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ENVIRONMENTAL REGULATION AND PRODUCTIVITY: EVIDENCE FROM OIL REFINERIES

Eli Berman
Linda T.M. Bui

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ABSTRACT

We examine the effect of air quality regulation on the productivity of some of the most heavily regulated manufacturing plants in the United States, the oil refineries of the Los Angeles (South Coast) Air Basin. We use direct measures of local air pollution regulation in this region to estimate their effects on abatement investment. Refineries not subject to these local environmental regulations are used as a comparison group. We study the period of increased regulation between 1979 and 1992. On average, each regulation cost \$3M per plant on compliance dates and a further \$5M per plant on dates of increased stringency. We also construct measures of total factor productivity using plant level data which allow us to observe physical quantities of inputs and outputs for the entire population of refineries. Despite the high costs associated with the local regulations, productivity in the Los Angeles Air Basin refineries *rose* sharply during the 1987 - 1992 period, a period of *decreased* refinery productivity in other regions. We conclude that measures of the cost of environmental regulation may be significantly overstated. The gross costs may be far greater than the net cost, as abatement may be productive.

Eli Berman
Boston University
270 Bay State Road
Boston, MA 02215
and NBER
eli@bu.edu

Linda T.M. Bui
Boston University
270 Bay State Road
Boston, MA 02215
ltbui@bu.edu

Environmental Regulation and Productivity: Evidence from Oil Refineries

Environmental regulation is commonly thought to reduce industrial productivity. Although there has been great concern surrounding the productivity slowdown, the level and stringency of environmental regulation has continued to increase steadily worldwide since the early 1970s as environmental quality has assumed growing importance on both the political and public agenda. In the United States, total pollution abatement control costs are approximately 1.5-2.5% of GDP per year.[1] Pollution abatement control expenditures (PACE) in manufacturing, alone, have increased by more than 137% between 1979 and 1993 at a compound annual rate of approximately 6%. By all indications, this trend will continue.

The gross costs associated with meeting environmental regulation (as measured by PACE) are very high and of growing concern. But does this accurately reflect the *real* costs of regulation? PACE may, in fact, either under or over-estimate the actual costs of regulation. For example, if pollution abatement control expenditures are mismeasured, and miss such costs as the time spent by managers dealing with environmental regulators and regulations, PACE will under-estimate the actual cost of regulation. On the other hand, if environmental regulation induces plants to install cleaner, more efficient technology, pollution abatement expenditures may be productivity enhancing so PACE will over-estimate the actual cost of environmental regulation. In either case, the gross cost of regulating the environment may differ significantly from the net cost.

A large body of literature attempts to quantify the effect of environmental regulation on productivity. Previous empirical work has shown that environmental regulation has had an adverse effect on productivity. In some cases, researchers have found that it has contributed significantly to the productivity slowdown in the U.S. Yet, the most recent discussions on the relationship between environmental regulation and productivity suggest that the effects need not be negative -- and may, indeed be positive (see Jaffe et all (1995)). An obvious question that arises from this literature is, why is there no consensus on the effects of environmental regulation on productivity?

Estimates in this literature may well be confounded by selection bias and measurement error, which may explain the existence of the conflicting results. Selection bias may occur because

[1] Gross abatement costs, which include transfers to government agencies. Source: PACE Survey, 1993. 1993 figure is $17555 and 1979 figure is $7399.9 in thousands of current dollars.

plants that can most easily implement pollution reduction may actually choose to undertake such abatement activity without the impetus of regulation. Plants may choose to abate for many different reasons, including for strategic purposes or in conjunction with changes in their production process that include cleaner, more efficient technologies. This will depend upon the characteristics of the market in which the plant is competing. Regardless of the reason for the reduction, if researchers measure the effect of environmental regulation on economic outcomes by looking at the relationship between the outcome of interest (eg. productivity) and pollution abatement control expenditures without taking into account the fact that some plants may have *voluntarily* undertaken pollution abatement activities, the estimated relationship will *underestimate* the effect on productivity of regulations which force plants to abate.

Measurement error may also impart a bias, probably towards zero, on the relationship between environmental regulation and economic outcomes that are estimated from a regression of productivity on abatement. Pollution abatement control expenditures may sometimes be difficult to classify. For example, if a plant purchases a new boiler to replace an existing boiler and the new piece of equipment is more efficient and produces less emissions, managers must decide whether part or all of this expenditure should be included as pollution abatement control. The questionnaires that managers must answer to provide data on PACE are often confusing on this point, asking them to classify as PACE all expenditures that they would not have made if no pollution regulations were in place.[2] In addition, the allocation of managerial time devoted to pollution control is difficult to measure. Thus measurement error in PACE data may be responsible for understating the effect on environmental regulation on productivity.

In this paper we take two approaches to investigate the effect on productivity of a specific set of environmental regulations that affect the petroleum refining industry -- one of the single most regulated industries in the United States and one which has had a noticeable decline in employment over the past two decades. In the first approach we use micro-regulatory changes to provide variation between regions to address the estimation problems that have frustrated research to date and get directly at the consequences of environmental regulation on the petroleum industry. We deal with the problems of selection and measurement error bias by estimating the effects of regulatory changes on PACE directly. Thus we examine only variation in abatement behavior of

[2] From an economist's point of view, the questionnaire asks exactly the correct question. It is the question that tries to determine what the counterfactual would be. In practice, however, the question is very difficult to answer.

petroleum refining plants *induced* by changes in local environmental regulation.

In the second approach, we take petroleum refining plants located in a region in Southern California, the South Coast Air Basin, and compare productivity changes in these refineries to those outside the scope of local regulations. We construct measures of total factor productivity using unique data involving detailed products and material records from the Census of Manufactures. We make use of several different measures of productivity to check for the robustness of our results.

Our methodology requires substantial variation in regulations and abatement behavior, which we found by examining *local* regulations and using data on individual plants. In particular, we focus our attention on the set of regional environmental regulations in California enacted by the South Coast Air Quality Management District (SCAQMD), that affect petroleum refining activities. We have constructed a unique data set for this purpose which matches SCAQMD regulations to plant level data on production and abatement collected by the Census Bureau and study how petroleum refineries react to environmental regulations at their adoption dates, compliance dates, and at dates when existing regulations become more stringent. We use two comparison groups in our analysis: the rest of the nation, and the rest of California combined with Texas and Louisiana, allowing the interpretation of our results as predictions of the consequences of applying the local air pollution regulations in the SCAQMD on the average refinery located outside of this regulatory area. Doing so allows us to distinguish the effects of *local* regulation from those of pervasive (state or national) regulations.

The SCAQMD governs air pollution in the South Coast Air Basin of Southern California.[3] We make use of this regulatory region because the South Coast Air Basin has some of the worst air quality in the nation as well as some of the most stringent air pollution regulations. Since the development of national uniform air quality standards for the six criteria air pollutants[4], the South Coast Air Basin has been out of compliance with the federal standards for three of the six pollutants, and has reached compliance for a fourth only in 1994 (check).[5] The air pollution regulations developed by the SCAQMD are of particular interest because some have recently been adopted

[3] This region includes Los Angeles, Orange, Riverside, and the non-desert portion of San Bernardino Counties.

[4] The six criteria air pollutants are SO_x, NO_x, ozone, PM_{10}, airborne lead, VOCs.

[5] South Coast Air Quality Management District, Annual Report, 1994.

nationally by the U.S. Environmental Protection Agency (EPA) and they are often considered for adoption by other AQMDs.

We find strong econometric evidence that South Coast regulations have induced very large investment in air pollution abatement capital and visual evidence that it has induced increases in abatement operating costs. Surprisingly, we find no evidence that these large costs incurred to abate emissions had more than a negative, transitory effect on the productivity of South Coast refineries. These refineries suffered a productivity decline in the 1980s but recovered to the national average by 1992, despite their heavy regulatory burden. In fact, petroleum refining productivity in the South Coast Air Basin between 1987-1992 rose sharply during this period -- both when several environmental regulations came into compliance and when productivity was *falling* in this sector elsewhere in the country. What this suggests is that pollution abatement control expenditures associated with the SCAQMD regulations may, in fact, have been productivity enhancing so that the gross cost of pollution abatement may be an over-estimate of the net cost of regulation.

A natural question that arises from this result is: if environmental regulations in the SCAQMD increased the productivity of oil refineries, why haven't plants adopted the same productivity enhancing technology elsewhere? One possible explanation for this counter-intuitive result comes from the "real options" hypothesis of investment under uncertainty. These issues are discussed further in Section 7. Anecdotal evidence we have taken from firms and regulators in the SCAQMD region support this hypothesis.

