AN ANALYSIS OF THE SO_2 CAP AND TRADE MARKETABLE PERMIT SCHEME: ARE HOT SPOTS A CONCERN?

by

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I Executive Summary

The objective of my project is to determine if the marketable permit scheme for sulfur dioxide emissions has resulted in the development of hotspots within specific states and counties. As SO2 is a regional pollutant, and no geographic or temporal restrictions were put in place at the start of the program, SO2 emission hot spots could well be a concern. My data are directly from the EPA, and are comprised of two datasets; one of state-level measurements on SO2 emissions and other explanatory variables, and one of county-level measurements with the same explanatory variables as in the state-level data. My analysis took the form of running a number of regressions so that I could find out which/how many states and counties experienced an increase in SO2 levels. Particularly, stage 1 of the program (1995 to 1999) and stage 2 of the program (2000 to 2010) were compared to the base period of stage 0 (1980, 1985, 1990). It was found that, at the state-level, while for the most part states experienced a significant drop in SO2 emissions during stage 1 of the program relative to the period before the program (stage 0), there were a number of states which experienced significant increases in the pollutant at stage 1 relative to stage 0. There were, however, no states which experienced positive SO2 emissions during stage 2 relative to stage 0. At the county-level, it was again found that a number of counties experienced an increase in SO2 emissions during stage 1 relative to stage 0, though the majority of counties experienced a decrease in emissions during stage 1 relative to stage 0. Subsequently, it was found that there were still a number of counties which experienced an increase in emissions during stage 2 relative to stage 0, but this number was less than those positive-increase counties of stage 1 compared to stage 0. It was also found that a number of states and counties experienced a net increase in their levels of pollution across the life of the program to date, 1995 to 2010. Lastly, banking of permits in stage 1 for use in stage 2 was not observed to have occurred at the state level, but was found to have happened at the county level. Further analysis of the net and banking effects could well serve as the basis of an additional paper. This, however, falls outside the realm of this analysis.

II Introduction

Within the realms of both the hard and soft sciences, pollution is a salient concern. We are only beginning to understand with full measure the deep and lasting impacts that various types of pollution have on ourselves, and the environment which we live in. In our attempt to understand, and therefore (hopefully) reduce the damages which would accrue as a result of pollution, we find ourselves face to face with a number of concerns. How much pollution is optimal, if any? What is sustainable? How can we assure that firms are held accountable for their actions? How can they fully internalize their real costs of production? How can we assure that what we are doing is in fact for the best? Economics allows us to attempt answering such a diverse array of questions.

One solution that has been offered in an attempt to curb air pollution specifically is that of a marketable permit scheme. This paper will analyze a real world example of the implementation of such a permit scheme, specifically the SO_2 Cap-and-Trade (hereafter CAT) scheme of 1990. Nationally, the CAT plan has enjoyed great success, but examination of the literature points towards a current divide in analysis concerning the results accrued by the CAT plan, and this revolves around the possible development of unforeseen externalities. Critics maintain that, due to the national trade of pollution permits, localized 'hot-spots' of pollution have formed. In an effort to better understand the current state of affairs regarding CAT, I will analyze two datasets via regression analyses. The first dataset is comprised of state-level data on emissions and other factors from the 48 contiguous states plus the District of Columbia for annual levels of SO_2 emissions. The second dataset is county-level data, observations of which have the same explanatory variables as the state-level data do. In both cases, the data span from 1980 to 2008. I hypothesize that my state and county-level analyses will be in line with previous literature, showing that the CAT plan has had a positive effect on the diminishment of aggregate, nation-level pollution. I hypothesize further, however, that after analyzing both the state-level and county-level data, I will find that some, though perhaps few, regions actually experienced an increase in levels of SO_2 emission.

III Literature Review

Scientific background

Sulfur Dioxide, or SO2, is a gaseous airborne pollutant which is harmful to both the environment and public health. It can cause severe cardiorespiratory damage to those people who maintain a close proximity to the point of issue. Further, SO2 also contributes strongly to the prevalence of acid rain, which harms many ecosystems, with aquatic life being among the primary victims of SO2's damaging chemical composition. The most detrimental aspect of SO2 emission, however, is its contribution to the spread of secondary particulates, which are precursors to particulate matter. SO2 and particulate matter are both highly associated with significant morbidity and mortality effects.[i] SO2 is emitted primarily from coal-powered power plants. As of 1985, electric utilities accounted for 70% of SO2 emissions.[ii] Since SO2 and PM emissions are regional pollutants, the effects are largely borne by those in the immediate area surrounding the emission site. As such the effects of SO2 have been most prominent in northeast US and southeast Canada.[iii]

The Clean Air Act Amendment: Creation of CAT

The first attempt at dealing with SO2 was put forward under the 1970 Clean Air Act. Existing facilities were subject to emission rate limits imposed by the state, while new plants were subject to installing 'best available technology' means of dealing with SO2. In essence, traditional Command and Control (CAC) policies were employed to decrease pollutant levels. The 1990 CAA Amendment sought to revise and improve on the original CAA, however, and under Title IV of the amendment implemented a Cap-and-Trade (CAT) system for SO2 emissions. The hoped-for advantages of the new program were clear from an economic perspective. Free trade and market mechanisms would lead to efficient operation, while the over-arching objective of decreasing pollution control would be realized. All that was required for the successful operation of such a program and efficient abatement would be cost-minimizing utilities and an efficient market for trading.

As the primary goal of the CAAA under Title IV was to set SO2 emission levels at half that of 1980 levels, an aggregate nation-wide cap was set at roughly 8.95 million tons, which was 10 million tons, or approximately 50%, less than emitted by firms in the base-line year of 1980.[iv] This overall goal was to be achieved in two stages. The first stage began in 1995, and targeted the 110 dirtiest coal-fired power plants in the nation. Stage 2 began in 2000, and opened coverage to smaller power plants that produced at least 25 megawatts of electricity, as well as those plants which had a fuel sulfur content of greater than 0.05%.[v]

The program issued a total number of permits which were equal to the desired cap, with each permit allowing the owner to emit one ton of SO2. The historic heat output of each plant was used as a baseline for how many permits were issued to any individual firm. Thereafter, firms could trade these permits with outside firms, or among subsidiary plants. In addition, if a particular firm, at the end of a given year, had in its possession more permits than were needed in that year, they were allowed to bank the extra permits for later use or trade. Therefore, for a given calendar year, total average aggregate emissions must equal or be less than the cap, plus any outstanding unused banked permits from previous years.

