5855	4.7233	4.7402	6.7738	7.066	4.359	6.1672	5.5727	6.8993
1987	6.559	7.5454	5.6562	6.336	5.8694	7.9632	5.7078	6.857	6.7556	6.0014	5.989	7.9155	8.1062	5.5105	7.3216	6.7421	7.8536
1986	7.7217	8.7613	6.9103	7.425	7.0083	9.068	6.8794	8.1433	7.8803	7.2504	7.1361	9.1404	9.1145	6.6797	8.5474	7.9591	9.0469
1985	8.8964	9.845	8.2202	8.5789	8.1203	10.1516	8.0577	9.5244	8.9597	8.4703	8.1816	10.4485	10.0907	7.8666	9.8447	9.2236	10.4791
1982	10.0831	10.7964	9.5859	9.7975	9.2054	11.2141	9.2426	11.0003	9.9936	9.6611	9.1255	11.8398	11.035	9.0713	11.2134	10.5359	12.1503

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

Chapter 3

Shadow Pricing Pollutants for China's Paper Industry

3.1 Introduction

China began its program of economic reforms in 1978 and has enjoyed double-digit annual growth ever since. Agricultural reform was 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 one of the biggest casualties of two decades of booming growth (e.g., Wong 1998).

The central government's position on the competing challenges of environment and development is pragmatic. It aggressively seeks growth but it also desires environmental improvement. The first environmental protection law was passed by National People's Parliament in 1979, with legislation in water and air control and various administrative documents addressing environmental issue followed. In 1982, China began imposing a system of pollution levies and standard on industrial pollutant discharges.

This chapter is a continuation of our inquiry of the effectiveness of China's pollution control policy. In chapter 2 we observed that the pollution levy was effective in the sense that firms' emissions were sensitive to increase in intensity of pollution levy enforcement. It remains unclear as to whether this policy effect is a consistent trend over time or a mere reflection of regional difference, since our policy effect is constructed as the relationship between pollution levy intensity and the level of pollutant emissions. If it is a time trend we can more comfortably say that current pollution levy system is indeed improving the environment, but there was serious doubt about this, even among senior environmental officials (Qu, 1991). It is possible that this policy effect just reflects the regional difference in policy enforcement and other local characteristics, as China's national environmental policy is implemented through local government and local administration is highly variable.

Another question can also arise regarding the effectiveness of environmental policy: whether the policy has led to the efficient allocation of resources. Jefferson and Rawski (1994) examined marginal revenue products of labor across a sample of state-owned firms. They found convergence of these marginal revenue products over time, and concluded that efficiency was improving in the state-owned firms. The convergence of marginal abatement cost could be used as an indicator to the efficiency performance of current policy in pollution control.

The purpose of this chapter is to examine these two questions: efficiency and effectiveness of the environmental policy. We will derive shadow prices for pollutants in China's paper industry. These shadow prices are used as indicators of paper mills' marginal abatement cost.

We adopt an output distance function approach, introduced by Fare, Grosskopf, Lovell and Yaisawarng (FGLY, 1993), to calculate producer- and time-specific shadow prices for pollutants for China's paper industry, through a sample of panel data. These shadow prices will be used to represent the opportunity cost to the firm for a unit reduction of pollutant discharge in terms of forgone output and revenue. We will name our shadow prices in terms of foregone output as output-based shadow prices and the shadow prices in terms of foregone revenue as revenue-based shadow prices. With panel data, our output-based shadow prices can provide information on whether firms in our sample has actually reduced their pollutant emissions over time, and the convergence of our revenue-based shadow prices serves as an indicator to reflect the efficiency of current pollution control policy.

Shadow prices are also indicative of willingness of firms to pay for marginal adjustment. This would be an indication of their response to a tradable permit system. In fact, China has been experimenting with a tradable permit system since early 1990's, aiming at controlling the aggregate emissions while allowing individual firm's emissions to vary. Firms to determine whether participating in emissions trading is worthwhile can use the shadow prices derived here.

This chapter unfolds as follows. Section 2 gives a detailed presentation of the theoretical model as in FGLY. Section 3 covers our sampling and data issues. Section 4 presents the empirical model specification and estimation procedure. Section 5 discusses our estimation results. Section 6 concludes with a discussion of policy implication.

3.2 The Model

FGLY (1993) introduced the property of week disposability with respect to outputs, especially undesirable outputs, in order to allow for regulations which restrict the ability of producers to costlessly dispose of undesirable byproducts of the production process. Assuming that a producer employs input vector $x \in \Re_+^N$ to produce output vector $u \in \Re_+^M$ in accordance with a production technology represented by the output correspondence $P: \Re_+^N \rightarrow 2^{\Re_+^M}$. The output set $P(x)$ denotes all output vectors that are technically feasible which employ the input vector x, i.e., $P(x) = \{ u \in \Re_+^M : x$ can produce $u \}$. Weak disposability of outputs requires that if $u \in P(x)$ and $\theta \in [0, 1]$, then $\theta u \in P(x)$, in contrast to strong disposability, which requires that if $v \leq u \in P(x)$ then $v \in P(x)$. Under weak disposability reduction of a byproduct can only be achieved by simultaneously reducing some desirable output(s). This is consistent with regulations which require abatement or cleanup of pollutants. Since this abatement is resource-using, there is an associated opportunity cost of foregone marketable output.

The output distance function we employ in this paper is defined on the output set $P(x)$ as

$$D_0(x,u) = \inf\{\theta : (u/\theta) \in P(x)\}, \qquad (1)$$

which possesses the following properties (Coelli, Rao and Battese, 1998):

(i) $D_o(x, u)$ is non-decreasing in u and increasing in x;

(ii) $D_o(x, u)$ is homogeneous of degree +1 in u;

(iii) $u \in P(x)$ if and only if $D_o(x, u) \leq 1$;

(iv) $D_o(x, u) = 1$ if u belongs to the “frontier” of the production possibility set.

The concepts of output distance function and weak and strong disposability are illustrated graphically in Figure 3.1. Here we assume that two outputs u_1 and u_2 are produced using input vector x. Production possibility curve (ppc) *acde* represents the case in which both u_1 and u_2 are desirable, whereas *bcde* represents the one in which one of the outut (e.g. u_1) is undesirable. The value of output distance function for the firm using input x to produce outputs defined by point f is equal to the ratio $\theta = 0f/0g$.

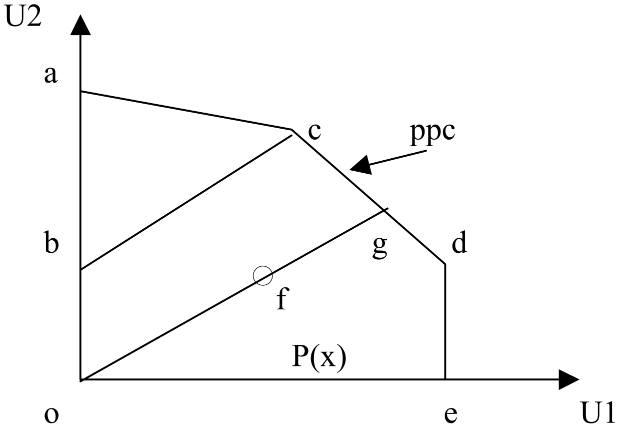

Figure 3.1: Production Set, Distance Function and Weak Disposability

When output u_1 is undesirable (ppc is *bcde*), starting at point c, a reduction in u_1 requires a reduction in u_2 when input is held fixed. Hence output u_1 is weakly disposable; to dispose of it from c is costly, in terms of sacrificed u_2. Starting at point d, however, a reduction in u_2 can be achieved at no cost to the producer, so output u_2 is strongly disposable.

As FGLY stated, the output distance function has several advantages over more traditional representation of technology such as the production function. First, it completely describes technology and is scalar-valued (as is the production function). In contrast to the production function, the distance function models joint production of multiple outputs. Second, the output distance function (like its parent technology, $P(x)$) can incorporate weak disposability, which allows us to model bad outputs as not necessarily freely disposable. Third, the duality between the output distance function and the revenue function allows us to retrieve the output shadow prices.

We denote output prices by $r = (r_1, \ldots, r_M)$ and assume that $r \neq 0$. Weak disposability allows prices of undesirable outputs to be non-positive. We define the revenue function in terms of distance function as

$$R(x, r) = \sup_u \{ru\colon D_0(x, u) \leq 1\}. \qquad (2)$$

If the parent technology has convex output sets $P(x)$ for all $x = \Re_{+}^{N}$, then one can prove (Shephard, 1970 or Fare, 1988) that the following duality holds:

$$R(x, r) = \sup_{u}\{ru\colon D_0(x, u) \leq 1\}$$

$$D_0(x, u) = \sup_{r}\{ru\colon R(x, r) \leq 1\}, \tag{3}$$

where ru is the inner product of the output price and quantity vectors. The revenue function can be derived from the output distance function by "maximization" with respect to outputs, and the output distance function is obtained from the revenue function through "maximization" over output prices.

