E C O N O M I C S B U L L E T I N

Air pollution and unleaded gasoline in Mexico City

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Abstract

Using a spline regression model and a monthly time series from January 1989 to December 2004 for Mexico City, we test for changes in the time trend for air pollution that coincide with the introduction of a new and relatively expensive unleaded gasoline in September 1990. At this time, new cars were required to have catalytic converters and leaded gasoline was significantly cheaper than unleaded gasoline. The price difference provided an incentive to use leaded gasoline in automobiles that were not suited to its use, thereby increasing emissions. We find that there was a statistically significant and adverse change in the pollution time trend after September 1990 that persisted until leaded gasoline was eliminated from the Mexico City market eight years later. The use of leaded gasoline in new cars is a possible explanation for this result.

Citation: Gleeson Hanna, Bríd and Alethia Jimenez Garcia, (2008) "Air pollution and unleaded gasoline in Mexico City." *Economics Bulletin,* Vol. 18, No. 3 pp. 1-13
Submitted: May 24, 2008. **Accepted:** July 16, 2008.
URL: http://economicsbulletin.vanderbilt.edu/2008/volume18/EB-08R00002A.pdf

1. Introduction

Mexico City is one of many megacities that suffer from serious air pollution problems.[1] Of 18 megacities, it ranked 4th highest in terms of levels of exposure to sulfur dioxide in 2001.[2] In 2004, the annual average exposure level of the average Mexico City resident to outdoor particulate matter (PM_{10}) was 51 μg/m^3. In 2001, the annual average exposure level to sulfur dioxide (SO_2) was 74 μg/m^3 and the daily mean concentration of nitrogen dioxide (NO_2) was 130 μg/m^3. The current World Health Organization (WHO) air quality guidelines for these three pollutants are 20, 40, and 20 μg/m^3, respectively.[3] The purpose of this paper is to investigate how the type of fuel that is used by the car fleet affects air quality in this city. Specifically, we examine the time trend of air quality, controlling for seasonal fluctuations and for economic conditions, and test for structural breaks in that trend at points in time when new unleaded gasoline products were introduced to the Mexico City market.

When a new unleaded gasoline, Magna, was introduced in 1990, a cheaper leaded gasoline was still available in the city. In addition, from 1991 onwards all new cars were required to have catalytic converters. For a sufficiently large leaded – unleaded gasoline price differential, drivers would have an incentive to use leaded gasoline, even in cars fitted with these catalysts. This practice of misfueling damages the efficiency of the catalytic converter, thereby increasing emissions. Our regression estimates suggest that the introduction of unleaded gasoline at this time was followed by an adverse change in the air quality time trend and it did not revert to its earlier downward trend until leaded gasoline was completely removed from the market in 1998.

Bravo and Torres (2000) also discusses this issue. However, to our knowledge, this is the first attempt to examine the issue by applying Mexico City data to a spline regression model.[4] Riveros *et al.,* (1995) examine air quality and vehicle emissions data from 1987 to 1996 and find evidence that three-way catalytic converters, on average, have a 45% efficiency rating in Mexico City, below the expected 90% value. The authors point to lead contamination as one possible cause of this inefficiency. The authors refer to a 1992 survey finding that 13 percent of those who were surveyed and had cars with catalytic converters used leaded gasoline.

In the next section, we briefly discuss the fuel types that have been used in Mexico City and their likely effect on air pollution. Then, in section 3 we describe the data that we analyze. We then describe the econometric model and the results of our analysis in sections 4 and 5. Section 6 concludes.

2. Background: Gasoline types and quality

PEMEX, the Mexican oil monopoly, introduced various new gasoline products to the Mexican market over the last 20 years. From the beginning of our time series, January 1989, to August 1990, there were two gasoline products for sale in Mexico City: Nova, a

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[1] A megacity is usually defined as a metropolitan area with a total population of at least 10 million.
[2] See Gurjar et al. (2008).
[3] See World Bank (2007) table 3.13.
[4] Our study focuses on identifying structural breaks in that data that coincide with different gasoline 'regimes'. Future work will look at the issue in more detail by using a regression model that takes into account gasoline price differentials and the relative quantities of the various gasoline products sold.

leaded gasoline, and Extra, an unleaded gasoline.[5] In September 1990, Extra was replaced by Magna, an unleaded gasoline with specifications very similar to regular unleaded gasoline that is sold in the United States. Magna was consistently more expensive than Nova.[6] This encouraged drivers to switch to Nova, the leaded gasoline, even drivers whose cars were equipped with catalytic converters. While it is also true that Extra was consistently more expensive than Nova, catalytic converters were not mandatory during the time period when Extra was sold.[7] Finally, in November 1996, a new gasoline was introduced, Premium, that has a relatively high octane rating. Currently, Magna has an octane rating of 87 and Premium has an octane rating of 93. In 1998 Magna accounted for approximately 94 percent of total sales of gasoline in Mexico and in 2002 that figure was 89 percent.[8]