The amount of permits issued to a firm by the government was for the most part below its current level of emissions. Should this be the case, a firm could then reduce emission levels to the amount of permits in the firm’s possession. This abatement generally causes production to be moved from dirtier to cleaner production facilities, burning coal with a lower content of sulfur, or installing ‘best available technology,’ which was usually scrubbers. In no situation does the government mandate by what means a given firm should decrease its pollutant emissions to the level that they have allowances for; they leave this up to the firm, as well as the market. In the end, all that is required of a firm by CAT is that a particular firm can only emit SO2 to that amount which they have permits for. This is where the market component comes into play. If a firm cannot decrease the amount of SO2 emitted, it has one final possibility. A firm could either purchase permits from other firms which do not have immediate need for them, or the firm can reallocate the possession of permits throughout it’s company, therefore realigning SO2 emissions in a more efficient way. This allows the utilization of ‘pollution rights’ by those that truly value them. Those firms that operate at high marginal abatement cost buy permits from those firms with lower MAC.

An efficient market is the preliminary prerequisite for the permit scheme to operate effectively; without it, least-cost abatement cannot move forward. It would seem at first blush that the market for SO2 emission permits created by Title IV would be practically paradigmatic in efficiency and competitiveness. There are no trade or entry restrictions as well as a large number of buyers and sellers who are all price takers and are all trading a perfectly homogenous good. In fact, the market was deemed competitive by the time allowances were needed in 1995.[vi]

The Operation of the Cap and Trade Market

Over the beginning years of the implementation of the CAT it was found that there was a considerably high degree of compliance, bordering upon over-compliance.

This was made most conspicuous by the fact that firms banked allowances for future use. As regards the form of dealing with SO2 which was taken up by firms, 37% of actual pollution abatement came from scrubbers. The remainder came from fuel switching.[vii] The actual trading began slowly and in low volume, as most firms focused on trading permits in-house. Essentially, firms just moved their operations around and attempted to cut their own individual pollution relative to the amount of permits they had been issued. 75% of permit allowance demand was met through internal trade, while the remainder was met from external purchase or banking. Firms have learned, however, to appreciate the clear advantages that the creation of a permit market has to offer in subsequent years. Given this, the volume of trade doubled yearly for the first three years of the program.[viii] As a result, firms that value pollution more are more willing to pay for permits, and as a result pollution is spread optimally across firms and industries. Given this, aggregate prices of goods and services produced by these firms and industries better reflect both the prices of inputs and cost-effectiveness of production.

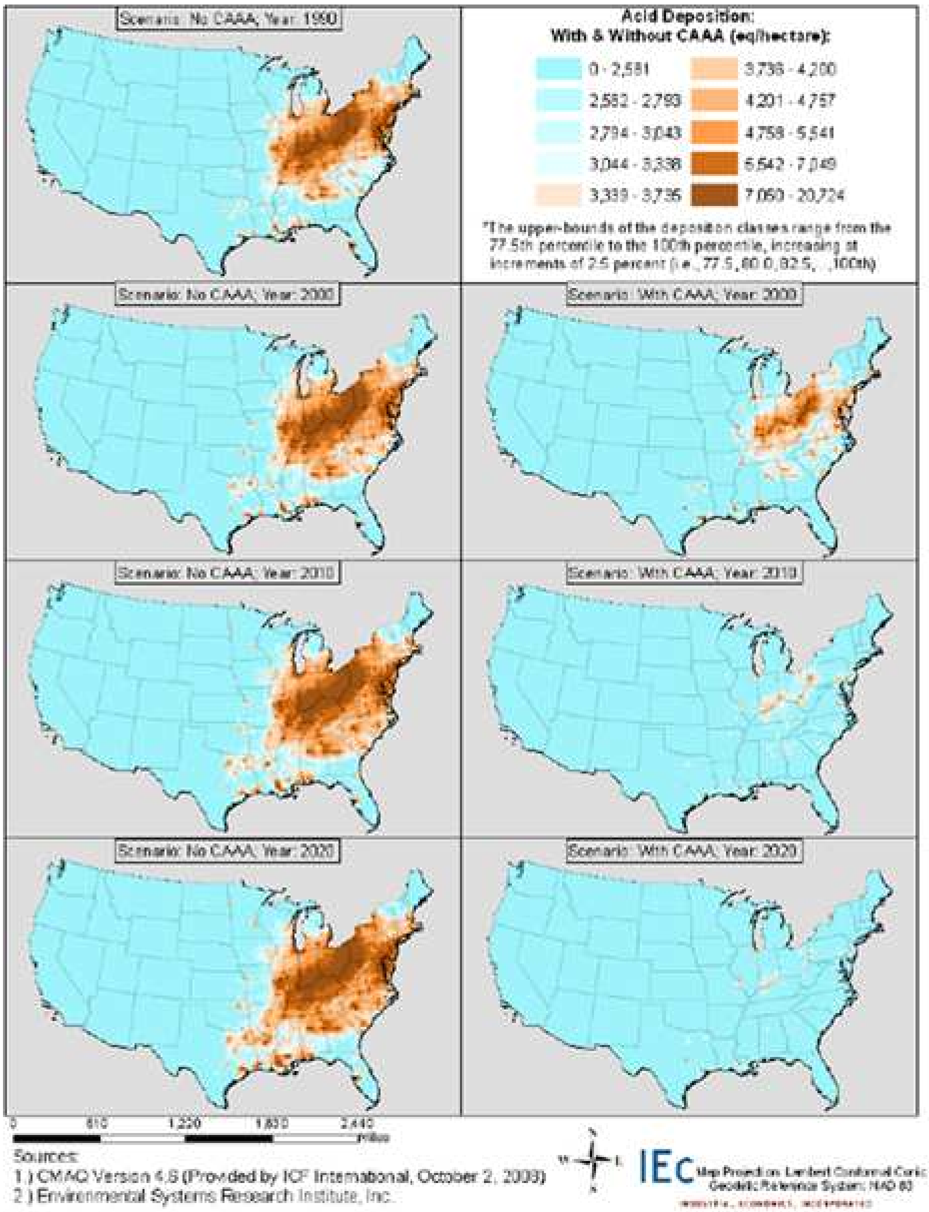
There is no debate that, at the national level, the CAT program has been successful at reducing SO2 emissions. In the first year of the program alone (1995), total emissions were 11.87 tons, which is 25% below emission levels of 1990 and more than 30% lower than 1980 levels.[ix] This was primarily due to the provision of the ‘banking’ clause of Title IV. Essentially, it was realized by firms that it would be wise to hold onto unused permits given the inability to foresee to what degree they would have to pollute in the future. This kick-started the program, and caused a core interest in both abiding by and promoting the CAT. Further, firms wanted to ‘lock in’ the value of these permits, specifically the ones that they had banked. For the remainder of the first stage, SO2 emissions continued to decrease. 11.6 million permits were banked at the end of Phase I.[x] For the period of 1995-1999, this indicates that aggregate emissions were 11.6 million tons below the capped level. By the end of 2000, total SO_2 emissions were 10.63 million tons, which is 40% below 1980 levels.[xi] The next two years, however, saw a relative increase in emissions which exceeded the national cap by approximately one million tons each year. This was facilitated via the use of banked permits.