We assume that the revenue and distance functions are differentiable, and consider the Lagrange problem

$$\max\ \Lambda = ru + \lambda\,(D_0(x, u) - 1). \tag{4}$$

The first order conditions with respect to outputs are

$$r = -\lambda \nabla_u D_0(x, u), \tag{5}$$

where r and $\nabla_u D_0(x, u)$ are of dimension (M × 1) and λ is a scalar. FGLY proved that at the optimum the Lagrange multiplier equals the revenue function, i.e., $-\lambda = \Lambda = R(x, r)$. Thus we may write (5) as the following system of equations:

$$r = R(x, u) \bullet \nabla_u D_0(x, u). \tag{6}$$

The second part of the duality theorem (3) can be represented as the following

$$D_0(x, u) = r^*(x, u)u. \tag{7}$$

where $r^*(x, u)$ denotes the revenue maximizing output price vector from the second part of (3). Shephard's dual lemma applied to (7) yields the relationship

$$\nabla_u D_0(x, u) = r^*(x, u). \tag{8}$$

Substitution of (8) into (6) yields

$$r = R(x, u)r^*(x, u). \tag{9}$$

$r^*(x, u)$ can be interpreted as a vector of normalized or revenue deflated output shadow prices. The undeflated shadow prices r can be computed when maximum revenue $R(x, r)$ is known. With the following assumption

One observed output price equals its absolute shadow price,

we can compute maximum revenue R. Suppose the observed price of the mth output r_m^o equals its absolute shadow price r_m, then

$$R = r_m^o / r_m^*(x, u). \tag{10}$$

In practice, we can use the observed price of a desirable output as our normalizing price, since desirable outputs have observable, market-determined prices (which the undesirable outputs do not). For all m' ≠ m, absolute shadow prices $r_{m'}$ are given by

$$\begin{aligned} r_{m'} &= R \bullet r_{m'}^*(x, u) = R \bullet [\partial D_o(x, u) / \partial u_{m'}] \\ &= r_m^o \bullet \frac{\partial D_o(x, u) / \partial u_{m'}}{\partial D_o(x, u) / \partial u_m}. \end{aligned} \tag{11}$$

The calculation of shadow prices for undesirable outputs (pollutants) based on (11) provides a measure of opportunity cost to firms for a unit reduction of these undesirable outputs, in terms of foregone revenue. We call these types of shadow prices the “revenue-based shadow prices”.

To compare changes in a firm’s opportunity cost of reducing pollutant emissions over a period of time, we should use a shadow price net of price change. As was pointed out by FGLY, the ratio of shadow prices between bad output and good output represents the relative opportunity cost, or technical rate of transformation between bad and good outputs. This ratio can be used to indicate change in the level of emissions in terms of physical output, for a firm in a given time period. This ratio can be computed as

$$r'_{m'} = r_{m'} / r_m^0 = \frac{\partial D_0(x, u) / \partial u_{m'}}{\partial D_0(x, u) / \partial u_m}. \tag{12}$$

Unlike revenue-based shadow prices, this ratio measures opportunity cost to firms for a unit reduction of pollutants in terms of foregone physical output. We should, therefore, call it output-based shadow price, which is the reciprocal of the marginal pollutant emission rate for a unit increase in output level.

In FGLY paper, the procedure generated producer-specific measure of revenue-based shadow prices of all bad outputs based on (11). As an indicator of marginal abatement cost, these shadow prices can be compared to calculations of marginal benefits of pollution abatement. If these shadow prices equal the marginal benefits to society, then current regulations are leading to an efficient allocation of resources. Furthermore, if the marginal benefit of emission control is equal for all firms, then efficient regulation would lead to equal shadow prices across firms.

Our research uses a panel data set, therefore extends the scope of the policy questions that FGLY approach can answer. The procedure applied to panel data can generate time- and producer-specific measures of shadow prices for firms in the study. With revenue-based shadow prices we examine if an efficient allocation of resources in pollution control has been achieved by looking at the variation level of the shadow prices across firms and the trend of the variation over time. With output-based shadow prices we examine whether firms actually have reduced their pollutant emissions level by looking at the trend of the shadow prices for each firm. If no convergence of revenue-based shadow prices and no increase in output-based shadow prices are observed, we can conclude that the effectiveness of current policy in pollution control is largely a reflection of regional characteristics, and water quality is not improving over time. That being the case, government's suspicion over current system is appropriate and the experiment in tradable permit system and moving environmental authority to central control are all justified.

3.3 Data

A firm level survey was conducted in two of China's southern provinces, Fujian and Yunnan. The main reason for conducting survey in these two provinces was that willing local collaborators were found. Fujian's annual paper production is in the mid-upper level among China's 31 provinces but it has China's largest newsprint mill and largest sack and Kraft paper mills and therefore it has the largest wood fiber-based pulping processes. Wood fiber-based production accounted for about 40% of the provincial total. Fujian is considered as representative of the advanced portion of China's paper industry which is subject to broader and longer government intervention because of its importance in supplying major national needs (newsprint, for example, for major national newspapers). In terms of structure of paper sector, with mill size running from large (annual production exceeding 30,000 tons, a Chinese standard), medium (between

10,000 to 30,000 tons per year) to small, majority of the mills still using non-wood fiber, Fujian provides a complete image of China's paper industry in these matters. There are no large paper mills but a couple of medium sized ones in Yunnan. The wood fiber-based production is about 20 of the provincial total, about average of the national level. Most of the mills utilize agricultural residuals and other types of locally available non-wood fiber resources. In general, Yunnan represents an average paper-producing region in China.

Variables in the survey include annual quantity of wastewater emissions (in cubic meters), total suspended solid emission (TSS, in tons), chemical oxygen demand (COD, in tons), and the total pollution fee that each firm was charged each year. Unfortunately, the time spots in the completed surveys from two provinces did not fully match each other. For Fujian the survey covered year 1982, 1985, 1986, 1987, 1989, 1990, 1992 and for Yunnan the period covered is 1986-1992. We selected 30 mills (out of 50 in Fujian and out of 40 in Yunnan) which had been operating on regular basis, from each province. Selectivity bias might occur in the sense that mills included in the sample were those in good economic situation. Efficiency analysis may just reflect the performance of the better portion of the industry. But, given the very volatile economic environment and frequent entry and exit by a portion of the paper sector, the full-scale analysis would be too complicated.

Based on data quality we selected 17 mills for each province from about 20 surveys that were returned from each province. We matched these pollution data with mill level production data collected by the former light industry ministry from early 1970s to 1992. Now we have a panel data set of 34 mills (17 for each province) for a period from 1986-1992 (1986, 1987, 1989, 1990, 1992). The production statistics includes information on physical and value output, fixed cost (capital cost), number of employees, energy consumption, as well as water and chemical uses. We combined data from these two provinces in the estimation[15].

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[15] A Chow-test has been conducted in chapter 2 to validate the combination of two provinces' data. Since the output distance directly measures efficiency performance, the assumption made when the Chow-test was conducted is still valid here.

Our next question is: 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 our 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 be an enormous task. Indeed, this is the reason our sample is limited.

Alternatively, we can compare Fujian's 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.)[16] We will base an argument that Fujian's and Yunnan's mills are representative on this evidence.

3.4 The Empirical Specification

The parametric form of our output distance function is translog. This functional form has the advantage of flexibility and more importantly, it allows for weak disposability of outputs. As in FGLY,

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[16] Tables and statistics available from the author.

$$\begin{aligned}\ln D_o(x,u) = \alpha_o &+ \sum_{n=1}^{N}\beta_n \ln x_n + \sum_{m=1}^{M}\alpha_m \ln u_m \\ &+ \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N}\beta_{nn'}(\ln x_n)(\ln x_{n'}) \\ &+ \frac{1}{2}\sum_{m=1}^{M}\sum_{m'=1}^{M}\alpha_{mm'}(\ln u_m)(\ln u_{m'}) \\ &+ \sum_{n=1}^{N}\sum_{m=1}^{M}\gamma_{nm}(\ln x_n)(\ln u_m). \qquad (13)\end{aligned}$$

We employ a linear programming technique to estimate the parameters of a deterministic translog output distance function. Our problem is stated as

$$\max \sum_{k=1}^{K}[\ln D_o(x^k, u^k) - \ln 1] \qquad (14)$$

subject to

$$\text{(i)} \quad \ln D_o(x^k, u^k) \leq 0, \qquad k = 1,\ldots,K,$$

$$\text{(ii)} \quad \frac{\partial \ln D_o(x^k, u^u)}{\partial \ln u_m^k} \geq 0, \qquad m = 1,\ldots,i, \quad k = 1,\ldots,K,$$

$$\text{(iii)} \quad \frac{\partial \ln D_o(x^k, u^u)}{\partial \ln u_m^k} \geq 0, \qquad m = i+1,\ldots,M, \quad k = 1,\ldots,K,$$

$$\text{(iv)} \quad \sum_{m=1}^{M}\alpha_m = 1, \qquad \sum_{m'}^{M}\alpha_{mm'} = \sum_{m=1}^{M}\gamma_{nm} = 0, \qquad m = 1,\ldots,M, \qquad n = 1,\ldots,N,$$

$$\text{(v)} \quad \begin{aligned}&\alpha_{mm'} = \alpha_{m'm}, \quad m = 1,\ldots,M, \quad m' = 1,\ldots,M, \\ &\beta_{nn'} = \beta_{n'n}, \quad n = 1,\ldots,N, \quad n' = 1,\ldots,N,\end{aligned}$$

where $k = 1,\ldots,K$ indexes individual observations, $\ln D_o(x^k, u^k)$ has an explicit functional form as in (13), the first i output are desirable and the next (M - i) outputs are undesirable. The objective function "minimizes" the sum of the deviations of individual observations from the frontier of technology. The first set of constraints labeled (i) restricts individual observations to be on or "below" the frontier. The constraints in (ii) ensure that the desirable outputs have nonnegative shadow prices and those in (iii) ensure that the undesirable outputs have nonpositive shadow prices. The constraints in (iv) impose homogeneity of degree +1 in outputs (which also ensures that technology satisfies weak disposability of outputs). The final set of constraints in (v) imposes symmetry.