The rest of the paper is organized as follows. In Section 2 we discuss the existing literature on the effects of environmental regulation on productivity. Section 3 provides background on petroleum refining and the relevant environmental regulations affecting this industry in California. Section 4 gives the framework from which the econometric model is derived, and in Section 5 we discuss the data that will be used in the estimation. Section 6 has a discussion of the results and Section 7 has concluding remarks and suggests avenues for further research.

2. Literature Review

The belief that environmental regulation is detrimental to productivity is reflected in numerous studies that have focused attention on the role that environmental regulation has played in the productivity slowdown that started in the early 1970s (see Christiansen and Haveman (1981) for a good survey). Recently that belief has been questioned. Environmental regulation may be *productivity enhancing*, by introducing cleaner, more efficient technologies in the workplace. This dichotomy of beliefs underscores the fact that theory, alone, cannot predict the outcome of environmental regulation on productivity. (For a survey of the two opposing views, see Jaffe et al (1995).)

Several different approaches have been taken in the literature to measure the productivity effects of environmental regulation. The three most common approaches include growth accounting, macro-economic general equilibrium modelling, and econometric estimation. A good example of the growth accounting methodology is given in Denison (1979). Denison measures changes in total factor productivity and estimates the incremental environmental cost due to regulation post 1967. Environmental costs measured as annual operating, maintenance and depreciation costs are assumed to crowd out "productive" investment on a one-for-one dollar basis. Denison finds that environmental regulation post 1967 is responsible for between 13-20% of the productivity loss during this period. One of the difficulties in interpreting the results of the growth accounting methodology is that environmental quality is not measured as an "output" of the production process, and therefore will over-estimate the productivity loss associated with regulation (Solow (1992)). Furthermore, highly aggregated studies of the sort done by Denison and many others miss the importance of sectoral differences which drive many of the observed results.

Using a general equilibrium macro-model, Jorgenson and Wilcoxen (1990) model the U.S. economy including a long-term growth component with and without environmental regulation and find that in the absence of all environmental regulation, the capital stock would have been 3.792% higher and GNP would have been more than 2.5% higher. Jorgenson and Wilcoxen separate out the effects of the removal of environmental operating and maintenance costs (responsible for 0.544% reduction in the capital stock and 0.728% reduction in GNP, respectively) from the economy and abatement capital expenditures (2.266% and 1.290%) in an attempt to detail differences in types of environmental regulation. The authors find strong sectoral effects, especially in chemicals, petroleum refining, and primary metals.

There are also several econometric studies that estimate the relationship between environmental regulation and productivity. Good examples include Gray (1987) which investigates the effect of OSHA and EPA regulations on productivity and finds that together, they account for 30% of the measured slowdown in productivity in the 1970s; Gollop and Roberts (1983), who focus on fossil fueled electric power plants and estimate that 44% of the productivity slowdown was attributable to regulation in this sector between 1973 and 1979; Barbera and McConnell (1986, 1990), who find in two separate papers that average capital and labor productivity had been suppressed due to environmental regulation during the 1970s -- and that the results differ across sectors -- chemicals, primary metals, and stone, clay and glass showing a reduction in labor productivity and average capital productivity growing in primary metals after 1973.

In general, these studies provide a consistent finding of small, negative effects of regulation on productivity. The literature indicates that the effects of regulation on productivity (measured as either total factor productivity, labor productivity, or capital productivity) may differ strongly across industrial sectors, and that different measures of productivity may lead to slightly different results. Pollution intensive industries that bear the burden of environmental regulation show the largest negative effect on productivity.

Jaffe et al (1995) note, however, that market based regulations may have a very different effect on productivity than the traditional command and control type strategies that have been studied in the above mentioned articles. Because market based controls provide incentives to plants to continually update and improve their abatement methods, productivity may actually increase under this type of regulation.

3. Background

Historically, the petroleum industry has played an important role in the economy of California. In 1990, the value of California oil and gas production was more than $5.5 billion.[6] California is the fourth largest producer of crude oil in the nation and has 24 operating refineries within the state, with a capacity of nearly 1,870,000 bbls/day. This industry, however, has been pollution intensive and has contributed to the air pollution problems of California as well as to its economic well being. Below, we outline some of the relevant characteristics of this industry and provide a description of the regulatory structure under which this industry operates in California.

A. Petroleum Refining in California

In the simplest terms, petroleum refining converts crude oil into useable products, such as gasoline, asphalt, and jet fuel. This process heats crude oil to separate its components into several final products. By altering the temperature and the specific gravity of the crude oil, refineries may alter the over-all composition of their final products. For example, if the price of jet fuel increased

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[6] California Department of Conservation study, "A Profile of California's Oil and Gas Industry, 1992-1994," (1996).

significantly, a refinery may produce less motor gasoline and more jet fuel by changing the temperature to which the crude is heated.

Table 1 presents the composition of petroleum refining outputs by percentage volume for 1992 and the corresponding price per barrel of output for 1977-1992. Gasoline, fuel oil, and jet fuel were the three leading products refined in California. The price per barrel of finished product varied widely during this time period. Between 1977 and 1992, gasoline prices increased by approximately 153% (164% and 168% for fuel oil and jet fuel, respectively). Although output prices may have risen dramatically during this time period, the costs of inputs also rose. This wild fluctuation of input and output prices dictates special care in measuring productivity.

California refineries are unusual as they use primarily domestic sources of crude oil in their production. As a percent of the value of materials used in 1992, 45% of input costs at US refineries were due to domestic crude and 34% were from foreign crude. By volume, measured in barrels per day of crude oil, California refineries use 96% domestic crude and only 4% foreign crude. Of the domestic crude, 43% is from California and 46% is from Alaska.[7] Table 2 summarizes the average price per barrel of crude oil from domestic and foreign sources. Notice that corresponding to the large increase in price of refined petroleum products between 1977 and 1982, was a similarly large increase in the cost of domestic and foreign crude oil inputs (190% and 150% increase, respectively).

[Table 2 somewhere near here]

One of the consequences of using California crude in their production process is that California crude is "heavy" crude. This increases both the cost of extracting the oil as well as refining the oil. The price for California crude is largely dependent upon the price of Alaskan and North Slope crude oil[8] -- its major competitor in the California petroleum refining market.[9]

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[7] California Department of Conservation study, "A Profile of California's Oil and Gas Industry, 1992-1994," (1996).

[8] Alaskan/North Slope crude oil typically is a higher quality, "lighter" crude oil which is less expensive to refine.

[9] The Merchant Marine "Jones Act" states that Alaskan/North Slope oil must move in American tankers and the legislation opening up Alaska's Prudhoe Bay prohibits this oil from being exported -- forcing the Alaskan oil to be marketed exclusively in the U.S. In a California Department of Conservation study, they claim that this has kept Alaskan crude oil prices artificially low. This ban was lifted after 1996. (See California Department of Conservation study, 1996.)

B. Air Pollution Regulations and Petroleum Refining in California

Federal involvement in environmental regulation started in 1970 with the creation of the United States Environmental Protection Agency (EPA). Prior to 1970, environmental regulation fell under State and local jurisdiction. The lack of coordination between States and locales in setting environmental standards, as well as a belief that environmental regulation was costly to industry and inhibited competition, led to a fear that there would be a "race to the bottom" in setting environmental standards. Therefore one of the EPA's primary mandates was, and is, to set uniform national standards for environmental quality. Individual states are responsible for developing State Implementation Plans (SIPs) that must be approved by the EPA, which indicate how the state will meet the federal environmental standards. States that fail to provide acceptable SIPs may have federal monies withheld by the EPA or lose control over setting environmental regulations within their own state.

In general, federal environmental regulation is limited to setting national standards based on health criteria. Some exceptions are the minimum level environmental regulations that are imposed on all new sources of pollution (New Source Performance Standards, (NSPS)), and regulations in effect for non-attainment regions and regions considered to be "pristine" (Prevention of Significant Deterioration (PSD) regions). Existing sources of pollution and mobile sources are typically regulated at the State and local level.

Within California, air pollution is regulated by the California Air Resources Board (CARB). Individual air basins are regulated by local authorities that fall under the jurisdiction of the CARB. There are a total of 34 local air pollution control districts (APCD) in California. Typically, mobile sources of pollution are regulated at the state level and stationary sources are regulated by the individual APCDs.

Petroleum production in California largely is located in six separate APCDs: the South Coast Air Quality Management District, the San Joaquin Valley United Air Pollution Control District, the Bay Area Air Quality Management District, the Santa Barbara County Air Pollution Control District, the Ventura County Air Pollution Control District and the Monterey Bay Air Pollution Control District. Within these six Districts, the first three cover the majority of the State's population and petroleum production, but the most stringent regulations are found in the SCAQMD so we focus our attention only on this region.