While a benefit-cost analysis which would focus on comparing the existence of the program to the lack of its existence is outside the realm of this paper, it is still constructive to examine the following two images which reflect the real and projected effects of CAT. The illustrations in the left-hand column of Image 1 show the country as it would experience depositions of SOX and NOX without CAT, while those images in the right column illustrate and project what the country would experience in the presence of CAT.

Figure 1: A comparison of SOX and NOX depositions between the lack of CAT and its presence (March 2011)[xii]

The Benefits and Costs of the Clean Air Act fron 1990 to 2020

FIGURE 6-1. COMBINED NO$_x$ AND SO$_x$ DEPOSITION ESTIMATES FOR 1990, 2000, 2010, AND 2020 WITH AND WITHOUT THE CAAA



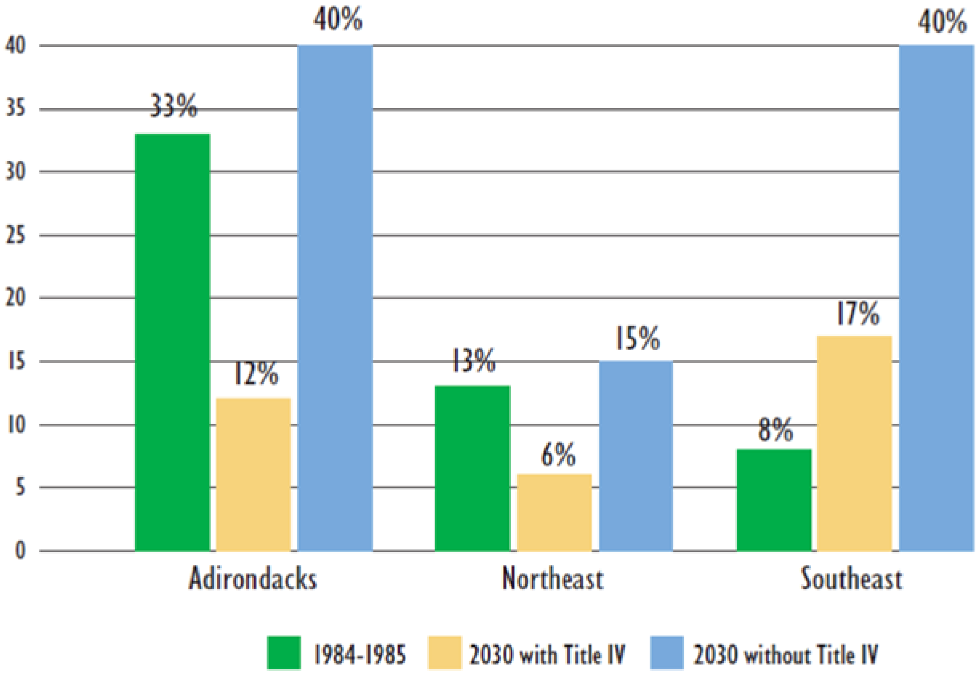
Sources:
1.) CMAQ Version 4.6 (Provided by ICF International, October 2, 2008)
2.) Environmental Systems Research Institute, Inc.

This second image clearly demonstrates the acidification of lakes and streams both with and without CAT.

Figure 2: Comparing acidification of lakes and streams with and without CAT (2010)[xiii]

FIGURE 6.

Projected changes in percentage of lakes and streams with chronic acidification with and without Title IV.



Source: NAPAP Report to Congress (2005).

Concern Over Hot Spots

Upon first examination, it would appear quite evidently that CAT's success buttresses the position that economic, free-market solutions lead to unbridled success. Examining the literature behind the matter, however, shows us that there is still some debate about the topic. Specifically, there are concerns that CAT may have led to the development of unforeseen externalities, as CAT placed no regional or temporal controls on the trading market. SO_2 is a highly regional pollutant, predominantly affecting those in the immediate vicinity of the pollution site. While the aimed-for level of aggregate national emissions may reach the desired level, there may still be dangerous concentrations of pollution in specific areas. Concentrations of SO2 at harmful levels may well arise as the result of trading and banking. While it may be cost-effective for firms in the west to sell a large proportion of their permits to eastern counterparts, this may still have dire consequences. In this example, inhabitants of the surrounding area of the eastern power plants, however, may be exposed to a much higher level of pollution than their western counterparts, who are exposed to much lower concentrations. It seems reasonable to hypothesize that this could lead to economic costs in the east that exceed the benefits accrued. While it may remain true that net national economic benefits of

CAT may be positive, very real negative effects may be felt by the inhabitants of a region in which pollution increases as a result of the trading of permits.

The fact that permits can be banked indefinitely may also cause similar damages. As of yet it seems that firms were generally over-complying, and were banking a large proportion of their permits in anticipation of future need or unforeseen events. Should this trend continue, it may well come to pass that future emissions could be significantly over the capped amount. This was already shown to be the case during the first few years of stage 2. As a result, firms may emit SO2 at considerably high levels, given the temporal nature of banking. This would lead to a lack of pollutant symmetry similar to the geographic concern, though of a temporal nature. Before we so whole-heartedly accept CAT as a uniformly unambiguous success, these concerns must be addressed.