3.5 The Results

Table 3.1 presents the parameter estimates of (13). These estimates were used to compute the value of the output distance function and shadow prices for each mill at each time. Table 3.2 presents values of output distance function for our sample of 34 paper mills and their maximum, minimum and mean, based on our estimates of firm- and time specific output distance function. We also have calculation of standard deviation and the coefficient of variation (CV) for each year in Table 3.2. The CV is computed as the ratio between the mean value and the standard deviation, reflecting the degree to which the calculated values spread. Table 3.2 shows that since 1986 there was no significant improvement in productive efficiency on average. The CV results show no evidence that firms' efficiency performance was converging to the frontier. It is shown that paper production for mills in our sample could be increased by 10% on average in 1992, if all mills operated at a point on the frontier of the production possibility set.

Our revenue-based absolute shadow prices of wastewater, TSS and COD are calculated using (11). In interpreting the meaning of different level of shadow prices, there are two factors that we consider are important, technical difficulty and level of pollution emissions. The more difficult it is to apply the pollution control technology in a process the higher abatement cost therefore the higher shadow prices. The more the emissions were reduced the higher marginal abatement cost therefore the higher shadow prices. What we are really interested in is the variation of these shadow prices and its trend. For this purpose we use our calculation of coefficient of variation for the shadow prices to build table 3.3, figure 3.3a and 3.3b, table 3.4, figure 3.4a and 3.4b, table 3.5, figure 3.5a and 3.5b. In these tables and figures we separate our CV results by provinces. In so doing we use the assumption that geographically closed regions should gain relatively similar environmental benefit from a unit reduction of pollutant emissions. If current policy has led to efficient allocation of resources in pollution control, the CV's of shadow prices for pollutants in each province should be small, and, more importantly, converging over time. In table 3.3, 3.4 and 3.5 and corresponding figures we also present CV results by disaggregating firms by size (large and small), fiber use (wood, nonwood) , and pulp processing (bleach, nonbleach). We believe these distinctions represent major technological variations in China's paper industry that were considered critical to affect firm's ability in pollution control. And in so doing we can separate the influence of technological difficulty in pollution control from that of policy, that is, if within a technological category we still observe large variation in shadow prices of pollutant we will conclude that current policy indeed fails to induce efficient allocation of resources. If CV is rising in absolute value, we will conclude that the shadow prices are converging over time, and for a relatively homogeneous region that current environmental policy is leading to an efficient allocation of resources in pollution control. Our results show that in both provinces, CVs for revenue-based shadow prices are generally small in absolute value (compared to the best cases, like CVs of wastewater for small mills in Fujian) and they are pretty stable over time with a few exceptions (CVs of wastewater for small mills in Fujian and Yunnan).

Our output-based shadow prices are calculated using (12) and presented in table 3.6a, 3.6b, figure 3.6a, 3.6b (for wastewater, Fujian and Yunnan, respectively), table 3.7a, 3.7b, figure 3.7a, 3.7b (for TSS, Fujian and Yunnan, respectively), table 3.8a, 3.8b, figure 3.8a, 3.8b (for COD, Fujian and Yunnan, respectively). We are not making inter-mill comparison with these physical shadow prices due to lack of exact knowledge of the technological homogeneity. What we are looking at is the trend of these shadow prices of each and every mills, in order to learn whether current policy has induced majority of the mills to reduce their pollutant emission load. If the shadow price for a mill gets larger over time, we will conclude that the mill has reduced its pollution level. Output-based shadow price is an indicator of the abatement cost in terms of foregone good output. The more the mill abate its emissions, the higher the marginal cost for a unit reduction of the emission, the more foregone output. Based on aforementioned tables and figures, with couple of exceptions (figure 3.6a, mill 16, figure 3.6b, mill20, for example), majority of the mills demonstrate little progress in pollutant emission reduction. The vastly different level of output-based shadow prices for each pollutant is either a result of technological difference or, more likely, a result of different level of regional policy enforcement.

3.6 Conclusion

We calculate revenue-based shadow prices for undesirable output to reflect the impact of current environmental policy on cross-sectional efficiency of resource allocation. We calculate output-based shadow prices to reflect the change of individual firm's effort level in cutting back these undesirable outputs. For a relatively homogeneous (in terms of marginal benefit of environmental improvement to society) region, we would expect that revenue-based shadow prices be equal among firms if the current policy is efficient and the policy enforcement is uniformed. For each individual firm, increased output-based shadow prices reflect a decrease in pollutant emissions. Our calculations show large variation in revenue-based shadow prices and a pretty constant level of variation over the time period for each province as a whole. This suggests that under current environmental policy resource allocation had been inefficient in China's paper industry, and the overall allocative efficiency was not improving over time, which also indicates that local enforcement of policy differs from each other in strictness and the cross-location pattern is pretty rigid. To separate the impact of technology difference from that of policy, we disaggregate firms based on size, fiber use and bleaching/nonbleaching choices. The results are basically similar except for a few exceptions.

Our results of output-based shadow price show that the overall pollution level was not decreasing due to lack of real effort from individual mills. Mills from different locations (different counties in our sample) have very different output-based shadow price level and the pattern is largely consistent over time. This might be additional indication of different level of long term policy enforcement by different local authority.

In chapter 2 we found that pollution levy intensity had positive effect in reducing pollution emission on the same sample of firms. Incorporating those findings in this study of shadow prices, we conclude that there was large variation in paper mills' pollution control performance and there existed great difference in the intensity of pollution levy enforcement across locations. Although the central government made increased commitment in curbing the deteriorating industrial pollution problems, difference in local policy enforcement that directly dealt with individual firm appears to be the deciding factor and this difference has produced rather rigid pattern in firms' environmental performance. The difference is more cross-sectional than occurring over time. These results reinforce the observation that as a whole the environmental performance in China's paper sector is not improving and some more radical change is called for.

Policy renovations under consideration are three folds: raising the levy rate, centralizing the environmental authority and experimenting with emission trading system. Integrating results from two empirical chapters we will conclude that raising the levy rate will have insignificant impact if the policy implementation is still non-uniformed. It should be accompanied by centralization of environmental authority if a unformed policy implementation is desired. The possibility of increase in administrative cost of this centralization, however, needs to be carefully assessed. Due to the evidence of differential local enforcement as a function of local characteristics, tradable permit system might be a favorable choice in the future. It provides a mechanism to accommodate local differences, legalize differential pollution control, therefore, probably lead to greater economic efficiency in the effort to control pollution.

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Tables and Figures

Table 3.1: Coefficient Estimates

Variable[1]	Estimate	Variable	Estimate	Variable	Estimate
Constant	2.408	ln(K)ln(ALK)	-0.098	ln(K)ln(WA)	-0.062
ln(K)	-0.11	ln(L)ln(E)	0.326	ln(K)ln(TSS)	-0.011
ln(L)	-1.437	ln(L)ln(ALK)	0.137	ln(K)ln(COD)	5.98E-05
ln(E)	-0.123	ln(E)ln(ALK)	-0.008	ln(L)ln(OUT)	-0.071
ln(ALK)	-0.133	$(\ln(OUT))^2$	0.003	ln(L)ln(WA)	0.097
ln(OUT)	-0.11	$(\ln(WA))^2$	0.013	ln(L)ln(TSS)	-0.028
ln(WA)	0.87	$(\ln(TSS))^2$	0.033	ln(L)ln(COD)	0.019
ln(TSS)	0.194	$(\ln(COD))^2$	9.20E-04	ln(E)ln(OUT)	0.072
ln(COD)	0.046	ln(OUT)ln(WA)	-0.034	ln(E)ln(WA)	-0.105
$(\ln(K))^2$	0.038	ln(OUT)ln(TSS)	-0.019	ln(E)ln(TSS)	0
$(\ln(L))^2$	-0.16	ln(OUT)ln(COD)	-0.037	ln(E)ln(COD)	0
$(\ln(E))^2$	-0.125	ln(WA)ln(TSS)	-0.014	ln(ALK)ln(OUT)	0.007
$(\ln(ALK))^2$	-0.006	ln(WA)ln(COD)	0.002	ln(ALK)ln(WA)	0.028
ln(K)ln(L)	-0.063	ln(TSS)ln(COD)	0.004	ln(ALK)ln(TSS)	-0.013
ln(K)ln(E)	0.062	ln(K)ln(OUT)	0.056	ln(ALK)ln(COD)	0.011

[1] Variable definitions: K=capital; L=labor; E=energy; ALK=alkali; OUT=output; WA=wastewater; TSS=total suspended solid; COD=chemical oxygen demand;