In terms of their contribution to actual levels of pollution, Table 3 summarizes South Coast petroleum refinery emissions of SO_x and NO_x as a percentage of total California emissions between

1981 and 1991. For both pollutants, there have been substantial declines in refinery emissions -- much larger than the reductions in emissions from regulated, non-refinery sources. This suggests that the regulations in place in the SCAQMD have caused refineries to clean up their emissions at a faster rate than other regulated industries in the same region.

[Table 3 somewhere near here]

Tables 4 and 5 summarize air pollution abatement control expenditures in California. Data on the U.S., Texas, and Louisiana are provided for contrast. In almost every year, environmental costs incurred by California petroleum producers was larger than those incurred in either Texas or Louisiana, although both of those regions have more oil production and refining activity. California's share in total U.S. petroleum air pollution abatement control expenditures rose from 17 to 44% between 1982 and 1992.

[Tables 4 and 5 somewhere near here]

The higher PACE costs in California reflect both the (differentially) higher volume and stringency of regulation in the state. South Coast regulations affecting petroleum refineries are discussed in Section 5 below. (A list of regulations is given in Appendix A.)

4. A Framework for Estimation

Earlier, we emphasized the need to estimate the effects of environmental regulation using a method that can address measurement error and sample selection biases. In this section we derive estimating equations and discuss estimation. First we present a model of production that includes quasi-fixed factors which have their levels set by constraints rather than by cost minimization alone. We treat as quasi-fixed factors those inputs constrained by environmental regulation: pollution abatement capital and abatement operating costs (which include costs of labor, materials, and services). Assume that these are complete measures of the costs of abatement at the plant level. Labor, materials and capital are variable factors.

Assume a cost minimizing firm operating in perfectly competitive markets for inputs and output. There are M "quasi-fixed" inputs and L variable inputs. The variable cost function has the form:

$$CV = H(Y, Z_1, \ldots, Z_M, P_1, \ldots, P_L) \qquad (1)$$

where Y is output, the Z_m are quantities of quasi-fixed inputs, and P_l are prices of variable inputs.

Petroleum refineries are subject to a variety of air quality regulations that constrain their behavior. Generally these regulations mandate the use of certain abatement equipment or set maximum emission levels, though there are other forms of regulation. (A full description is given in Appendix A.) Refineries typically comply by installing equipment, redesigning production processes, changing their mix of inputs, increasing maintenance and putting much more effort into measuring and reporting emissions.

Let R be a binary variable measuring regulation. The effect of regulation on abatement activity can be written as:

(2) $$\frac{\Delta Z_m}{\Delta R} \quad for\ m = 1\ to\ M.$$

The demand for variable input X_i may be derived from the solution to the profit maximization problem and approximated with a linear function of the form:[10]

(3) $$X_i = \alpha_i + \pi_i Y + \sum_m^M \beta_{i,m} Z_m + \sum_l^L \gamma_{i,l} P_l \ .$$

Environmental regulation potentially affects the demand for variable inputs X_i through its effect on output, abatement activity (Z) and factor prices.

Two Measures of Effects on Productivity:

Total factor productivity is given by:

(4) $$TFP = \frac{Y}{V}, \quad where\ \ Y = \sum_k^K p_k Y_k , \quad V = \sum_m^M q_m Z_m + \sum_l^L q_l X_l .$$

Here, p and q represent output and input prices, respectively. This form accommodates both multiple inputs and multiple outputs in production which is important as refineries produce a large range of products other than motor gasoline. Approximately 80% of the value of input is crude oil.

Total factor productivity growth can then be measured as:

[10] A linear approximation is due to data limitations on pollution abatement capital services, where investment flows are measured rather than capital stocks.

(5) $$T\dot{F}P = \dot{Y} - \sum_{m}^{M} s_m \dot{Z}_m - \sum_{l}^{L} s_l \dot{X}_l .$$

A dot over the variable indicates a rate of change and s_j is the cost share of factor j. In practice we use a divisia index of outputs as well as of inputs, which we suppress here for notational simplicity. Maintaining the assumption that all abatement costs are measured by the Z_m, if abatement inputs are entirely unproductive, this equation indicates that the effects of regulation on productivity growth can be directly measured by examining its effects on abatement inputs, Z_m. This is the approach taken by Gray (1987) in measuring the cost of abatement.

Our experience visiting oil refineries leads us to question both the assumption that abatement costs can be well measured and the assumption that those costs reflect entirely unproductive activity. Costs of abatement are incompletely measured if they are only part of the job of a manager or engineer. Similarly, air pollution is sometimes abated by switching to higher quality and more expensive crude oil. That extra cost was not included in reported abatement costs in the two refineries we visited. On the other hand, abatement activities may be productive. For example, they may induce productive recycling of gases to produce more output or to co-generate power.

An alternative is to ignore the distinction between abatement and other inputs in the measurement of total factor productivity. Let V_l measure the sum of abatement and conventional inputs of type l (labor, capital services, crude oil, other materials). Then:

(6) $$TFPA = \frac{Y}{\sum_{l}^{L} s_l V_l} .$$

Compared to the measure in Equation 4, this measure has the advantage of relaxing both the assumption that all abatement activity is captured in Z and the assumption that Z is entirely unproductive.

Estimation:

We estimate the effects of regulation on Z by measuring regulations directly. That procedure is designed to avoid the biases due to sample selection, measurement error and any potential omitted variables that would occur if we used Z as a regressor -- the common practice in the literature. R is a count of the number of regulations in effect.

The effect of regulation on abatement inputs, Z, can be estimated by:

(7) $$Z_m = a_m + b_m R.$$

We expect the sign of b_m to be positive, as regulations generally increase abatement activity. An exception would occur if a regulation increased one type of activity but decreased another through substitution.

The panel of plants allows estimation including a separate intercept for each plant that remains for more than one period. Equation 7 can be taken to data as:

(7') $$Z_{it} = c_i + d_t + b_m R_{it} + e_{it},$$

assuming $E(R_{it}, e_{it}) = 0$ or,

(7'') $$\Delta Z_{it} = \Delta d_t + b_m \Delta R_{it} + \Delta e_{it},$$

assuming $E(\Delta R_{it}, \Delta e_{it}) = 0$ for $i = 1,\ldots,N_t$ plants and $t = 1,\ldots,T$ years.[11] In some specifications we can include separate intercepts in (7'') for regions. Note that for each South Coast refinery subject to a new regulation, estimation is achieved by comparison to a refinery in another region not subject to the new regulation. This comparison with refineries in other regions is informative for policymakers as they often turn to the South Coast for examples of regulations worth adopting to meet federal ambient air quality standards -- standards which are constantly under pressure to be changed to a more stringent level. A local regulator considering adopting a South Coast regulation could consult b_m from (7'') for an estimate of the cost in abatement activity.[12]

An alternative approach to measuring the costs of environmental regulation is to use the more general approach in Equation 6, which can be calculated for fixed prices in Census years. Census materials and product files allow a rare opportunity to estimate TFP controlling for changes in the value of inputs (including some quality change) using fixed input prices. This has several advantages over the standard practice of fixing the shares, s, using regression coefficients and calculating TFP as a residual. First, measurement error does not impart a bias on estimated averages as it does on regression coefficients. As discussed above, measurement of PACE and capital are especially suspect, particularly at the plant level.[13] Second, this approach allows us to

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[11] At most two new regulations are introduced per year, and none of these regulations was ever withdrawn, so $0 \leq \Delta R \leq 2$.

[12] The coefficient b_m should be interpreted as the average effect of a number of regulations.

[13] See Griliches (1986) for a discussion of measurement error bias in plant level data.

be nonparametric about a production function, avoiding possible bias due to mis-specification. Third, we avoid the possibility of endogeneity bias if output affects the choice of inputs. Finally and most importantly, we can calculate productivity using measures of physical quantities for a number of outputs and inputs that would imply an impractical number of covariates in regression analysis even with fairly large samples. With these Census estimates we compare productivity in the South Coast refineries to that in comparison regions.

We measure employment annually from 1979-93, productivity in census years 1977, 82, 87 and 92. Regulations are recorded annually from 1977-93. Estimation of (7'') requires matching plants across years and with regulations. We describe the data before turning to results.

5. The Data

We make use of plant level data for petroleum refineries (SIC 2911) from two sources -- the Survey of Pollution Abatement and Control Expenditures (PACE), which are linked to plant records contained in the second source and the Longitudinal Research Database ("LRD") panel compiled by the Center for Economic Studies of the Census Bureau. PACE measures expenditures on pollution abatement are available by abatement categories -- air, water, and hazardous wastes -- are also classified by type -- end of line capital outlays, operating and maintenance costs, and depreciation. We use plant level observations on the prices of inputs and outputs from a third source, the Census of Manufactures.

The LRD is constructed from the Annual Survey of Manufactures, which samples the population of manufacturing plants, including large plants (250 or more employees) with certainty. Entry and exit of large plants is well measured by presence or absence on a year-to-year basis. From these data we use the employment, value added, and capital investment variables.