Burtraw et al. outline such a measure in their 1999 piece, *The Effects of Trading and Banking in the SO_2 Allowance Market*. Their results projected estimates, and are broken down into effects experienced due to trading, and effects experienced due to banking. Burtraw found that the estimates of concentration of pollutants was not uniform across the geography of the United States. Specifically, pollution increased in IN, KY, MO, MS, OH, TN, and WV due to trade. Further, Midwestern states experienced an aggregate increase in sulfur deposition, while northeastern, eastern and southeastern states all experienced a significant decrease in deposition of sulfur.[xiv] This movement of emission concentration, however, was not significantly strong, nor potentially harmful. Temporal shifts were relatively small as well. After some examination, EPA concluded that sellers and buyers operating in stage 1 were generally roughly 200 miles apart.[xv] Further, it seems unlikely that national-level permit trading could cause hot spots, given the fact that local ambient air quality standards for SO2 emissions are still in place. The CAT program was an amendment to previous legislation governing such emissions, and as such plants must continue to abide by local standards as well. It should still, however, be highly informative to establish which states and counties, if any, experienced an increase in SO2 emissions in either stage 1 or stage 2, relative to stage 0, as states and counties can often be outside of attainment, purposefully or unpurposefully obfuscate attempts at measurement and regulation, and cause aggregate state or county level effects of SO2 emissions.

IV Description of Data

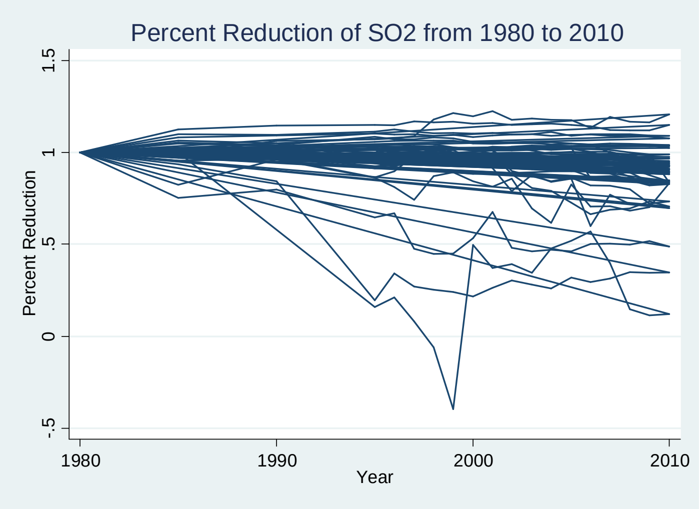
The data that I am working with come directly from EPA.[xvi] While they cover the period from 1980 to 2010, the data are not perfectly consecutive. Specifically, the data include the years 1980, 1985, 1990, and 1995-2010. Each observation included the following variables: year; state; Gross Load (MWh), which is the output of a given coal-burning facility as measured in megawatt hours; Steam Load (1,000 lb), which is the output of the facility in 1,000 lbs.; SO2 mass, which is emissions of SO2 measured in tons that have been emitted and recorded by coal-burning facilities. The overall yearly amount of SO2 emissions was calculated by multiplying the facility's emissions rate per hour by the operating hours of the facility for a particular year. Heat Input (mmBtu), which is a measure of utilization of a given facility, was calculated by multiplying the quantity of fuel by the fuel's heat content.

Once these data were downloaded, I created a number of other variables in order to facilitate my analysis. Firstly, I created dummy variables which reflect the program's roll out. As the first phase of the program was from 1995 to 1999, and the second phase of the program is from 2000 to present, I created a dummy called Stage 0 for years before 1995, Stage 1 for observations with years from 1995 to 1999, and Stage 2 for observations with years 2000 to 2010. I also created a variable called Progyear, which refers to the year of the program (0 being 1995). Lastly, I created a variable named ln_SO2 which is the natural log of SO2 emissions.

The data being examined are in two datasets. Firstly, I have a dataset comprised of the 48 contiguous United States, including Washington DC. This results in 49 different observations, and includes the variables described above. The second data set includes information on 862 counties throughout the United States, and includes the same variables as those described above. It is important to note, however, that while the State-level data came directly from EPA and required little in the way of modification, the County-level data was found by downloading a dataset for which the observation base was the SO2 emitted from specific facilities. This dataset was collapsed into one in which the individual facility-level information was aggregated into a county-level database. I used this for my County-level analysis.

Before beginning with my analysis, I first had to make sure that my data were suitable. For both the State-level and County-level data, this required 'balancing', or dropping those states or counties which did not have full recordings of the observations for the years 1980 to 2010. For the State-level data, this resulted in dropping just one state, Idaho. The county-level data initially included 862 counties, but as only about half of that number had full data, balancing resulted in 482 counties. Most of the missing observations in the county-level data were for Stage 0, which must be included in the analysis in order to test for differences compared to Stages 1 and 2. Please find below Figures 3 and 4 which depict the balanced data for both the state-level and county level datasets.

Figure 3: State Level Percent Reduction of SO2 emissions from 1980 to 2010

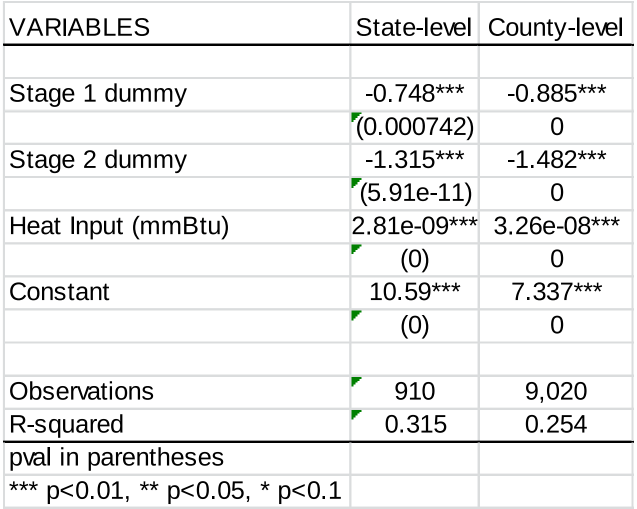


V Methods and Results

National Level Results

The actual method of my approach was straightforward. I first ran a fixed effects regression of ln_SO2 on stage 1, stage 2, and Heat input. I did this for both my state-level data, as well as my county-level data, in an attempt to be thorough. The regression itself was done to gain a broad view/macro understanding of what the overall, national-level picture looked like. These regressions return results which show whether stage 1 and stage 2 are significantly different from stage 0. Heat input was included in order to control for any overall net changes in energy production over the period 1980 to 2010, i.e. to control for the entrance or exit of firms into the program over time and changes in the capacity of existing firms. The results of this regression are below:

Table 1: National-level analysis of both the state and county level datasets.