Table 3.2: Distance Estimates

	1992	1990	1989	1987	1986
Mill1	1	0.987	0.956	0.97	1
Mill2	1	0.847	0.863	0.829	0.836
Mill3	0.872	0.918	0.985	1	0.978
Mill4	1	0.77	0.79	0.947	1
Mill5	0.772	0.914	0.947	0.945	0.888
Mill6	0.791	0.842	0.86	0.886	0.828
Mill7	0.909	0.884	0.826	0.85	0.863
Mill8	0.909	0.898	0.858	0.875	0.912
Mill9	0.961	0.891	0.904	0.944	0.917
Mill10	0.944	0.881	0.895	0.989	1
Mill11	0.846	0.91	0.937	0.907	0.93
Mill12	0.968	0.906	0.844	0.963	0.989
Mill13	0.877	0.851	0.844	0.869	0.815
Mill14	0.974	0.965	1	0.866	0.936
Mill15	1	0.764	0.868	1	0.987
Mill16	0.859	1	0.962	0.893	1
Mill17	0.916	0.853	0.855	0.849	0.853
Mill18	0.854	0.855	0.871	0.833	0.946
Mill19	0.829	0.872	0.866	1	1
Mill20	1	0.813	1	0.991	0.832
Mill21	0.895	0.937	0.99	0.914	0.922
Mill22	0.852	0.805	0.838	0.874	1
Mill23	0.837	0.798	0.92	0.859	0.917
Mill24	0.699	0.8	0.858	1	0.916
Mill25	0.968	1	0.995	0.996	0.832
Mill26	0.9	0.432	0.823	0.791	0.815
Mill27	0.789	0.928	1	0.969	0.941
Mill28	1	0.889	0.897	0.885	1
Mill29	0.94	0.894	0.924	1	1
Mill30	1	0.507	0.827	0.905	0.936
Mill31	0.853	0.945	0.939	0.97	1
Mill32	1	0.93	0.921	0.918	0.955
Mill33	0.827	0.877	0.913	0.939	0.894
Mill34	0.9	0.738	0.646	0.507	0.78
Max	1	1	1	1	1
Min	0.699	0.432	0.646	0.507	0.78
Average	0.904147059	0.855911765	0.894764706	0.909794118	0.924058824
Stdev	0.079716213	0.117876506	0.074293056	0.093013775	0.068491513
CV	11.34207233	7.261088665	12.04371928	9.781283633	13.49158142

Table 3.3: Coefficient of Variation for Wastewater Shadow Prices (Revenue-based)

	1992	1990	1989	1987	1986
Fujian	-0.909801719	-1.650075991	-1.599267226	-1.631119888	-1.422329547
Large	-1.000506839	-1.764122023	-2.074486546	-2.270559164	-1.846078173
Small	-2.204415236	-1.982160504	-1.797425568	-1.633579042	-1.653939763
Wood	-1.524039009	-1.271422146	-1.244429527	-1.331071459	-1.234348762
Nonwood	-0.866464101	-3.979356079	-4.230168473	-2.159399543	-1.58520849
Bleach	-0.898089809	-1.918953345	-2.06839602	-1.943584969	-1.626356342
Nonbleach	-1.491689492	-1.295458106	-1.1222053	-1.319766386	-1.337674283
	1992	1990	1989	1987	1986
Yunnan	-0.699577021	-0.847363356	-1.019546805	-1.065046213	-0.856876913
Large	-1.038769857	-1.004505001	-1.184731287	-1.134957446	-1.264494122
Small	-1.604931039	-0.752046836	-1.232732488	-1.475574051	-1.495117733
Wood	-0.7387802	-0.915256288	-1.472689163	-0.933369893	-0.864548799
Nonwood	-0.649603761	-0.784436255	-0.804183078	-1.234067491	-1.049810921
Bleach	-0.801402449	-0.76763358	-1.222085275	-0.970458828	-0.854058619
Nonbleach	-0.644833322	-0.923852617	-0.900864732	-1.17511739	-0.923750152

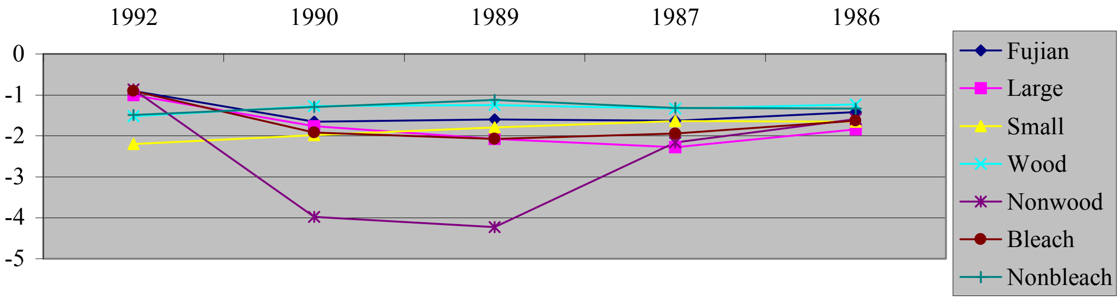

Figure 3.3a: CV for Wastewater Shadow Prices in Fujian (Revenue-based)

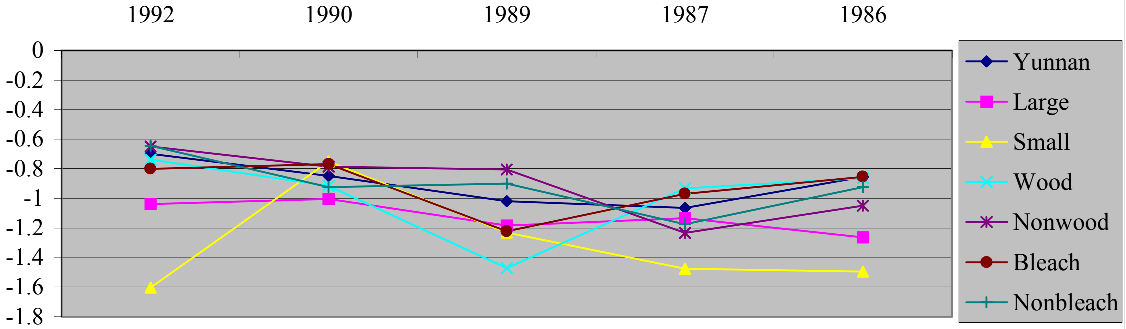

Figure 3.3b: CV for Wastewater Shadow Prices in Yunnan (Revenue-based)

Table 3.4: Coefficient of Variation for TSS Shadow Prices (Revenue-based)

	1992	1990	1989	1987	1986
Fujian	-1.196555296	-0.975102067	-0.89820803	-1.103319603	-1.071190444
Large	-1.357814873	-0.882573166	-0.938430624	-1.140515909	-1.193028567
Small	-1.353968756	-1.093754114	-0.95490469	-1.198433906	-1.385470386
Wood	-1.166306466	-0.967492449	-0.930872953	-1.230042865	-1.203637693
Nonwood	-1.337430839	-1.224633945	-0.885420811	-0.95569811	-0.920089162
Bleach	-1.318837022	-1.525459837	-0.979132732	-1.0809593	-1.093214023
Nonbleach	-0.973770606	-0.816316586	-0.785522949	-1.051096511	-0.962649296
	1992	1990	1989	1987	1986
Yunnan	-0.794210135	-0.354815705	-0.703088481	-1.02259951	-0.838564924
Large	-1.102840346	-1.039774901	-0.871352754	-1.264282313	-0.963564501
Small	-0.658170978	-0.359373488	-0.635416668	-0.909896381	-0.943583537
Wood	-0.893454883	-0.506930133	-0.775718688	-0.972395752	-0.885049993
Nonwood	-2.071068119	-1.203251901	-1.149242757	-1.092185937	-0.947164972
Bleach	-0.839751701	-0.414926449	-0.75018501	-1.180184863	-1.165894284
Nonbleach	-0.853195996	-1.011386368	-0.970963758	-1.028664554	-0.558152617

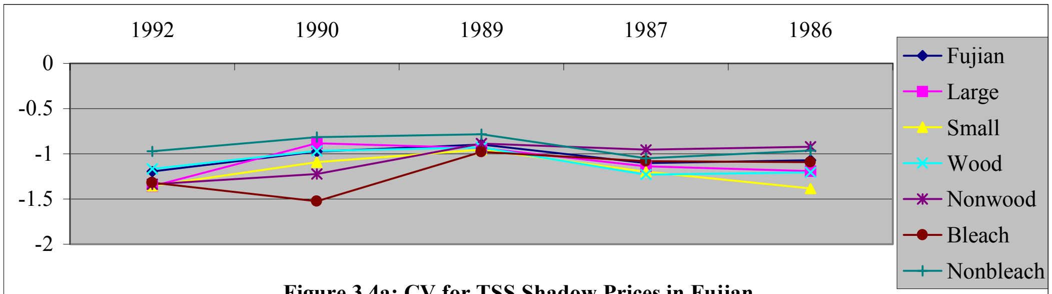

Figure 3.4a: CV for TSS Shadow Prices in Fujian (Revenue-based)