A subset of the data on local regulations originally constructed for the SCAQMD in Berman and Bui (1997) is used in this paper. This regulatory data set matches individual air pollution regulations to specific plants located in the SCAQMD.

In total, we identified 11 separate regulations affecting petroleum refining in the SCAQMD during this time period. For each regulation, we tracked their adoption dates, compliance dates, and dates of increased stringency, as well as the pollutant involved and the required method of compliance. This mapping of regulations to affected industries was done in consultation with the local regulators and with an environmental quality engineer at a refinery who hosted a plant visit. From this information we created the variable R_{it}, which is a count variable for the number of regulations in effect for industry *i* in year *t*.

Table 6 describes the PACE sample of refineries. Petroleum refineries are large, capital intensive operations with relatively few employees. Average output is $1.7 billion (1991) with average employment of 372. Air pollution abatement investment is a large cost, averaging $2.1 million per year or 2% of value added. In our sample, 12.9% of plant-years in the population are in California, and 5.6% are in the South Coast Air Basin, which is a significant oil refining center.[14]

Oil refineries generally serve the local market. The proportion of refining capacity in the South Coast Air Basin is approximately the same as the regions' proportion in the population.

Employment and value added decline between 1979 and 1993 in the refining industry. Value added is cyclical, but declined sharply after the 1979 increase in oil prices and did not regain the 1982 level until 1993. Nationally, employment has decreased fairly monotonically over this 15 year period. Census Bureau disclosure regulations prevent a separate description of the South Coast Air Basin plants. They are slightly larger than the national average, in employment, value added, and shipments and follow similar patterns to the national figures in the cyclicality of value added and the decrease in employment.

[Table 6 somewhere near here]

6. Empirical Results

Abatement Investment and Costs

Figures 1 and 2 demonstrate that South Coast refineries have more abatement activity than the U.S. as a whole, providing visual evidence that the South Coast regulations have induced significant abatement activity. Beginning in 1986, when compliance dates for the major regulations begin, South Coast refineries start investing twice as much as those in the rest of the US in abatement as a proportion of shipments (Figure 1). That ratio rises to over four times as much by 1993 when investment to meet "clean gas" regulations begins. Similarly, in the period after 1986 South Coast refineries spent twice as much on abatement operating costs as did other refineries, as a proportion of shipments.

For comparison, we included the two other states with the largest concentrations of oil refining capacity in the country. Note that their trends closely match the national average. Texas

[14] Petroleum refining is concentrated in the Long Beach area of the South Coast Air Basin, just south of Los Angeles.

and Louisiana make good comparison groups for California because they represent a counterfactual with similar concentrations of refining but with far less stringent local air quality regulation. Both Texas and Louisiana use the National Ambient Air Quality Standards as their standards for air quality. California, however, has ambient air quality standards that are more stringent than the national standards. Furthermore, Texas and Louisiana are out of compliance only for ozone, whereas California has been out of compliance with 4 of the 6 criteria air pollutants since the 1970s. Finally, Texas and Louisiana have very different environmental regulatory structures compared to California with relatively little local air quality regulation for manufacturing plants.

Table 7 shows that regulations caused substantial investment in abatement capital. The regulations completely capture the effect of being in the South Coast. That result is robust to using net rather than gross investment, to weighting the regression using sample weights and to using a Louisiana - Texas comparison group rather than the rest of the U.S. Compliance dates with new regulations seem to induce about $3 million in abatement investment for the average refinery, while increases in stringency of regulations induce about $5 million in abatement investment.

Table 8 shows that the change in operating costs is too noisy to learn anything from it. Columns 3 and 4 are the specifications in first differences suggested in Equation 7''.

Productivity

We would like to measure productivity on an annual basis to take advantage of our annual data on regulatory change. Figure 3 shows the ratio of all costs to shipments. This is the inverse of TFP using current, plant-specific prices. South Coast plants seem to have relatively high costs in 1986, but in 1991 and 1992 they are far below the average for U.S. refineries, suggesting a surprising increase in productivity in the period of the greatest increase in regulation and abatement costs.

Could those frequent fluctuations in productivity be due to fluctuations in relative prices rather than in true productivity? To calculate productivity more precisely we used information from the Census of Manufactures (COM). The detailed product and materials data from the COM are a unique resource which give us unusual accuracy in calculating total factor productivity change at fixed prices.[15] Products and materials are identified by seven digit SIC codes. Value (price

[15] Very little previous research has been conducted using this data source. An exception is Roberts and Supina (1996), who use these data to study cross-plant variation in prices and mark-ups.

x quantity) is reported for all codes and quantities are recorded (whenever they are well-defined). This method is extremely well suited for analysis of petroleum refineries, since (unlike many plants) the majority of materials have well-defined quantities. About 80% of materials consumed fall into two seven digit categories: domestic and foreign crude oil (Table 2). For that reason this data source can provide uniquely high quality measurement of total factor productivity for refineries.

We measure TFP=Y/V as in Equation 6, using both varying and fixed prices.[16] The results are given in Table 9, which reports 3 measures of productivity for each Census year in the South Coast and four other regions for comparison. The first measure, labeled P_{it}, uses plant-specific transaction prices for each input and output to calculate TFP. These prices are calculated by dividing values of inputs or outputs by quantities. The second measure, labeled P_t, uses as a fixed price the annual national average of P_{it}, weighted by quantities of inputs, to calculate TFP. Thus, it fixes prices across plants within the same year. The measure of TFP labeled P uses as a fixed price the 4 period average of P_{it}, weighted by a quantities of inputs. These fixed price calculations could be conducted for the 84% of inputs and the 79% of outputs that had well defined quantities. (For a complete list see the note to Table 9.) For all other inputs and outputs we used the P_{it}.

The first column shows that the fixed price measure of TFP for U.S. refineries shows less fluctuation and a quite different pattern than the measure that ignores price fluctuations. The P_{it} measure declines between 1977 and 1982, then increases in 1987 and decreases in 1992. With fixed prices the *P* measure increases between 1977 and 1982, remains stable through 1987 and drops in 1992. The last three rows show average values for the four Census years. These figures reveal that while in variable prices California and the South Coast appear to be more productive than the U.S. average, at fixed prices they are actually less productive as they benefit from using a higher proportion of cheaper domestic crude oil from California and Alaska.

Our major finding is that the apparent productivity increase in the early 1990s for the South Coast refineries in Figure 3 above is replicated in the Census data even when we measure total factor productivity using fixed prices. Figure 4 shows a comparison of the fixed and variable price series for South Coast TFP. The lower line plots the fixed price series from the rightmost column of Table 4. *Surprisingly, productivity is stable during the period of increased regulatory stringency*

[16] An additional option would be to use the Tornquist approach, averaging prices over pairs of years for the same plant. The large number of missing plants in the materials records in 1987 and difficulties matching plants between Census years preclude this approach.

in the mid 1980s and actually rises between 1987-92. Figure 5 illustrates that this pattern is not due to a secular increase in productivity in the U.S. in the early 1990s. In fact, the average refinery in the rest of the country experienced a productivity decline in the 1987-92 period. These basic findings are robust to selecting only plants available in all Census years.[17] They are not due to reallocation of production from less-efficient to more efficient plants, but to increased productivity within plants.[18]

7. Concluding Remarks

What we have found is that during an era of unprecedented levels of air quality regulation and investment in abatement activity in the South Coast there was an increase in productivity levels in petroleum refining. This is true even when South Coast refineries are compared to refineries in other regions of the United States. The lack of a significant decrease in productivity attributable to abatement costs and investments brings into question the general interpretation of measured abatement costs (i.e. PACE) as a net cost of regulation. The productivity results suggest that abatement investments are often productive, and therefore, abatement costs, alone, may severely overstate the true cost of environmental regulation.

One of the most puzzling questions that arises from this work is, why haven't other plants adopted the new technology if it is truly more productive? We can offer two plausible explanations. First, there is a gaming aspect to environmental regulation that is not often discussed. Firms may attempt to pre-empt regulators from choosing a technology standard by introducing new abatement technologies to the regulators for adoption. This practice may be used by a firm to (1) reduce the uncertainty of future regulations, or (2) impose costs on either existing or potential local

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[17] While in principle all plants are surveyed in Census years, the materials files are missing plants accounting for approximately 40% of refinery output in 1987. At this writing, the mystery of the missing plants remains unresolved at the Census Bureau. There is also some exit and entry of refineries in the population. The basic patterns in Figures 4 and 5 are preserved in a sample of continuously present plants.