3. Data

Our pollution data are for the period January 1989 through December 2004, giving us 192 monthly observations. These are an index of air quality called the IMECA (Metropolitan Index of Air Quality). The index is based on the National Ambient Air Quality Standards (NAAQS) of the USA.[9] The Atmospheric Monitoring System of Mexico City (SIMAT) publishes these data.[10] The index incorporates readings on the levels of ozone (O_3), nitrogen oxide (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), lead (Pb) and particulate matter (TSP and PM_{10}). Table 1 shows how values of the IMECA correspond to the US NAAQS.[11] An index value of 100 for a particular pollutant corresponds to the air quality standard for that pollutant. Air standards for monitored pollutants for both the United States and for Mexico are given in table 2. An index value of 500 corresponds to an ambient level of that pollutant for which significant health damages have been detected. All other possible index values are assigned in a similar fashion. The IMECA is a combined index for all monitored pollutants, which are listed above, and the pollutants are reported as hourly averages. We took the monthly average of these hourly IMECA data for each monitoring station and then took the average of that value across all monitoring stations. Thus, our pollution variable is a

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[5] The lead content of Nova was reduced gradually over time; from June 1991 to September 1992 the lead content was 0.3 – 0.54 Pb grams per gallon and from October 1992 to July 1997 it was 0.2 – 0.3 Pb grams per gallon. See Nava et al. (2006).

[6] The difference in price between Nova and Magna was 297 pesos per meter^3 in September 1990 (a difference of more than 50 percent), when Magna replaced Extra, and this difference decreased to 80 pesos per meter^3 in October 1998 (a difference of slightly more than 2 percent) and approximately 390 pesos per meter^3 in November 1998 (a 10 percent price difference), when Nova was removed from the market.

[7] The difference in price between Nova and Extra was 80 pesos per meter^3 in January 1989, the starting point of our time series (a difference of 16 percent) and it stayed relatively stable up to June 1990. However, for the last three months that Extra was on the market this difference grew to over 200 pesos per meter^3 and was 297 per meter^3 (a price difference of almost 43 percent) when Extra was removed from the market.

[8] Molina and Molina (2002) page 85, figure 3.5.

[9] The US Clean Air Act, as amended in 1990, requires that the EPA set NAAQS. These are mandatory limits on ambient levels of certain pollutants. For example, the standard for lead is currently a quarterly average of 1.5 $\mu g/m^3$. For further details see http://www.epa.gov/ttn/naaqs/.

[10] The IMECA data are available from the SIMAT website http://www.sma.df.gob.mx/simat/home.php?cont=bd

[11] See Molina and Molina (2002) Appendix A.

measure of average air quality throughout the MCMA for each month.[12] We use monthly averages of hourly data to avoid some of the noise inherent in high frequency pollution data.

While gasoline-fueled vehicles are not the only source of the pollutants used in this index, CAM (2001) reports that, in 1998, transportation accounted for 98 percent of Mexico City's CO emissions, 36 percent of PM_{10}, 81 percent of NO_X, 40 percent of VOCs, and 21 percent of all SO_2 emissions. Riveros *et al.,* (1995) estimate that 75 percent of hydrocarbon (HC), a VOC, comes from mobile sources.

We control for economic conditions by using data for the price of Mexican Maya crude oil, in dollars per barrel, as of the end of each month. The rationale is that one significant influence on the overall level of economic activity, and therefore on emissions from both transportation and industry, is the cost of fuel. These crude oil price data come from the Energy Information Administration of the US Department of Energy.

A version of our regression model incorporates data on total gasoline sales in the MCMA, in thousands of barrels per month. These data come from the IFAI (the Mexican Federal Institute for Access to Public Information). The original source of these data is the PEMEX Corporate Finance Office. We do not have access to monthly sales for each or the different types of gasoline.

4. Econometric Model

The purpose of our analysis is to use linear regression analysis to estimate how the time trend of pollution changes when the available mix of gasoline products changes, holding constant other influences on air quality such as the level of economic activity, and seasonal changes in weather conditions. The basic regression equation that is used for this purpose is given by

$$\begin{aligned} Pollution_t &= \alpha_0 + \alpha_1 time_t + \alpha_2 d_{2t} + \alpha_3 d_{3t} + \alpha_4 d_{4t} \\ &+ \alpha_5 time_t \cdot d_{2t} + \alpha_6 time_t \cdot d_{3t} + \alpha_7 time_t \cdot d_{4t} + \boldsymbol{\alpha_8 X_t} + \upsilon_t \qquad \text{(M1)} \end{aligned}$$

The dependent variable, pollution, is the natural log of the pollution variable as described in section 3 and *t* is a time sub-script; our time-series runs from January 1989 to December 2004. We experiment with using the natural log of pollution per thousand barrels of gasoline sold as the dependent variable and, as we discuss below, we find that the results do not change significantly in that case.

X represents control variables, which include the natural log of oil prices, and a dummy variable that identifies the period after the 1995 economic crisis. In addition, we include month fixed effects to control for seasonal variation in air pollution. *Time* is linear time trend. d_2, d_3, d_4 are dummy variables that denote periods of time when different groups of gasoline products were used in the MCMA. These allow for changes in the level of pollution for these different ranges of time. The interaction variables, $time \cdot d_2$, $time \cdot d_3$, $time \cdot d_4$, allow for changes in the time trend of pollution depending upon what gasoline products were in use.