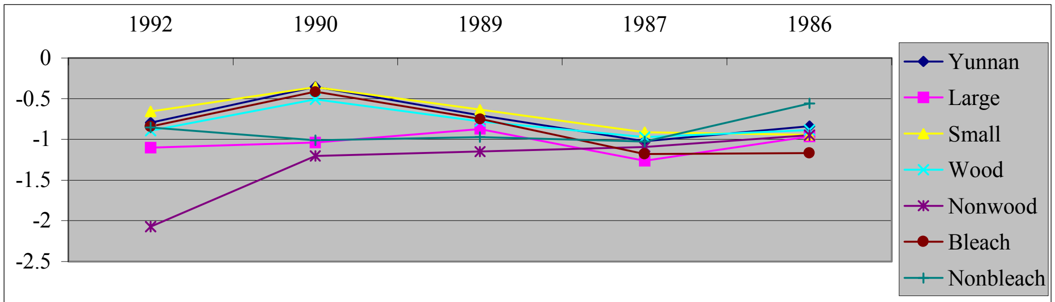

Figure 3.4b: CV for TSS Shadow Prices in Yunnan (Revenue-based)

Table 3.5: Coefficient of Variation for COD Shadow Prices (Revenue-based)

	1992	1990	1989	1987	1986
Fujian	-0.966837022	-1.311157786	-1.409350552	-1.033216475	-0.91964553
Large	-0.98529326	-1.524313776	-1.900860982	-1.069563165	-0.995620786
Small	-1.198820098	-1.476692112	-1.488283527	-1.49050621	-1.357166328
Wood	-0.84404375	-1.525682112	-1.464780712	-1.027108672	-0.911062039
Nonwood	-2.11400223	-1.17413975	-1.294034365	-1.282389125	-0.970363023
Bleach	-0.912833334	-1.277292403	-1.516684604	-0.907987506	-0.862579169
Nonbleach	-1.273471705	-1.38532772	-1.20727464	-1.960281153	-1.723416284
	1992	1990	1989	1987	1986
Yunnan	-0.360228982	-0.539916025	-0.512613088	-0.666956795	-0.608098836
Large	-0.534384553	-0.601967014	-0.652766942	-0.754611183	-0.82057492
Small	-1.134190181	-0.82510269	-0.77775803	-1.002898722	-0.798641783
Wood	-1.713732376	-1.063335979	-1.044696577	-1.150864892	-0.817075717
Nonwood	-0.383987052	-0.45394605	-0.455518041	-0.621853099	-0.540642586
Bleach	-1.346813635	-0.938285161	-1.018431468	-1.300258946	-1.005033042
Nonbleach	-0.464285821	-0.512158286	-0.496392324	-0.567319291	-0.643872654

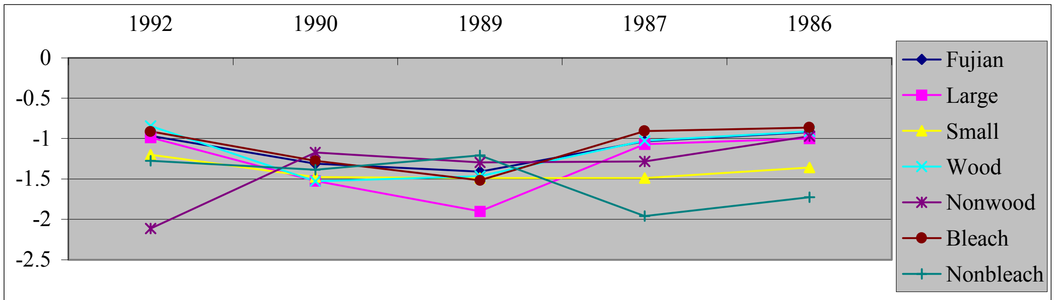

Figure 3.5a: CV for COD Shadow Prices in Fujian (Revenue-based)

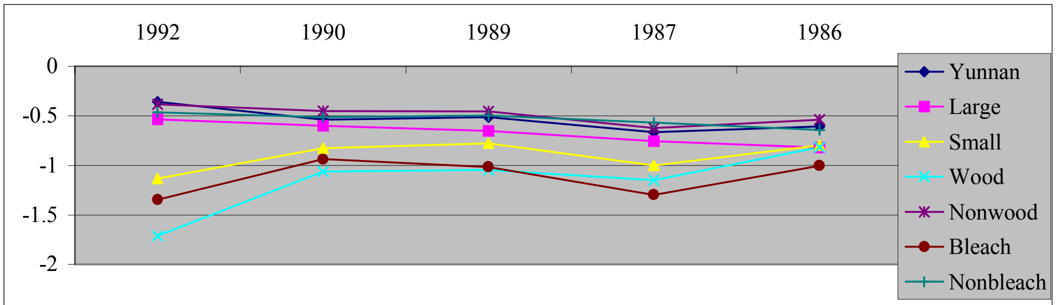

Figure 3.5b: CV for COD Shadow Prices in Yunnan (Revenue-based)

Table 3.6a: Output-based Shadow Price for Wastewater: Fujian

	1992	1990	1989	1987	1986
Mill1	-25.071	-25.841	-26.739	-23.128	-21.519
Mill2	-27.045	-33.247	-32.307	-37.175	-41.507
Mill3	-12.687	-17.859	-21.899	-21.851	-20.074
Mill4	-57.338	-47.358	-56.075	-49.409	-42.264
Mill5	-17.615	-16.51	-17.843	-24.504	-17.283
Mill6	-7.192	-10.293	-8.435	-7.442	-10.183
Mill7	-14.465	-11.437	-14.598	-12.945	-12.38
Mill8	-15.188	-14.865	-15.437	-21.836	-32.207
Mill9	-10.716	-9.842	-10.622	-12.125	-10.978
Mill10	-7.867	-14.202	-12.262	-7.831	-9.884
Mill11	-8.914	-6.962	-6.09	-2.249	-2.269
Mill12	-5.854	-6.391	-4.69	-3.988	-3.635
Mill13	-5.731	-5.917	-5.228	-4.378	-4.289
Mill14	-32.589	-33.506	-40.298	-26.991	-28.939
Mill15	-14.353	-18.238	-22.104	-20.277	-16.301
Mill16	-80.017	-10.22	-8.345	-6.822	-12.964
Mill17	-6.54	-8.969	-9.05	-7.769	-7.248

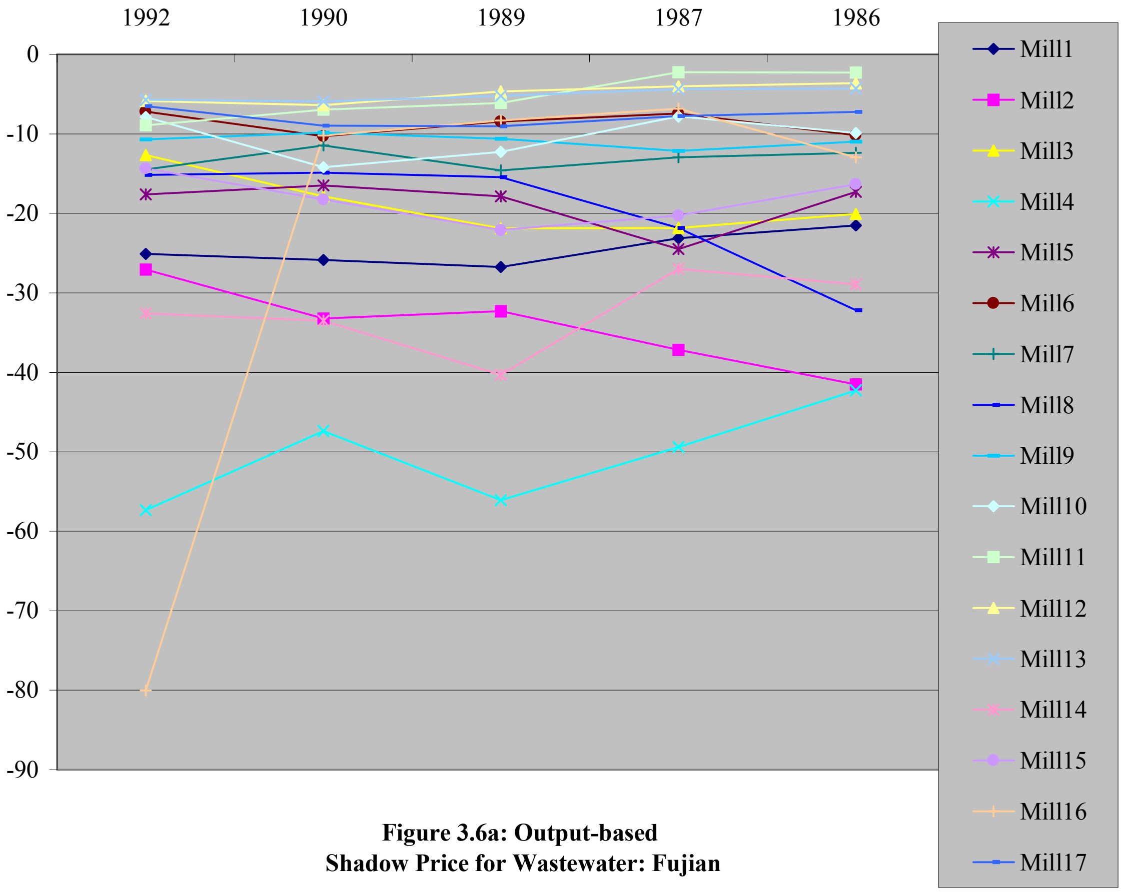

Figure 3.6a: Output-based Shadow Price for Wastewater: Fujian

Table 3.6b: Output-based Shadow Price for Wastewater: Yunnan

	1992	1990	1989	1987	1986
Mill18	-17.609	-20.953	-17.793	-10.842	-12.133
Mill19	-15.149	-12.638	-11.388	-9.666	-13.74
Mill20	-251.86	-173.649	-168.878	-86.055	-116.772
Mill21	-15.052	-15.824	-16.182	-22.103	-15.389
Mill22	-49.321	-21.92	-28.91	-27.843	-30.835
Mill23	-13.71	-13.375	-12.684	-11.426	-13.101
Mill24	-14.743	-17.755	-18.786	-22.094	-26.919
Mill25	-9.964	-8.134	-6.625	-7.395	-6.426
Mill26	-9.828	-111.21	-12.224	-7.867	-8.658
Mill27	-5.888	-11.734	-28.64	-21.826	-18.125
Mill28	-30.103	-19.048	-22.48	-19.15	-167.544
Mill29	-7.169	-9.592	-8.083	-9.799	-9.42
Mill30	-16.165	-6.871	-6.614	-11.061	-11.555
Mill31	-104.893	-32.019	-40.903	-81.352	-120.518
Mill32	-11.295	-20.06	-35.385	-35.268	-25.62
Mill33	-25.234	-38.477	-30.628	-34.391	-30.703
Mill34	-22.647	-5.663	-3.276	-3.83	-8.267