VARIABLES	State-level	County-level
Stage 1 dummy	-0.748***	-0.885***
	(0.000742)	0
Stage 2 dummy	-1.315***	-1.482***
	(5.91e-11)	0
Heat Input (mmBtu)	2.81e-09***	3.26e-08***
	(0)	0
Constant	10.59***	7.337***
	(0)	0
Observations	910	9,020
R-squared	0.315	0.254
pval in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

The results of this analysis are clear. For the national level analysis using the state dataset, both stage 1 and stage 2 are negatively significantly different from stage 0. Not only this, but their p-values are extremely small, implying that stage 1 and stage 2 are significantly different from stage 0 well beyond the p-value of 0.01. Further, as stage 2's p-value is significantly smaller than that of stage 1, we can conclude that while both stage 1 and stage 2 are significantly different from stage 0, stage 2 is even more different from stage 0 than stage 1 is. Examining the national level results of running a regression on the county-level data gives us a similar picture. Both stage 1 and stage 2 are significantly different from stage 0, and their p-values are so small as to effectively be zero. All of this implies that, nationally, SO2 emissions were reduced significantly during the period 1995 to 1999, and that this reduction was even more pronounced when comparing the period 2000 to 2010 to stage 0.

State Level Results

Subsequently, I conducted a similar regression for each state in order to determine which states were, during stages 1 and 2, significantly different from stage 0, and whether this difference is a positive or negative one, with a positive difference implying the existence of emissions hotspots. In addition to regressing each individual state in this manner, I also ran a seemingly unrelated estimation (SUE). I did this by using the "suest" command in Stata, which is different from the seemingly unrelated regression command, "sureg." As this returns results with more precise standard errors due to the fact that it pools the observations and allows for much larger number of degrees of freedom, the p-value is affected as a result. The full results for both the standard regression and the seemingly unrelated estimation are given in Table 5 and Table 6, which are in Appendix A. The following tables (which are here in the body of the text) are summary tables of the pertinent information for these two regressions.

Table 2: Stage 1 coefficients which were found to be significantly different from stage 0, results for both the simple regression and the seemingly unrelated estimation (SUE).

Stage 1 Coefficients	*** p<0.01	** p<0.05	*p<0.1
Negative, Regression	6: MO NH OH RI TN WV	6: CA GA IN MA SD VT	3: IL, KS, MN
Negative, SUE	14: CA GA IN MA VT MO NH OH RI TN WV DE NJ PA	3: IL KS NV	1: SD
Positive, Regression	3: OK OR TX	0	2: FL LA
Positive, SUE	2: OR TX	0	5: FL LA OK CO MS

As we are concerned about the development of hotspots, we can restrict our analysis to the examination of positive coefficients from the regressions. It is important to note, however, that overall the general trend for the states was a highly negative one. The Stage 1 negative coefficients which were highly significant (had a p-value equal to or less than 0.01) included 6 states for the normal regression and 14 states for the seemingly unrelated regression. Looking at coefficients with p-values less than 0.01, we can observe that, for the normal regression, 17 states were decreasing SO2 emission, while for the SUE, 19 states were significantly different from Stage 0, and negatively so.

Restricting our analysis to the positive coefficients, consulting Table 1, we can observe that at the 0.1 level of confidence, the simple regression found two of the states to have results which were positive and significantly different from stage 0. The SUE found that five states experienced increases in SO2 emissions. It is interesting to note that, at this level of significance, both FL and LA were featured in the results of both the regression and SUE. The SUE also included OK, CO, and MS. We can observe a similar phenomenon when examining the results of the stringent 0.01 level p-value. The simple regression found that three states were positively significantly different from zero, while for the seemingly unrelated regression, two states were different. Both results included OR and TX to be significantly different from Stage 1, while OK was included for the simple regression.

Table 3: Stage 2 coefficients which were found to be significantly different from stage 0, results for both the simple regression and the seemingly unrelated regression.

Stage 2 Coefficients	*** p<0.01	** p<0.05	*p<0.1
Negative, Regression	17: CA CT DC DE IL IN MA ME MO NH NV NY OH RI SD	6: GA KS MN NJ VT WI	3: KY MI ND
Negative, SUE	19: GA NJ VT CA CT DC DE IL IN MA MO NH NV NY OH RI SD TN WV	4: MI KS WI ME	2: KY NM
Positive, Regression	0	0	0
Positive, SUE	0	0	0

Moving on to Table 2, we can at a glance see that neither the simple regression, nor the SUE, returned any positive state coefficients that were significantly different from stage 0, at any p-value. As above, however, we can also observe that there are a great many states which were significantly different from stage 0 in a negative way. For the p-value of 0.01, this included 17 states for the simple regression, and 19 states for the seemingly unrelated regression. Comparing this to the number of states in stage 1 which were negatively significantly different from stage 0 at the same level of significance, (6 for the simple regression and 14 for the SUE, from Table 1), we can also conclude that the number of states which experienced a diminishing of SO2 emissions increased from stage 1 to stage 2. Attempting the same approach with the positive results paints a similar picture: for stage 1, and p-value less than 0.1, 2 states were found to be positively significantly different from stage 0 by the simple regression, while the SUE returned 5, and for the p-value of 0.01, the simple regression returned 3 states which were positively different and the seemingly unrelated regression returned 2. This, in comparison with the lack of any states being positively significantly different from stage 0 for stage 2, indicates that, while pollution did increase for a few states during stage 1, there were no states which experienced a positive increase in emissions for stage 2.