[18] A useful decomposition of productivity change into within-plant productivity improvements on the one hand, and reallocations of inputs between plants with differing efficiency on the other is:

$$\Delta \frac{Y}{V} = \sum_{i}^{I} \Delta\left(\frac{Y}{V}\right)_i \left(\frac{\bar{V}_i}{V}\right) + \sum_{i}^{I} \left(\frac{\bar{Y}}{V}\right)_i \Delta\left(\frac{V_i}{V}\right),$$

competitors. This argument relies on the regulated firms competing in a local market where all of their competitors must meet the same environmental regulations that they do. This is the case for petroleum refining in California. So, even if the technology is productivity enhancing, the capital costs associated with the new technology may be high and this may prevent plants outside the regulatory region from voluntarily adopting the technology.

A second, somewhat related explanation may be in the "real options" hypothesis of investment under uncertainty. Plants located outside the local regulatory region face two types of uncertainty -- (1) uncertainty regarding future regulatory levels of stringency and (2) uncertainty regarding the efficacy of untested abatement technologies (as well as their impact on production). Because abatement capital costs are high, these plants would prefer to wait as long as possible before making any abatement investment. There is an obvious advantage to being a follower rather than a leader in the adoption of abatement technology. This means that the required rate of return on their abatement investment would have to be great enough (and higher than that in the South Coast) to compensate them for the additional uncertainty that they face. So, if they believe that the SCAQMD regulations are some of the most stringent in the country and might plausibly be adopted outside of the South Coast, they may wait to see how successful the new abatement technology is, before adopting it, themselves, provided that the technology proves to be productive enough and with a high enough rate of return.[19]

Both of these hypotheses have been given support from discussions with the environmental engineers that we have spoken to during our plant visits.

The finding that abatement costs may be productive should help refocus the debate about what are the true costs of environmental regulation. Using PACE measures, costs are commonly estimated at 1-2% of GDP. But this may, in fact, be a gross over-estimate of the true costs. A more appropriate measure would be the cost net of increased production due to "abatement" activity.

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[19] In this case, we might see productivity gains associated with the adoption of the South Coast abatement technologies outside of the South Coast with some lag. Thus far, the necessary data that we would need to test this hypothesis are not yet available.

Selected References

American Petroleum Institute (1990). *The Use of Economic Incentive Mechanisms in Environ mental Management*. API Research Paper #051, Washington.

Barbera, Anthony J. and Virginia D. McConnell (1986). "Effects of Pollution Control on Industry Productivity: A Factor Demand Approach." *The Journal of Industrial Economics*, Vol. XXXV, 161-172.

Barbera, Anthony J. and Virginia D. McConnell (1990). "The Impact of Environmental Regulations on Industry Productivity: Direct and Indirect Effects." *Journal of Environmental Economics and Management*, 18, 60-65.

Bay Area Air Quality Management District (1996). *Rules and Regulations, Volumes 1-3*.

Berman, Eli and Linda T.M. Bui (1997). "Environmental Regulation and Labor Demand: Evid ence from the South Coast" National Bureau of Economic Research Working Paper No. 6299.

California Department of Conservation (1996). "A Profile of California's Oil and Gas Industry, 1992-1994." Department of Conservation, Sacramento.

California Environmental Protection Agency Air Resources Board (1994). *California Air Pollution Control Laws*, 1994 Edition. California EPA, Air Resources Board, Sacramento.

Christiansen, Gregory B., and Robert H. Haveman (1981). "The Contribution of Environmental Regulations to the Slowdown in Productivity Growth." *Journal of Environmental Economics and Management*, 8, 381-390.

Crandall, Robert W. (1981). "Pollution Controls and Productivity Growth in Basic Industries," in *Productivity Measurement in Regulated Industries*, Thomas G. Cowing and Rodney E. Stevenson (eds.), Academic Press, New York.

Dixit, Avinash K. and Robert S. Pindyck. (1994) *Investment Under Uncertainty*. Princeton University Press, Princeton, N.J.

Duffy-Deno, Kevin T. (1992). "Pollution Abatement Expenditures and Regional Manufacturing Activity." *Journal of Regional Science*, Vol 32, No. 4, pp. 419-436.

Gollop, Frank M. and Mark J. Roberts (1983). "Environmental Regulations and Productivity Growth: The Case of Fossil-fueled Electric Power Generation." *Journal of Political Economy*, vol. 91, no.40, 654-674.

Gray, Wayne B. and Ronald J. Shadbegian (1995). "Pollution Abatement Costs, Regulations and Plant Level Productivity." National Bureau of Economic Research Working Paper #4994, January.

Gray, Wayne B. (1987). "The Cost of Regulation, OSHA, EPA and the Productivity Slowdown." *American Economic Review*, 77(5), December.

Griliches, Zvi. (1986). "Economic Data Issues," in *Handbook of Econometrics, Volume III,* (Z. Griliches and M.D. Intriligator eds.) Elsevier Science.

Hahn, Robert W. (1989). "Economic Prescriptions for Environmental Problems: How the Patient Followed the Doctor's Orders." *Journal of Economic Perspectives*, Vol. 3, No. 2, 95-114.

Jaffe. Adam B., Steven R. Peterson, Paul R. Portney, and Robert N. Stavins, (1995). "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?" *Journal of Economic Literature*, Vol. XXXIII, pp. 132-163.

Jorgenson, Dale W. and Peter J. Wilcoxen (1990). "Environmental Regulation and U.S. Economic Growth." *RAND Journal of Economics*, Vol. 21, No. 2, Summer, 314-340.

Kopp, Raymond J. and V. Kerry Smith (1981). "Productivity Measurement and Environmental Regulation: An Engineering - Econometric Analysis." in *Productivity Measurement in Regulated Industries*, Thomas G. Cowing and Rodney E. Stevenson (eds.), Academic Press, New York.

Roberts, Mark J., and Dylan Supina (1996) "Output price, markups and Producer Size," *European Economic Review* 40, 909-921.

South Coast Air Quality Management District (1996). *Rules and Regulations, Volumes 1-3.*

Appendix A

The following is a list of the major environmental regulations imposed on petroleum refining activities in the South Coast Air Quality Management District, Bay Area Air Quality Management District. These regulations were compiled using the regulatory data books along with consultation with the regulators.

South Coast Air Quality Management District

Rule #	Name
1105	Fluid Catalytic Cracking Units -- Oxides of Sulfur
1108	Cutback Asphalt
1108.1	Emulsified Asphalt
1109	Emissions of Oxides of Nitrogen from Boilers and Process Heaters in Petroleum Refiners
1119	Petroleum Coke Calcining Operations -- Oxides of Sulfur
1123	Refinery Process Turnarounds
1146	Emissions of Oxides of Nitrogen from Industrial, Institutional, and Commercial Boilers, Steam Generators, and Process Heaters
1148	Thermally Enhanced Oil Recovery Wells
1158	Storage, Handling and Transport of Petroleum Coke
1173	Fugitive Emissions of VOCs
1176	Sumps and Wastewater Separators

Table 1

Volume and Price of Major Petroleum Products

Output:	Motor Gasoline	Distillate Fuel Oil	Jet Fuel: Kerosene
Percent of Value of Output in 1992	47%	17.6%	7%
Price Per Barrel:			
1977	$15.64	14.00	14.40
1982	39.50	36.95	38.55
1987	22.97	20.84	21.56
1992	24.90	22.62	23.14

Source: 1992 Census of Manufactures, Industry Series. Petroleum and Coal Products MC92-1-29A.

Table 2

Percentage of Value and Price Per Barrel of Major Inputs to Petroleum Refining

Material:	Domestic Crude	Foreign Crude
Percent of Value of Materials in 1992	45%	34%
Price Per Barrel:		
1977	$10.85	12.87
1982	31.45	32.18
1987	17.50	17.79
1992	18.65	17.75

Source: 1992 Census of Manufactures, Industry Series. Petroleum and Coal Products MC92-1-29A.

Table 3

Air Emissions Trends in the South Coast by Group
As a Percentage of Total California Emissions: 1981-1991

Pollutant	Year	All Regulated Industries*	Petroleum Refineries	Regulated Industries net of Refineries	Unregulated Industries**
SOx	1981	21.0	18.3	2.7	6.3
	1991	20.0	16.8	3.2	0.8
NOx	1981	28.7	21.3	7.3	6.9
	1991	22.2	16.7	5.5	6.9

Source: California Emissions Database. Numbers are based on authors' calculations.

* Regulated industries are defined as industries that have SCAQMD regulations that affect them.