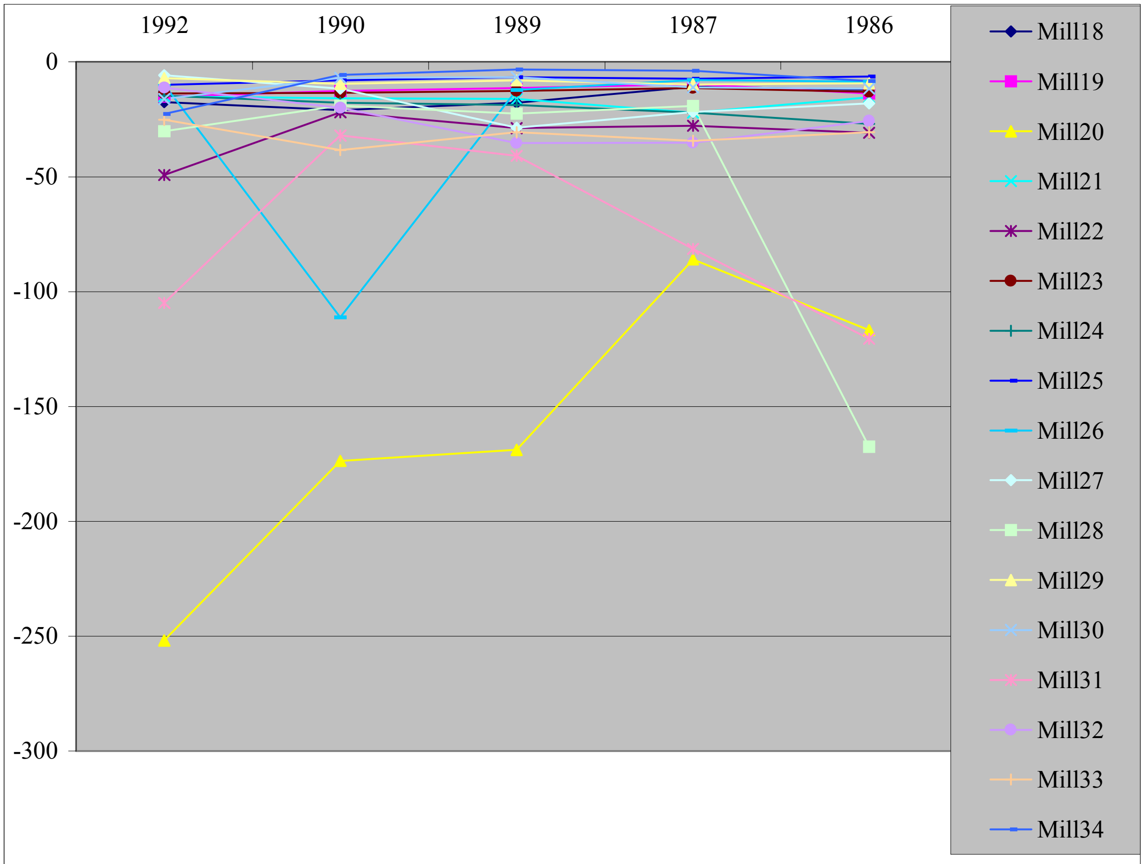

Figure 3.6b: Output-based Shadow Price for Wastewater: Yunnan

Table 3.7a: Output-based Shadow Price for TSS: Fujian

	1992	1990	1989	1987	1986
Mill1	-34.723	-42.963	-43.984	-39.732	-42.565
Mill2	-7.204	-4.939	-3.677	-2.064	-1.469
Mill3	-17.083	-25.519	-36.144	-38.674	-36.374
Mill4	-1.376	-0.196	-0.394	-0.666	-0.724
Mill5	-4.306	-4.994	-5.739	-9.958	-8.653
Mill6	-8.661	-11.68	-9.383	-9.083	-7.461
Mill7	-30.185	-26.19	-43.15	-51.138	-52.638
Mill8	-8.671	-8.43	-9.04	-11.408	-11.837
Mill9	-14.103	-7.812	-9.435	-10.692	-11.182
Mill10	-20.205	-30.709	-28.202	-22.298	-21.963
Mill11	-13.477	-21.409	-22.288	-11.873	-7.517
Mill12	-3.845	-4.348	-3.815	-4.568	-5.103
Mill13	-1.89	-1.792	-1.532	-6.055	-5.703
Mill14	-18.193	-18.365	-24.794	-18.052	-18.312
Mill15	-63.126	-7.244	-10.438	-18.854	-25.898
Mill16	-25.567	-0.243	-0.39	-1.94	-3.739
Mill17	-8.498	-9.327	-8.886	-7.263	-6.91

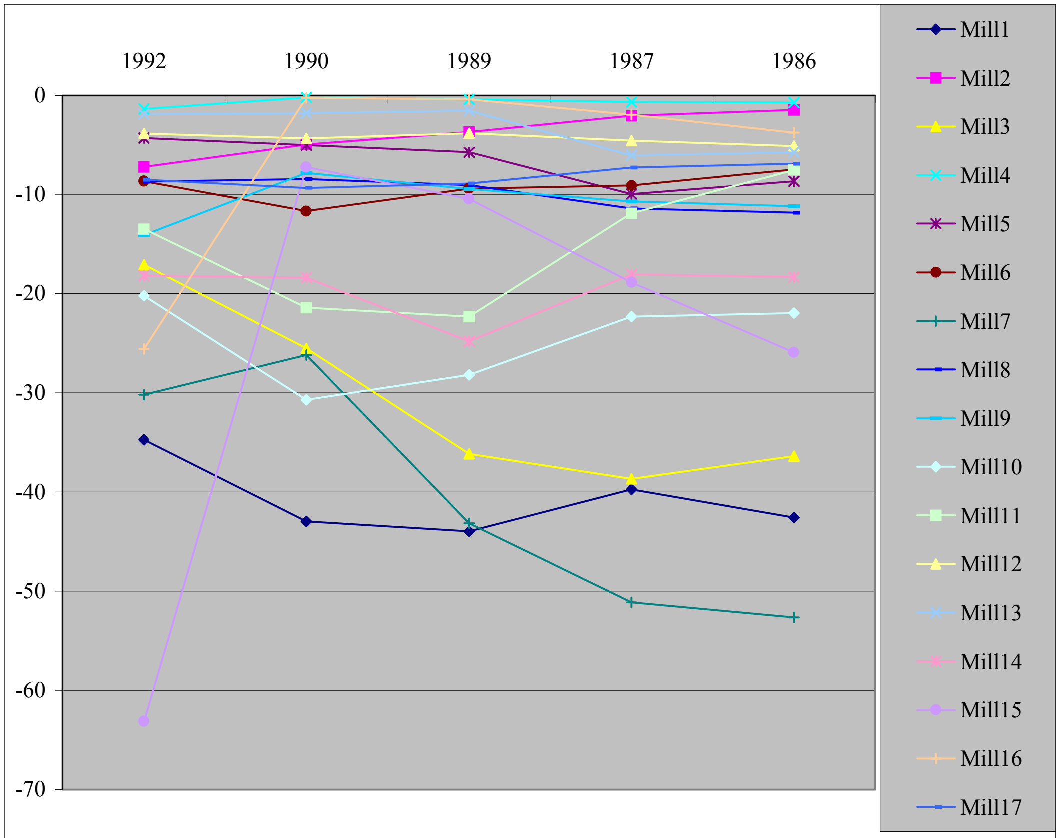

Figure 3.7a: Output-based Shadow Price for TSS: Fujian

Table 3.7b: Output-based Shadow Price for TSS: Yunnan

	1992	1990	1989	1987	1986
Mill18	-4.736	-6.143	-5.526	-4.716	-5.978
Mill19	-4.884	-4.116	-3.715	-3.196	-4.899
Mill20	-7.777	-22.778	-16.656	-9.244	-2.173
Mill21	-0.923	-0.861	-0.622	-0.736	-0.655
Mill22	-6.119	-13.525	-15.841	-28.569	-32.808
Mill23	-4.714	-3.185	-19.516	-13.847	-15.354
Mill24	-13.344	-14.063	-13.098	-9.794	-12.247
Mill25	-30.199	-30.115	-27.912	-17.14	-16.252
Mill26	-1.219	-262.216	-4.94	-13.434	-12.607
Mill27	-2.668	-3.109	-1.934	-0.647	-0.47
Mill28	-13.586	-6.49	-7.023	-4.773	-49.095
Mill29	-1.466	-1.777	-1.374	-0.166	-0.458
Mill30	-7.306	-6.188	-3.42	-5.258	-5.434
Mill31	-4.746	-0.64	-0.75	-1.006	-0.707
Mill32	-1.299	-0.649	-0.538	-0.409	-0.195
Mill33	-0.774	-1.166	-0.847	-0.956	-0.913
Mill34	-9.615	-4.03	-3.648	-4.935	-7.61