County level results

Table 4: County level results for the simple regression

	*** p<0.01	** p<0.05	*p<0.1
Negative, Stage 1	102	36	30
Positive, Stage 1	15	14	13
Negative, Stage 2	168	59	31
Positive, Stage 2	10	15	7

Examining county-level data allows the analysis to be done on a much finer scale, with a relatively large number of degrees of freedom, implying that the results are likely more precise. As the statistical software program I was using to conduct my analyses

(Stata 12) was unable to report a full table of results due to the fact that it would routinely stop running at random points when I was conducting the analysis, SUE was not capable of handling the 482 county observations, only the simple regression was used. Comparing row 1 with row 3, we can observe that, for all three levels of p-values, a greater number of counties experienced a significant decrease in SO2 emissions during stage 1 than those counties which experienced an increase of SO2 emissions in the same period. This holds true for Stage 2, as well. Focusing solely on the negative coefficients, we can observe that, for all p-value levels (but most particularly for the 0.01 value), significantly more counties experienced a decrease in SO2 emissions from stage 1 to stage 2. Examining the positive results, we see a similar trend; the number of counties which experienced a significant increase in SO2 emissions, in comparison to stage 0, decreased across the p-value board from stage 1 to stage 2.

VI Additional Results

Having determined whether and to what degree hot spots formed as a result of CAT, we can move on to perform some additional analysis that fleshes out the state of affairs a bit further.

Net Effect of the Program

Using the results of the regression analyses, we can very simply find what the overall net effect of CAT has been to date on both states and counties. This is done in a straight-forward fashion. Since phase one of the program lasted for five years, and stage two of the program has lasted 11 years, we can simply multiply five times the stage one coefficient and add to this eleven times the stage 2 coefficient. Performing this allows us to find the net effect that the program has had on emissions in a given state or county since the implementation of the program in 1995 to the last year we have data on, 2010. Performing this method on the state-level data, we find that, in decreasing order of positive magnitude, FL, LA, OR, OK, MS, SC, MT, NE, TX, CO, AZ and VA all experienced a net increase in emissions over the period 1995 to 2010. Further, we can also examine some general summary statistics as regards emission levels in order to make this analysis more comprehensive. First we must find total emissions over the period 1995 to 2010. This is determined by multiplying the net effect by the average per year emissions amount. Doing this, we can subsequently construct the table below.

Table 5: Summary Statistics for State Level Total Emissions

Average	-97.3505
Minimum	-322.722
Maximum	142.9126
Standard Deviation	126.776
95% CI Lower Bound	-345.832
95% CI Upper Bound	151.1306

From comparing these summary statistics to the state by state total emissions data, we find that no state had total emissions which were outside of the constructed 95% confidence interval.

Performing the same process for the county-level data, it was found that 115 counties of the 482 counties included in this analysis experienced a net increase in emissions over the timeframe of the program to date. Again, examining the total emissions levels of counties over the period 1995 to 2010, we find the following summary statistics.

Table 6: Summary Statistics for County Level Total Emissions

Average	-76.2362
Minimum	-528.435
Maximum	1140.223
Standard Deviation	138.4163
95% CI Lower Bound	-347.532
95% CI Upper Bound	195.0597

Again, from comparing these summary statistics to the county by county total emissions data, we find that 19 counties had total emissions below the lower bound of the 95% confidence interval, and included from least negative to most negative, Porter IN, Daviess KY, Ashland WI, Jackson IL, Lamb TX, Gibson IN, Christian IL, Ozaukee WI, Henry MO, Rock WI, New Madrid MO, Hamilton IN, Jasper MO, Clark NV, Hennepin MN, Pointe Coupee LA, Harrison WV, Ramsey MN, and Stewart TN. Additionally, eight counties had total emissions above the upper bound of the 95% confidence interval, and included from least positive to most positive, Palm Beach FL, Berkeley SC, Peoria IL, Rockland NY, Lauderdale MS, Pima AZ, Trimble KY, and Warren PA.

The Degree and Effect of Permit Banking

We can also use the available data to determine to what degree banking of permits took place in stage one, which was followed by the use of saved permits in stage two. This is performed by determining which states and counties had a negative coefficient for the dummy variable representing stage one, and a positive coefficient for the dummy variable representing stage two. At the state level, no states were found to have a negative stage 1 dummy variable coefficient along with a positive stage 2 dummy variable coefficient. At the county level, twenty counties were found to have a negative stage one coefficient value and a positive stage two coefficient value. This included, from most negative to most positive total emission levels for the period from 1995 to 2010, Iberville LA, Lafayette AR, Russell VA, TX Webb, Llano TX, Robeson NC, Mitchell TX, Delaware PA, Ward TX, Baltimore MD, Tulsa OK, Fannin TX, Chester PA, Galveston TX, McLennan TX, Rogers OK, Nueces TX, Dallas TX, Hidalgo TX, and Young TX. The average total emissions amount was 21.15, with a minimum of -8.87 and a maximum of 140.36. The total emissions level of all of these counties fell within the 95% confidence interval found above for the county level total emissions figures with the exception of Young, TX, which had a significantly positive level of total emissions.

VII Conclusion

In brief, these findings are interesting. At the national-level, for the analysis that utilized the state-level data, it was found that both stage 1 and stage 2 are significantly negatively different from stage 0. Further, it became apparent that, given the corresponding p-values of the coefficients, that stage 2 was more negatively different, in terms of emissions, than stage 1. For the analysis using county-level data, the same general trend was corroborated. All of this points to the fact that, at the national level, the program worked well in reducing overall SO2 emissions over the two phases defined.

Secondly, the number of states which experienced a significant diminishment of SO2 emissions during stage 1, as compared to stage 0, were high. Further, the number of states with drops in emissions increased even more when comparing the negative coefficient returns of stage 1 and stage 2. This was found generally across all levels of significance. It also holds true when comparing the results of the simple regression to the results of the SUE. There were, however, states for which the level of SO2 emitted was higher during stage 1 than that of stage 0. This held true across levels of p-values, and whether examining the simple regression results or the SUE. Specifically, the states with increased SO2 emissions during stage 1 from stage 0 included (at the 0.1 p-value), FL and LA for the simple regression and FL, LA, OK, CO, and MS for the SUE. Other states also experienced an increase (at the 0.01 p-value), and included OR and TX for both regressions, with OK in addition only being found for the simple regression. These states did not remain significantly positively different from stage 0 emission levels, as it was observed, by both the simple regression and SUE, that, for stage 2, there were no states which experienced an increase in emissions relative to stage 0.