** Unregulated industries are defined as industries that have no SCAQMD regulations that affect them.

Table 4:

Air Pollution Abatement Control Expenditures:
Total and in the Petroleum Industry (SIC 29)

	U.S.		California		Louisiana		Texas	
Year	Total	Petroleum	Total	Petroleum	Total	Petroleum	Total	Petroleum
1982	1828.2	533.2	174.9	97.9	1629.2	113.7	184.2	117.6
1986	1462.9	273.6	187.2	121.5	61.7	23.3	148.0	91.6
1989	1819.0	146.5	141.0	33.4	61.0	6.2	150.1	31.0
1992	4403.1	2079.8	418.7	352.9	477.6	293.7	777.2	524.8

Source: Current Industrial Reports, Pollution Abatement Costs and Expenditures: 1982, 1986, 1989, 1992.

Table 5:

Air Pollution Abatement Capital Investment and Operating Cost
(Millions of 1987 Dollars)

		Capital Investment		Operating Costs	
Year		California	U.S.	California	U.S.
1977	Petroleum	21.1	167.7	146.9	601.3
	All Manufacturing	89.7	1652.0	221.7	2240.4
	% Petroleum	23.5	10.2	66.3	26.8
1994	Petroleum	1166.8	1982.3	434.6	1742.0
	All Manufacturing	1271.3	4310.6	698.0	6139.1
	% Petroleum	91.8	46.0	62.3	28.4

Sources: Current Industrial Reports, Pollution Abatement Costs and Expenditures: 1977, MA200(77)-2, U.S. Department of Commerce, 1979; Current Industrial Reports, Pollution Abatement Costs and Expenditures: 1994, MA200(94)-1, U.S. Department of Commerce, 1976 (Tables 5 and 9);

Table 6:

Means and Standard Deviations: U.S. and California

Variable	Unweighted Mean	Weighted Mean	Weighted Standard Deviation
Value of Shipments*	2142499	1707848	2890197
Value Added	148899	118772	231349
Employment	461	372	500
Air Pollution Abatement Investment	2647.266	2096.317	7617.564
Net Abatement Investment	1907.022	1495.47	7475.146
Depreciation of Abatement Capital	740.245	600.8471	1795.955
New Regulation Adoption Dates	0.06531	0.05263	0.36945
New Regulation Compliance Dates	0.04963	0.04076	0.2670
New Increased Stringency Dates	0.01463	0.01194	0.1357
Abatement Operating Costs	8294.088	6585.689	16607.46
Difference in Abatement Operating Costs	160.628	141.242	6951.422
South Coast Indicator	0.06792	0.0555	0.22900
California Indicator	0.13636	0.1285	0.3347
Texas Indicator	0.21630	0.2080	0.4060
Louisiana Indicator	0.09874	0.0943	0.2923

* Thousands of 1991 dollars deflated by the PPI.
Source: Pollution Abatement Costs and Expenditures micro data.
Note: The sample contains 1914 observations weighted to represent 2425 plant-years in the population. Sampled from 1979-91, excluding 1983 and 1987. 1992 and 93 data were excluded due to errors. Variables in differences are defined for only those plants in the sample for two consecutive years. Employment is measured in single persons.

Table 7:

Air Pollution Capital Abatement and Regulation

	1	2	Net Investment 3	Weighted 4	CA, TX, LN 5
South Coast	3109.595 (1361.082)	94.048 (2275)	626.017 (2159.714)	351.264 (2230.178)	1720.04 (2370.629)
California	1126.653 (651.939)	1133.361 (657.063)	825.527 (649.188)	677.151 (583.810)	-297.053 (856.050)
Louisiana					913.701 (1052.369)
Adoption		-636.040 (829.091)	-799.697 (777.092)	-476.073 (831.672)	-2053.156 (923.061)
Compliance		3259.787 (1543.718)	2668.115 (1352.257)	3342.35 (1574.338)	3194.832 (1609.215)
Increased Stringency		5654.71 (3319.96)	5218.969 (3075.041)	6400.267 (3290.404)	4652.069 (3401.78)
Observations	1914	1914	1914	1914	920
R^2	0.055	0.076	0.0845	0.0699	0.0998

Table 8:

Air Pollution Operating Costs and Regulation

	Levels 1	Levels 2	Differences 1	Differences 2
South Coast	2177.769 (1936.457)	-902.975 (2947.176)	96.854 (867.984)	1036.811 (1049.456)
California	5109.752 (1418.036)	5113.708 (1420.291)	276.913 (631.077)	271.984 (631.902)
Adoption		391.455 (1125.326)		-597.787 (974.368)
Compliance		2962.958 (2038.145)		17.231 (513.626)
Increased Stringency		2428.385 (3252.545)		-2436.744 (1548.305)
Observations	1914	1914	1552	1552
R^2	0.0179	0.0194	0.0063	0.0084

Table 9:

Total Factor Productivity Results

Year	Quasi-Fixed Price Productivity	Region				
		USA	California	Louisiana	Texas	SCAQMD
1977:	P_{it}[1]	1.15	1.20	1.17	1.16	1.18
	P_t[2]	1.15	1.13	1.20	1.17	1.13
	P[3]	1.11	1.08	1.16	1.11	1.08
1982:	P_{it}	1.13	1.20	1.12	1.11	1.16
	P_t	1.13	1.08	1.14	1.16	1.05
	P	1.16	1.10	1.20	1.18	1.04
1987:	P_{it}	1.19	1.14	1.20	1.24	1.13
	P_t	1.19	1.03	1.25	1.26	1.03
	P	1.16	1.02	1.21	1.23	1.04
1992:	P_{it}	1.16	1.20	1.14	1.16	1.20
	P_t	1.16	1.13	1.18	1.20	1.15
	P	1.12	1.11	1.14	1.15	1.13
1977-1992:	P_{it}	1.15	1.19	1.15	1.15	1.17
	P_t	1.15	1.10	1.18	1.18	1.08
	P	1.13	1.08	1.17	1.16	1.08

Note: Material inputs and outputs (% of input/output value) for which we calculate fixed prices:
Inputs: Domestic crude (45%), Foreign crude (34%), Foreign unfinished oils (1.7%), Natural gas C_4, 80% purity (1.6%), Isopentane and natural gasoline (1.1%).
Outputs: Motor gasoline (47%), Distillate fuel oil (17.6%), Jet fuel: kerosene type (7%), Heavy fuel oils (3.2%), Liquefied refinery gases: other uses (1.6%), Jet fuel: naphtha type (1.2%), Paving grade asphalt (1.0%).
Percentages are from 1992 statistics. See Tables 1 and 2 for sources.

[1] P_{it}: Productivity measure calculated using current plant-specific implicit prices (value/quantity for each plant year).
[2] P_t: Productivity measure calculated using the weighted average of P_{it} in each year.
[3] P: Productivity measure calculated using the weighted average of P_{it} in all years.