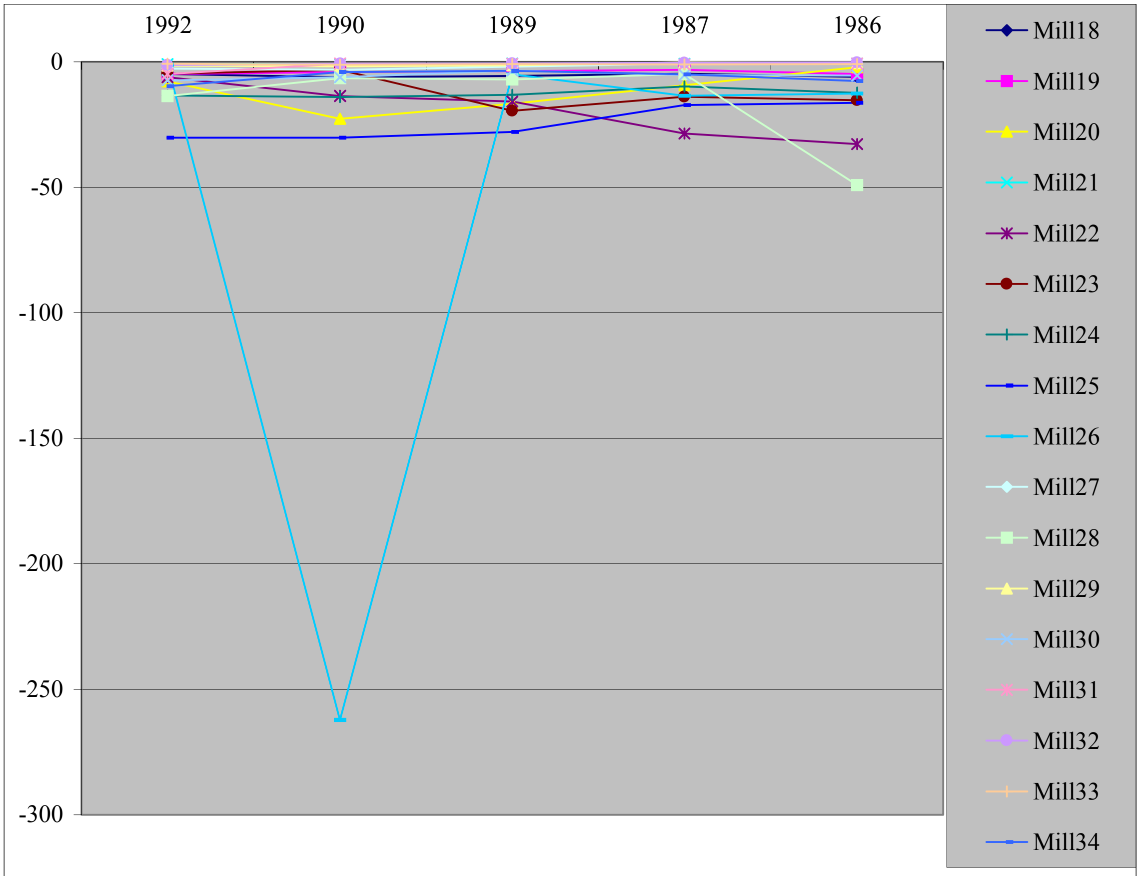

Figure 3.7b: Output-based Shadow Price for TSS: Yunnan

Table 3.8a: Output-based Shadow Price for COD: Fujian

	1992	1990	1989	1987	1986
Mill1	-4.356	-4.873	-5.119	-4.096	-3.502
Mill2	-4.028	-3.834	-3.697	-4.562	-4.6
Mill3	-1.43	-2.073	-2.365	-2.206	-1.882
Mill4	-11.172	-9.177	-9.549	-6.862	-5.305
Mill5	-3.065	-12.49	-11.401	-10.305	-4.521
Mill6	-0.517	-0.421	-0.377	-0.552	-0.551
Mill7	-2.55	-0.976	-1.389	-1.338	-1.304
Mill8	-1.888	-1.798	-0.974	-0.765	-1.197
Mill9	-8.245	-6.657	-6.932	-9.918	-8.251
Mill10	-0.82	-0.267	-0.339	-1.501	-1.626
Mill11	-1.478	-3.922	-3.603	-1.091	-0.948
Mill12	-0.962	-1.029	-0.775	-2.749	-2.33
Mill13	-1.178	-1.254	-1.011	-1.207	-1.238
Mill14	-8.082	-7.783	-9.868	-6.515	-7.439
Mill15	-21.613	-4.151	-6.539	-18.082	-14.342
Mill16	-2.975	-5.534	-4.12	-4.212	-9.286
Mill17	-2.995	-1.374	-1.42	-0.962	-0.931

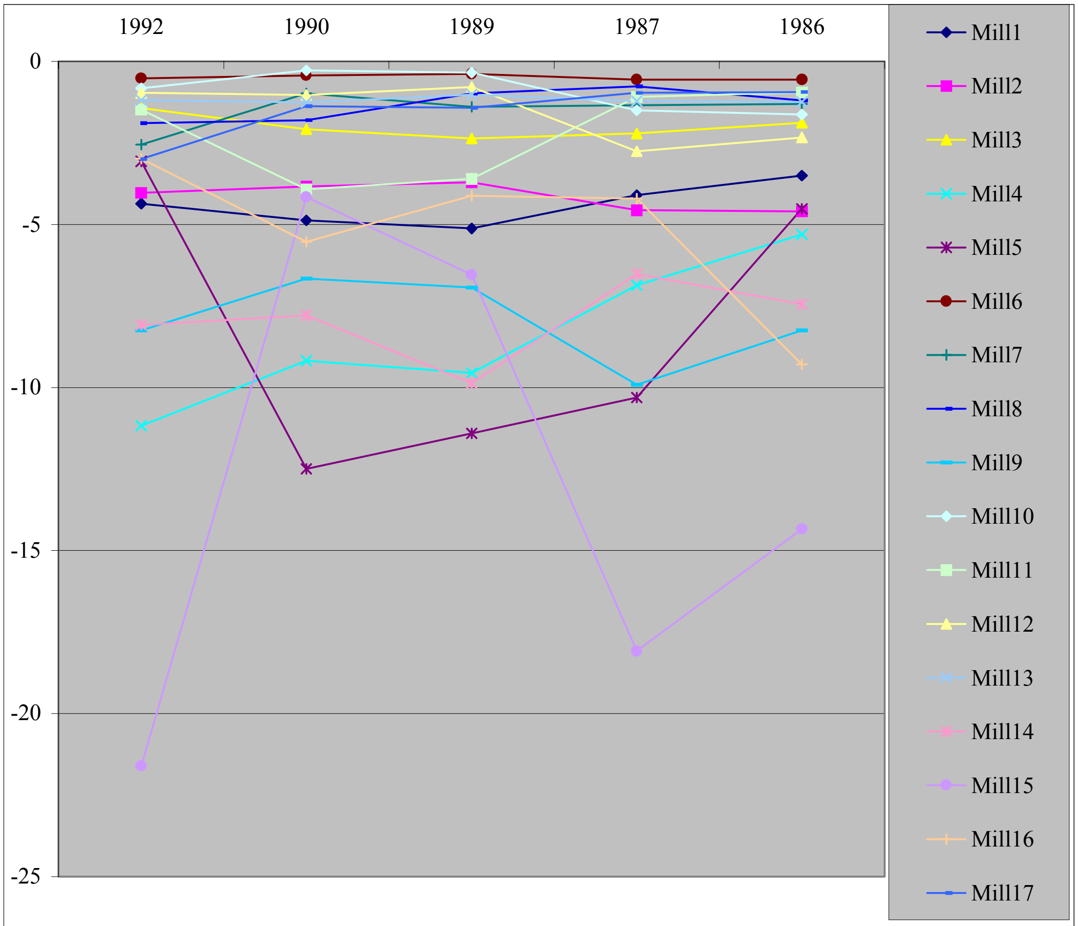

Figure 3.8a: Output-based Shadow Price for COD: Fujian

Table 3.8b: Output-based Shadow Price for COD: Yunnan

	1992	1990	1989	1987	1986
Mill18	-0.739	-1.19	-1.331	-1.211	-2.747
Mill19	-0.27	-0.284	-0.282	-0.325	-0.597
Mill20	-54.779	-36.434	-34.936	-15.555	-27.015
Mill21	-0.647	-0.702	-1.05	-1.138	-0.742
Mill22	-0.874	-0.958	-1.071	-1.829	-3.014
Mill23	-3.978	-3.102	-3.899	-3.146	-3.658
Mill24	-1.082	-2.238	-2.135	-1.884	-3.929
Mill25	-2.177	-1.999	-1.829	-1.036	-0.976
Mill26	-1.194	-2.936	-0.766	-0.465	-0.447
Mill27	-0.331	-0.624	-0.981	-0.616	-0.577
Mill28	-2.161	-1.061	-1.322	-1.267	-9.332
Mill29	-1.112	-0.613	-0.536	-0.334	-0.201
Mill30	-0.458	-1.614	-0.266	-0.425	-0.452
Mill31	-0.838	-1.109	-1.187	-1.661	-2.395
Mill32	-0.148	-1.725	-0.407	-0.708	-0.443
Mill33	-0.321	-0.384	-0.337	-0.47	-0.36
Mill34	-2.553	-0.817	-0.637	-0.686	-1.521