Thirdly, for the county-level results, it can be observed that a similar trend as those observed in both the state and national level analysis remains. Across all p-values, the number of counties with SO2 emissions which decreased, when comparing stage 1 and stage 0, were found to be high, and certainly higher than those counties with increases in emissions over the same period. It is important to point out, however, that the number of counties which experienced an increase in emissions between stage 0 and stage 1 was, at the 0.01 p-value mark, found to be 13. In comparing stage 2 to stage 1, however, the number of counties with lessened SO2 emissions increased significantly, while the number of counties which experienced increases in emissions decreased to, at the 0.01 p-value level, 10.

Lastly, analysis of the net effect of the program in addition to examining the effects of banking yielded additional interesting results. FL, LA, OR, OK, MS, SC, MT, NE, TX, CO, AZ and VA all experienced a net increase in emissions over the period 1995 to 2010. It was also found, however, that no state had total emissions over the period of 1995 to 2010 that was outside of the 95% confidence interval of the total emissions data. For the county data, 115 counties were found to experience a net increase in emissions. Here, however, 19 counties were found to be below the lower bound of the 95% confidence interval while eight were found to be above. Further, at the state level it was found that there was no evidence for banking and subsequent later use of permits. At the county level, however, 20 counties were found to have a negative stage one dummy variable coefficient and a positive stage two dummy variable coefficient, implying that banking did indeed take place at the county level. Young, TX particularly, one of the counties in which banking took place, had particularly high levels of emissions.

In sum, we can infer that the program was found to be, generally, a successful one when considering national-level emissions. This is intuitive, as the primary goal of the cap-and-trade program itself was to diminish aggregate, nation-level SO2 emissions to 50% of 1980 levels. No geographic bounds were placed on the trade of the permits, however, which generally led to the concern of hotspots which I have attempted to address in this paper. Through my regression analyses, using both a simple regression and the seemingly unrelated regression and examining both state and county-level data, I found that hotspots did indeed occur. Specifically, FL, LA, OK, CO, MS, OR, and TX all experienced a significant increase in emissions during the period 1995 to 1999. For the period 2000 to 2010, however, no states experienced an increase in emissions relative to stage 0 levels, with a great many additional number of states experiencing a decrease in state-level emissions during this same period. While examining the results of the county-level analysis generally supports the conclusion that the number of counties which experienced a further decrease in emissions between stage 1 and stage 2 was significant, there were also a number of counties, 15 in stage 1, which experienced an increase in emissions, with this number decreasing to 10 in stage 2. All in all, given the state and county-level results, it can be said that hotspots did indeed occur in the areas and numbers listed, but these hotspots either disappeared completely between stage 1 and stage 2, or diminished quite a bit. While these hotspots can be construed to be of concern, it is important to note that they generally pale in comparison to all of the reduction in SO2 emissions the program has caused.

Additional analysis found that FL, LA, OR, OK, MS, SC, MT, NE, TX, CO, AZ and VA as well as 115 counties were found to have a net increase in emissions across the life of the program to date, though the total emissions of these states were not outside of the 95% confidence interval of the total emissions data. Of the 115 counties, 19 were found to be below the lower bound of the 95% confidence interval for the county data, and eight were found to be above. Lastly, while there was no evidence of banking at the state level, 20 counties were found to employ banking. Of these counties, Young, TX had a particularly high level of emissions. These net effect and banking statistics are compelling, and could well serve as the basis of further examination of EPA's SO2 emissions data and an additional paper. This, however, falls outside the realm of this analysis and is as such left to the future.

VIII Appendix A:

Table 5: State-level coefficient, p-value, significant and sign table for stage 1

State	Stage 1 dummy coefficient, Regress	Stage 1 dummy p-value, Regress	Stage 1 significance, Regress	Stage 1 dummy coefficient, SUE	Stage 1 dummy p-value, SUE	Stage 1 significance, SUE
AL	0.0238	(0.946)		0.0238	(0.943)	
AR	-0.0229	(0.905)		-0.0229	(0.911)	
AZ	0.200	(0.201)		0.200	(0.122)	
CA	-2.167**	(0.0258)	--	-2.167***	(0.00433)	---
CO	0.315	(0.247)		0.315*	(0.0928)	+
CT	-0.0514	(0.925)		-0.0514	(0.826)	
DC	0.00122	(0.997)		0.00122	(0.993)	
DE	-0.264	(0.190)		-0.264***	(0.00355)	---
FL	0.929*	(0.0777)	+	0.929*	(0.0656)	+
GA	-0.675**	(0.0141)	--	-0.675***	(0)	---
IA	0.0712	(0.683)		0.0712	(0.479)	
IL	-0.298*	(0.0873)	-	-0.298**	(0.0142)	--
IN	-0.966**	(0.0103)	--	-0.966***	(0.00444)	---
KS	-0.807*	(0.0518)	-	-0.807**	(0.0490)	--
KY	-0.524	(0.313)		-0.524	(0.279)	
LA	0.735*	(0.0623)	+	0.735*	(0.0509)	+
MA	-0.568**	(0.0170)	--	-0.568***	(4.48e-09)	---
MD	-0.701	(0.225)		-0.701	(0.113)	
ME	-0.157	(0.806)		-0.157	(0.484)	
MI	-0.0982	(0.440)		-0.0982	(0.373)	
MN	-0.628*	(0.0714)	-	-0.628	(0.236)	
MO	-1.073***	(1.62e-05)	---	-1.073***	(2.92e-09)	---
MS	0.306	(0.221)		0.306*	(0.0643)	+
MT	0.190	(0.224)		0.190	(0.273)	
NC	0.0766	(0.873)		0.0766	(0.789)	
ND	0.0867	(0.446)		0.0867	(0.610)	
NE	0.109	(0.321)		0.109	(0.327)	
NH	-0.320***	(0.00895)	---	-0.320***	(0)	---
NJ	-0.564	(0.128)		-0.564***	(7.11e-06)	---
NM	0.223	(0.677)		0.223	(0.580)	
NV	-0.776	(0.161)		-0.776**	(0.0229)	--
NY	-0.351	(0.274)		-0.351	(0.204)	
OH	-0.947***	(0.00107)	---	-0.947***	(1.75e-07)	---
OK	0.437**	(0.0257)	++	0.437*	(0.0875)	+
OR	0.629**	(0.0223)	++	0.629***	(0.00368)	+++
PA	-0.200	(0.205)		-0.200***	(0.00833)	---
RI	-5.871***	(0)	---	-5.871***	(0)	---
SC	0.204	(0.470)		0.204	(0.255)	
SD	-0.418**	(0.0154)	--	-0.418*	(0.0776)	-
TN	-1.098***	(7.66e-06)	---	-1.098***	(0)	---
TX	0.359**	(0.0299)	++	0.359***	(0.00754)	+++
UT	0.104	(0.655)		0.104	(0.511)	
VA	0.254	(0.483)		0.254	(0.354)	
VT	-7.790**	(0.0128)	--	-7.790***	(0.00177)	---
WA	0.463	(0.541)		0.463	(0.221)	
WI	-0.645	(0.113)		-0.645	(0.127)	
WV	-0.931***	(0.00614)	---	-0.931***	(1.13e-05)	---
WY	0.0633	(0.705)		0.0633	(0.811)	