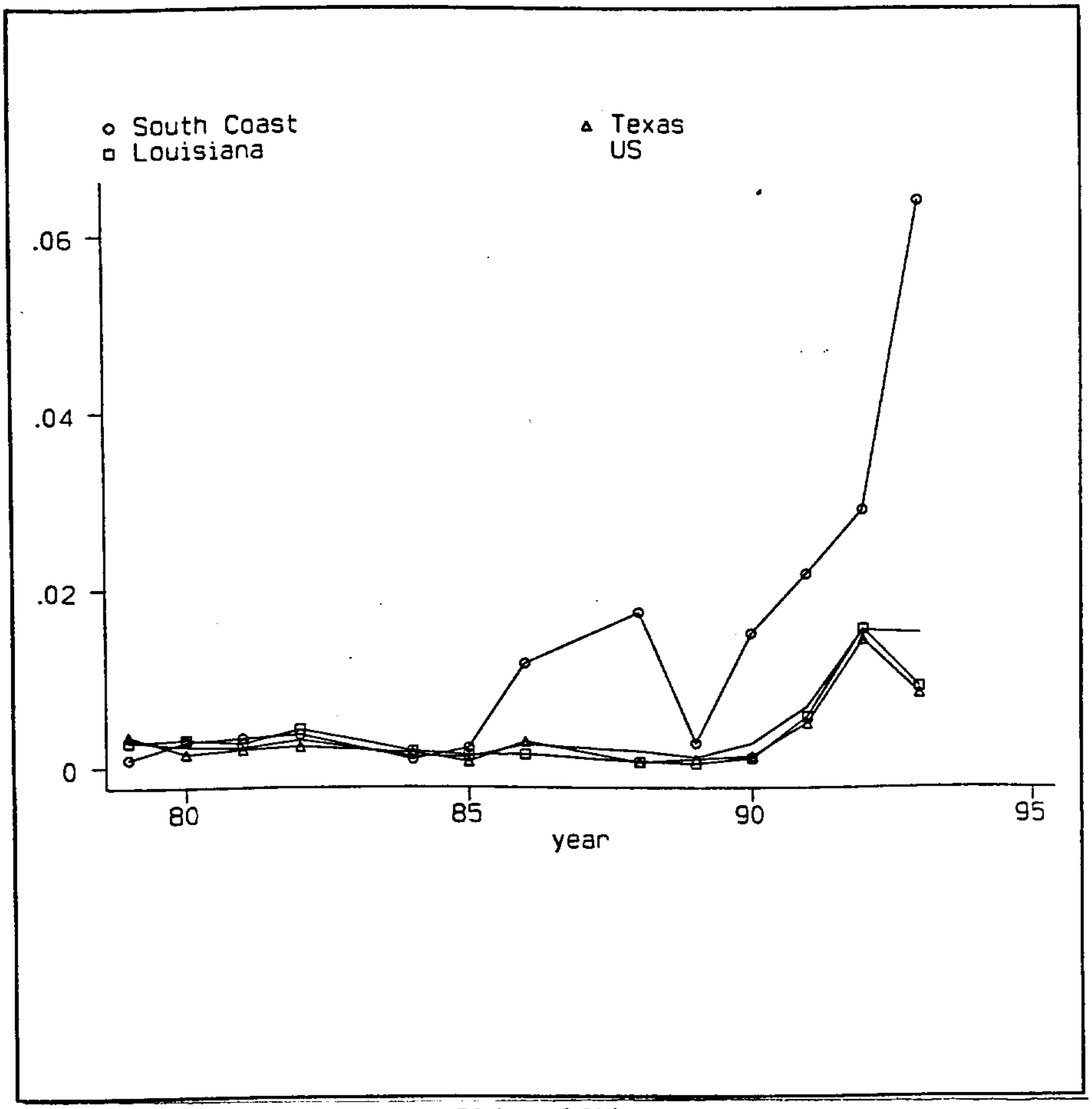

Figure 1: Abatement Investment/Value of Shipments
Source: PACE Survey

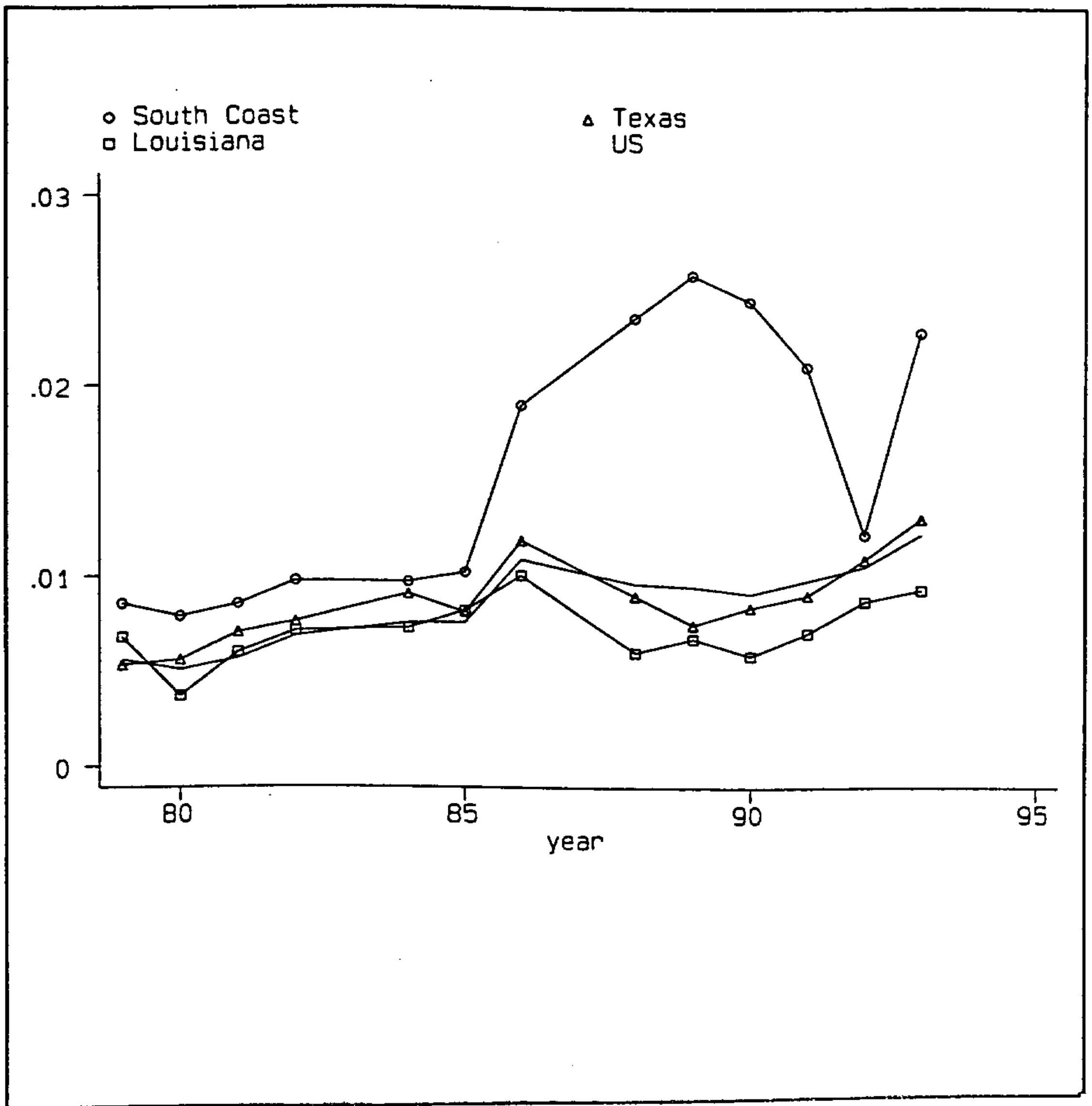

Figure 2: Abatement Cost/Value of Shipments
Source: PACE Survey

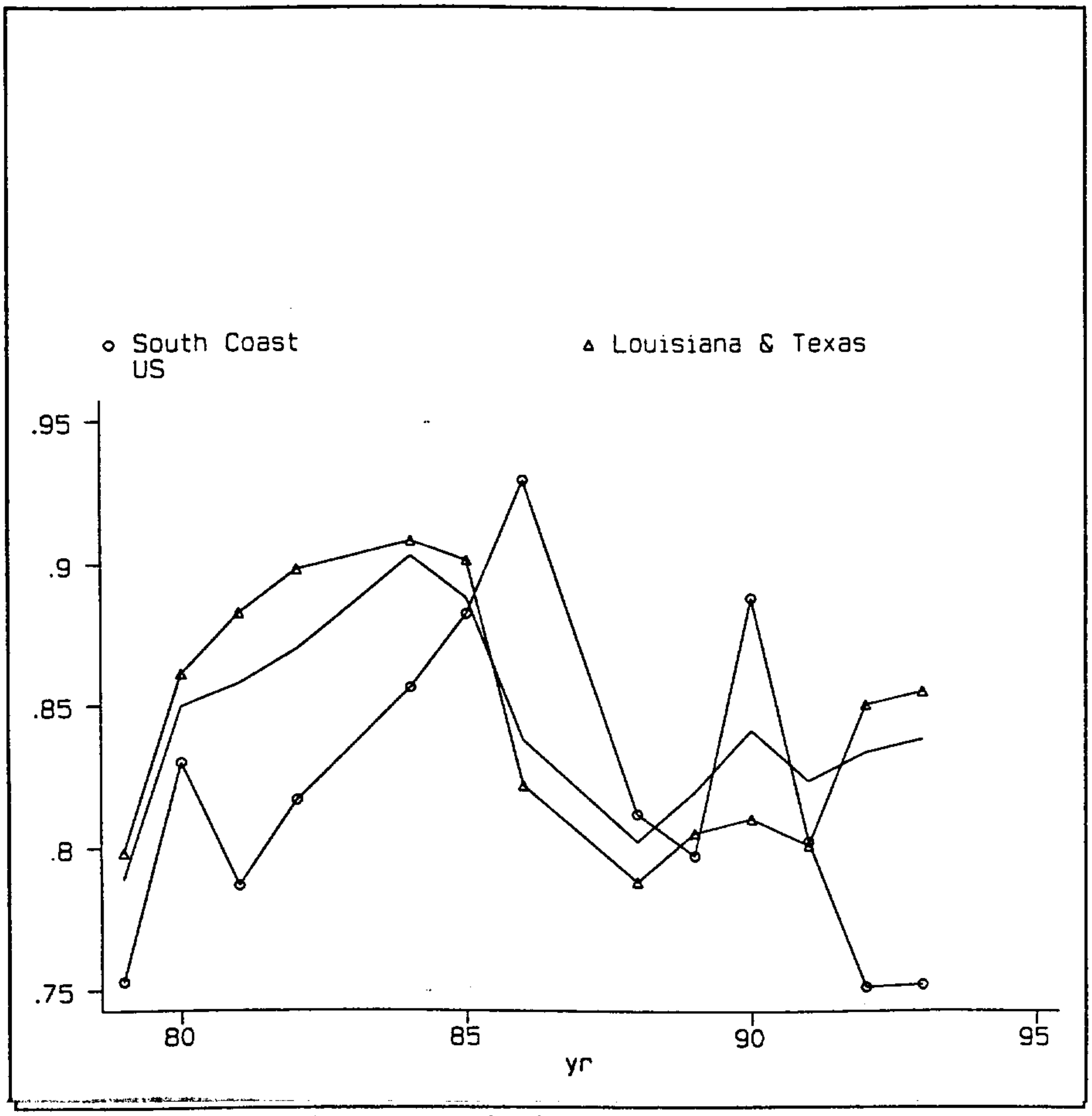