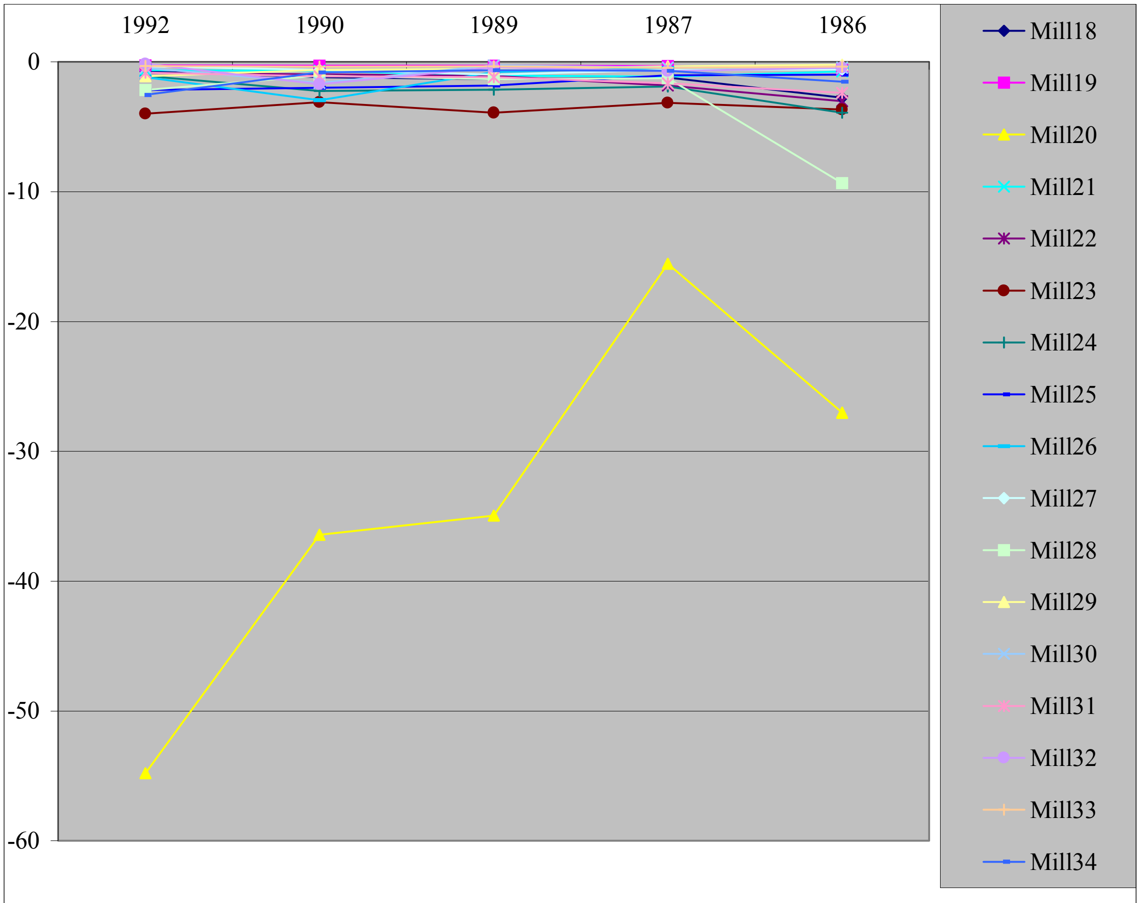

Figure 3.8b: Output-based Shadow Price for COD: Yunnan

Chapter 4

Conclusions

Balancing economic growth and environmental protection is a challenge to all the nations in the world. As stated in the introduction chapter, this dissertation study focuses on three critical issues that face Chinese policy makers but should be of interest to more people around the world in environmental management field: Has current policy led to environmental improvement? How the policy affects the economic performance of industry? And, is the policy implemented in a way that brings about maximum economic efficiency while achieving its targets?

In chapter two we examined the impact of pollution levy system on the environmental and efficiency performance of China's paper industry. Unlike previous studies on the topics, which related effluent levels directly to economic policy, we based our analysis on a frontier production model framework, which allows for the analysis of basic production technology as well as the derivation of firm- and time-specific efficiency measures. We incorporated pollutants as the input factors in our frontier production function, which facilitated us to examine firms' production decision when they were under environmental regulation. Our results showed paper mills' decision on effluent emissions were sensitive to the intensity level of levy enforcement, and the implementation of levy did not significantly affect these mills' efficiency performance. These results do not support the conventional distrust toward the economic instrument-pollution levy system. They proved that the economic instrument could be very effective in inducing polluting firms to abate their emissions without significantly damage their productive efficiency at this stage in China. This points the reason that the actual pollution problem is not lessening over time to another possibility particular to Chinese situation: the large variation in the enforcement of pollution control policy.

In the third chapter we used a distance function approach to derive shadow prices for pollutants for the same group of paper mills in chapter two. The purpose of this chapter was to examine the allocative efficiency of current environmental policy with an implication of the regional difference in policy enforcement. We derived revenue-based shadow prices and output-based shadow prices for three types of pollutants. The variation of the revenue-based shadow prices across mills and its trend over time indicates the efficiency level of current pollution control policy as well as the variation of regional policy enforcement. The trend in the output-based shadow prices indicates the change of effort level in each mill in reducing the pollution load. Our results showed large variation across mills in revenue-based shadow prices and little convergence over time. The output-based shadow prices for individual mills were largely stable too. These results indicate that current policy was not efficiently enforced and there existed significant regional variation in the commitment to environmental improvement, and the regional variation was a pretty rigid pattern over time.

Combining findings from two empirical chapters we conclude that current policy-pollution levy system as an economic instrument in particular-was effective, but only in the places where local authorities committed to strict enforcement. The large variation of the local enforcement characterizes the basic scenario of China's struggle in protecting its fragile water and air quality. The fact that China's environment is deteriorating over the last two decades is largely due to the differential views among its regional decision-makers on the conflict between economic target and environmental quality.

Policy renovations under discussion are three folds. The first is to raise the levy rate. The second is to implement tradable permit system. And the third is to centralize the environmental authority. Raising the levy rate must be accompanied by centralizing the environmental authority. The impact of levy raise will be insignificant if the enforcement can still varies across regions. Centralizing environmental authority is a way of bringing in uniformed enforcement, but increase in the enforcement cost needs to be assessed. Due to the evidence of local enforcement as a function of local characteristics ("endogenous enforcement" studies by the World Bank group), tradable permit system might be a favorable choice in the future. It provides a mechanism to accommodate local differences, legalize differential pollution control, therefore, probably lead to greater economic efficiency in the effort to control pollution.

There is much limitation to the study we have conducted. We identified regional disparity in policy enforcement but we do not know what are the exact reasons that caused the differences. Further analysis of these regional differences can provide valuable insights to policy makers and researchers in China and all over the developing world. Our data only include two of China's southern provinces. Although certain tests have been conducted to indicate the generality of our results, it will be of value to work on a more complete national data. Extensive data collection, more costly and time consuming though, is still possible. The mills in our sample are mostly state-owned mills. It is of course of great value to examine how state-owned (and larger) mills fared under economic reform and environmental regulations, as they are primary targets of these two lines of national campaigns. It is also interesting to learn how newly-born industrial sectors-namely, private, township and village enterprises-respond to these major national policies, as they are becoming increasingly important both in terms of contribution to GDP and in terms of share in environmental liability. We have estimated an output distance function in our second empirical chapter to derive shadow prices for pollutants. What we examined is the opportunity cost of pollution abatement of the firms in terms of foregone output and revenue. We may gain some additional insights if an input distance function can be estimated. In that way we base our study of opportunity cost of pollution abatement on the substitution ability between effluent emissions and regular inputs. Input distance function framework in addition to the output distance approach can provide a complete picture of the structure of pollution control technology in China's paper industry. These issues need to be addressed in the future.

VITA

Jintao Xu was born in Shijiazhuang City, Hebei Province, China, on June 21, 1963. He earned his Bachelor of Engineering degree at Jilin University of Technology, Changchun City, Jilin Province, China, in 1984, and his Master of Agriculture degree at Beijing Forestry University, Beijing, China, in 1988. He was a research fellow at China National Forestry Economics and Development Research Center for seven years before coming to the United States in 1994. He received Master of Arts degree in economics at Virginia Tech in 1996. Jintao Xu will be conferred Ph.D. in forestry in August 1999.