Table 6: State-level coefficient, p-value, significant and sign table for stage

State	Stage 2 dummy coefficient, Regress	Stage 2 dummy p-value, Regress	Stage 2 significance, Regress	Stage 2 dummy coefficient, SUE	Stage 2 dummy p-value, SUE	Stage 2 Significance, SUE
AL	-0.322	(0.523)		-0.322	(0.525)	
AR	-0.273	(0.212)		-0.273	(0.244)	
AZ	0.0177	(0.943)		0.0177	(0.914)	
CA	-3.606***	(1.47e-05)	---	-3.606***	(0)	---
CO	0.0522	(0.905)		0.0522	(0.894)	
CT	-2.009***	(0.000731)	---	-2.009***	(0)	---
DC	-1.020***	(0.00242)	---	-1.020***	(0)	---
DE	-0.664***	(0.00284)	---	-0.664***	(4.37e-05)	---
FL	0.574	(0.381)		0.574	(0.378)	
GA	-0.874**	(0.0203)	--	-0.874***	(3.60e-06)	---
IA	-0.140	(0.520)		-0.140	(0.303)	
IL	-1.134***	(0.000150)	---	-1.134***	(4.97e-08)	---
IN	-1.271***	(0.00142)	---	-1.271***	(0.000753)	---
KS	-1.262**	(0.0272)	--	-1.262**	(0.0398)	--
KY	-0.960*	(0.0742)	-	-0.960*	(0.0633)	-
LA	0.596	(0.218)		0.596	(0.121)	
MA	-1.414***	(2.04e-06)	---	-1.414***	(0)	---
MD	-0.726	(0.129)		-0.726	(0.141)	
ME	-2.816***	(0.00990)	---	-2.816**	(0.0323)	--
MI	-0.291*	(0.0652)	-	-0.291**	(0.0171)	--
MN	-0.832**	(0.0487)	--	-0.832	(0.221)	
MO	-1.260***	(0.000135)	---	-1.260***	(2.49e-07)	---
MS	0.301	(0.421)		0.301	(0.265)	
MT	0.175	(0.328)		0.175	(0.135)	
NC	-0.288	(0.605)		-0.288	(0.495)	
ND	-0.193*	(0.0769)	-	-0.193	(0.229)	
NE	0.196	(0.176)		0.196	(0.206)	
NH	-0.551***	(0.000190)	---	-0.551***	(9.54e-11)	---
NJ	-1.156**	(0.0168)	--	-1.156***	(0.000199)	---
NM	-0.611	(0.233)		-0.611*	(0.0773)	-
NV	-2.480***	(0.00304)	---	-2.480***	(1.01e-05)	---
NY	-1.335***	(0.000231)	---	-1.335***	(6.06e-08)	---
OH	-1.298***	(2.49e-05)	---	-1.298***	(2.02e-10)	---
OK	0.426	(0.133)		0.426	(0.110)	
OR	0.620	(0.137)		0.620	(0.138)	
PA	-0.193	(0.343)		-0.193	(0.167)	
RI	-6.071***	(2.01e-08)	---	-6.071***	(0)	---
SC	0.190	(0.676)		0.190	(0.518)	
SD	-1.087***	(6.53e-06)	---	-1.087***	(4.76e-10)	---
TN	-1.715***	(6.78e-09)	---	-1.715***	(0)	---
TX	0.0374	(0.873)		0.0374	(0.828)	
UT	-0.0577	(0.817)		-0.0577	(0.742)	
VA	-0.0554	(0.916)		-0.0554	(0.909)	
VT	-5.513**	(0.0260)	--	-5.513***	(0.00458)	---
WA	-0.708	(0.471)		-0.708	(0.528)	
WI	-0.961**	(0.0281)	--	-0.961**	(0.0409)	--
WV	-1.462***	(5.53e-05)	---	-1.462***	(1.75e-08)	---
WY	-0.170	(0.250)		-0.170	(0.489)	

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[i] Burtraw, Dallas and Palmer, Karen (2003), *The Paparazzi Take a Look at a Living Legend: The SO_2 Cap-and-Trade Program for Power Plants in the United States* (Resources for the Future, Washington D.C.), page 2

[ii] Cramton, Peter (2000), "A Review of Markets for Clean Air: The U.S. Acid Rain Program", *Journal of Economic Literature* 38(3):627-633, page 627

[iii] Cramton, Peter (2000), "A Review of Markets for Clean Air: The U.S. Acid Rain Program", *Journal of Economic Literature* 38(3):627-633, page 627

[iv] Burtraw, Dallas and Palmer, Karen (2003), *The Paparazzi Take a Look at a Living Legend: The SO_2 Cap-and-Trade Program for Power Plants in the United States* (Resources for the Future, Washington D.C.), page 5

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[viii] Burtraw, Dallas and Palmer, Karen (2003), *The Paparazzi Take a Look at a Living Legend: The SO_2 Cap-and-Trade Program for Power Plants in the United States* (Resources for the Future, Washington D.C.), page 18

[ix] Ibid, page 7

[x] Ibid, page 7

[xi] Ibid, page 8

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[xiii] US EPA, "Acid Rain Program Benefits Exceed Expectations," 2010, p.4 (citing Lauraine G. Chestnut and David M. Mills, "A Fresh Look at the Benefits and Cost of the US Acid Rain Program," Journal of Environmental Management, Vol. 77, Issue 3 (November 2005), 252-266.)

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