Figure 3: Abatement Costs/Value of Shipments
Source: PACE Survey

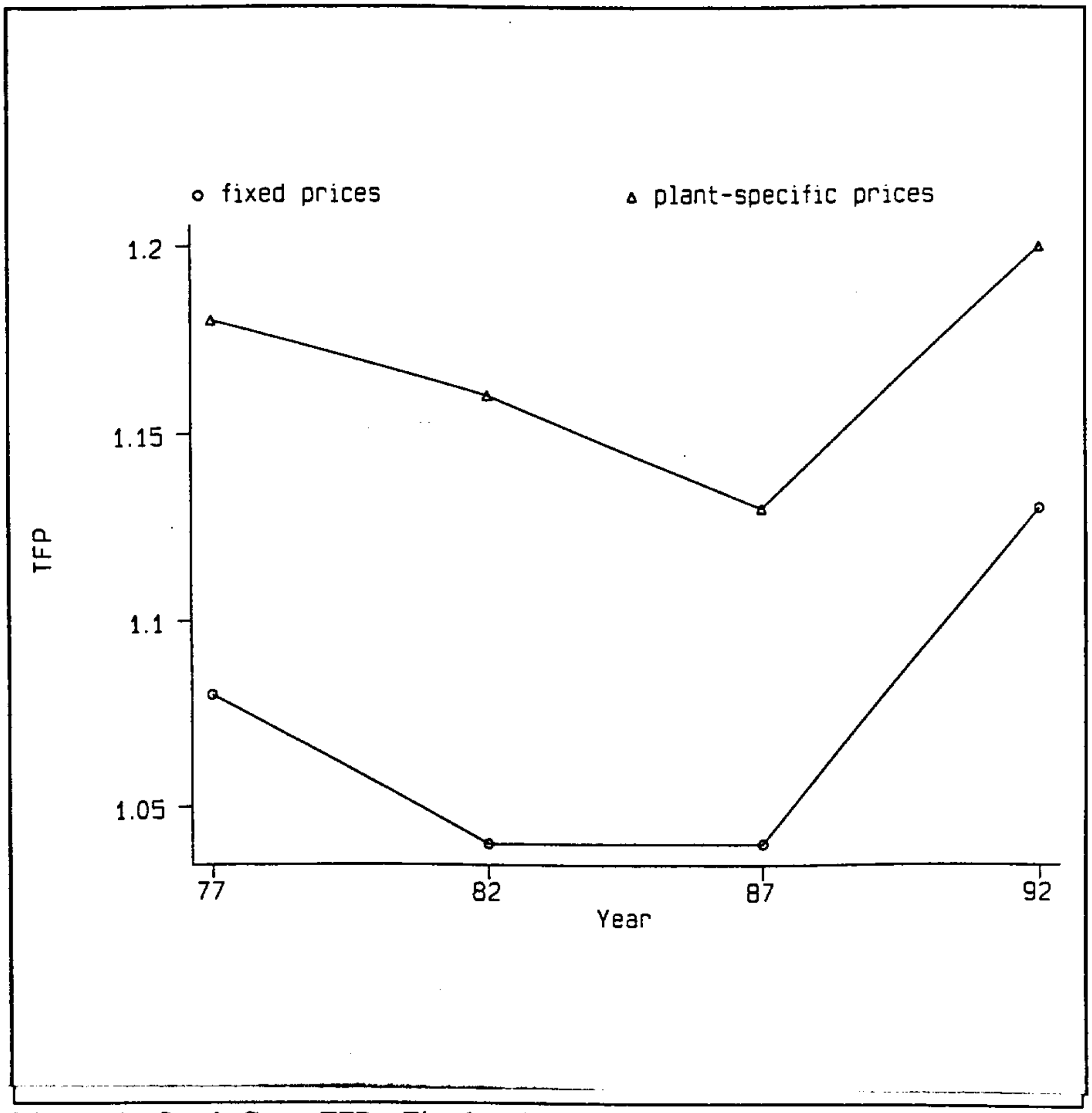

Figure 4: South Coast TFP: Fixed and Plant Specific Prices
Source: COM

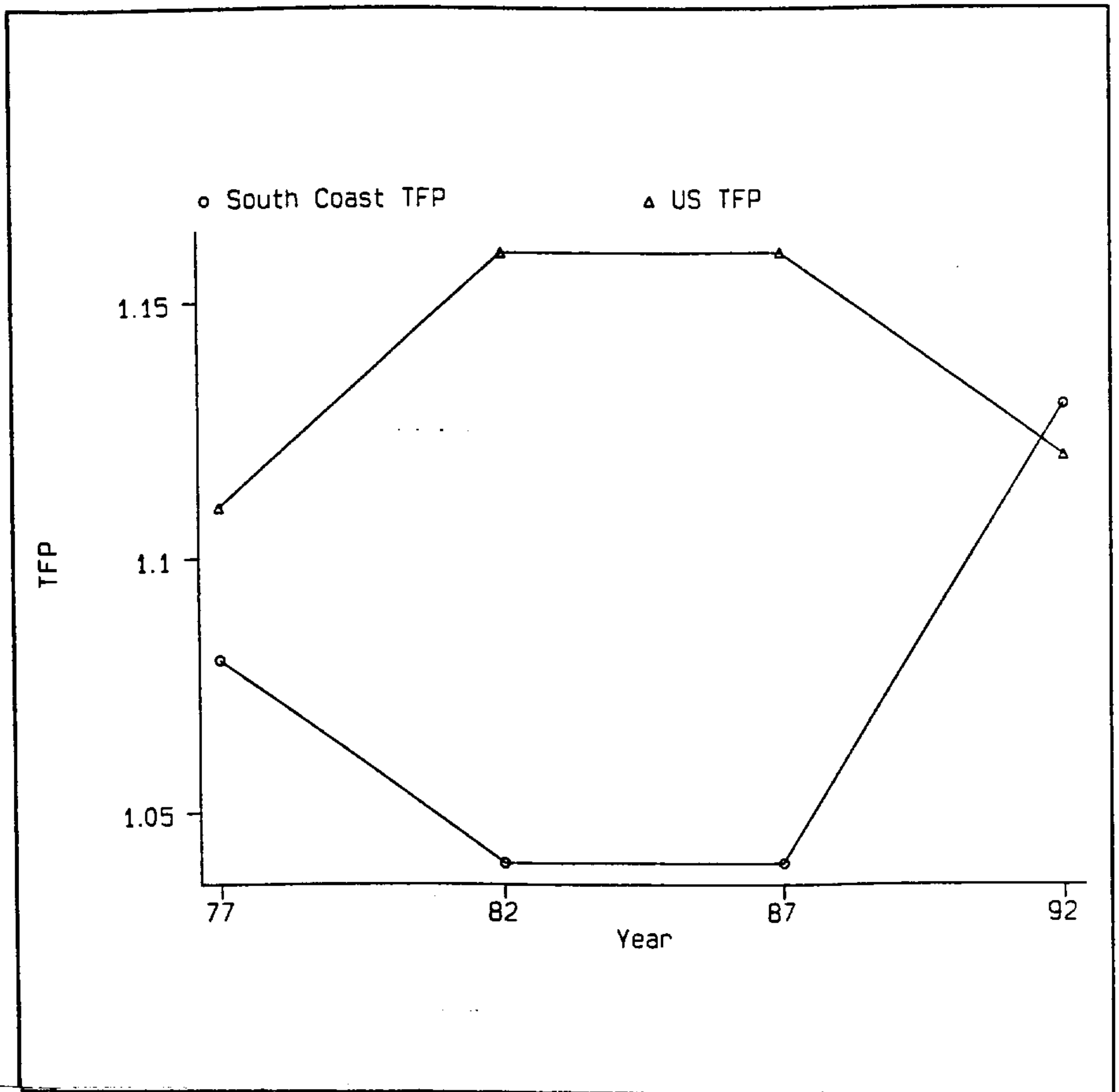

Figure 5: South Coast & U.S. TFP 1977-92
Source: COM
Note: See notes to Table 9.