[12] There are currently 37 monitoring stations located throughout the MCMA. However, the data used for this paper are the averages across just 5 monitoring stations: Cerro de la Estrella, La Merced, Pedregal, Tlalnepantla, and Xalostoc. This is because the time series from the other stations are very incomplete. However, one of these five stations located in each one of the five regions of the MCMA (northwest, northeast, southwest, southeast, and central). Thus, averaging across them is likely to provide a reasonable measure of the actual average air quality in the city.

For the period January 1989 to August 1990, Nova (leaded) and Extra (unleaded) were sold. For this period, $d_2 = d_3 = d_4 = 0$. From September 1990 to November 1996, Nova and Magna (unleaded) were sold and $d_2 = 1$. Three different gasoline products, Nova, Magna, and Premium (unleaded), were sold from December 1996 until November 1998 and $d_3 = 1$. Then Nova was removed from the market and from December 1998 to the end of our time-series, December 2004, Magna and Premium were used in the MCMA. For this period $d_4 = 1$.

We hypothesize that the introduction of the Magna gasoline in September 1990 will lead to a worsening of air pollution. The rationale is that, beginning in 1991, all new cars were required to have catalytic converters and, because Magna was so much more expensive than Nova, this gave drivers an incentive to switch from unleaded (Magna) to leaded gasoline (Nova). Using leaded gasoline in a car with a catalytic converter reduces the efficiency of that catalyst, thereby increasing emissions. Thus, we hypothesize that $\alpha_5 > 0$. We predict that slope would continue to be higher as long as the cheaper leaded substitute for unleaded gasoline exists. Thus, during this period of time when Nova, Magna, and Premium were all sold, we should continue to see higher slope estimates compared to the 'default' period, January 1989 to August 1990. That is, we hypothesize that $\alpha_6 > 0$. In the fourth period of time, leaded gasoline (Nova), the cheaper substitute to unleaded gasoline, had been removed from the Mexican market. It is only at this point that the benefit of catalytic converters to reduce automobile emissions will be fully exploited. Thus, we predict that $\alpha_7 < \alpha_6$.

Note that the above regression model allows the fitted trend of pollution over time to be discontinuous. We use a spline regression model, that is, a restricted version of the above model, that forces continuity in this fitted trend. This has some intuitive appeal. That is, rather than causing a discrete change in air quality, the introduction of a new gasoline fuel is more likely to cause a change in the slope of that trend. Thus, we impose restrictions on the regression equation that forces it to be continuous. Those restrictions are as follows:

$$\alpha_2 = -\alpha_5 \mathrm{T}_1 \qquad \text{(R1)}$$

$$\alpha_3 = \alpha_2 - (\alpha_6 - \alpha_5)\mathrm{T}_2 \qquad \text{(R2)}$$

$$\alpha_4 = \alpha_3 - (\alpha_7 - \alpha_6)\mathrm{T}_3 \qquad \text{(R3)}$$

T_1, T_2, and T_3 are the break points in the time series between each of the four periods of time when different sets of gasoline fuels were sold. Imposing these restrictions on the unrestricted model above, (M1), gives the following spline regression model.

$$Pollution_t = \alpha_0 + \alpha_1 time_t + \alpha_5[d_{2t}(time_t - \mathrm{T}_1) + (d_{3t} + d_{4t})(\mathrm{T}_2 - \mathrm{T}_1)] \\ + \alpha_6[d_{3t}(time_t - \mathrm{T}_2) + d_{4t}(\mathrm{T}_3 - \mathrm{T}_2)] + \alpha_7 d_{4t}(time_t - \mathrm{T}_3) + \varepsilon_t \qquad \text{(M2)}$$

This model can be rewritten in the following way:

$$Pollution_t = \alpha_0 + \alpha_1 time_t + \alpha_5 node_1 + \alpha_6 node_2 + \alpha_7 node_3 + \varepsilon_t \qquad \text{(M2)}$$

We estimate the parameters of both (M1) and (M2) and test the restrictions imposed on (M2). We present and discuss the estimation results for both regression models in the next section.

5. Results

Table 3 and figures 1 and 2 present the regression results for (M1) and (M2), where the natural log of pollution is the dependent variable. In all cases, the standard errors have been corrected for autocorrelation.[13] The parameter estimates for the month fixed effects have been omitted in the interests of space. For all models, these estimates suggest that air pollution is significantly lower in May through November compared to all other months. This is consistent with the fact that thermal inversions tend to be more prevalent during the winter months. The parameter estimates suggest that, for example, the air pollution index is approximately 48 percent lower on average in August than it is during the winter months, ceteris paribus.

We applied Chow tests of structural change to a model with the natural log of pollution as the dependent variable, and with the following independent variables: a linear time trend, 'time', the natural log of oil prices, a dummy variable for the 1995 economic crisis, and a set of month dummy variables.[14] The Chow test for structural change at the first break point produces an F statistic and probability value of 2.41 and 0.004, respectively, with the F statistic's numerator and denominator degrees of freedom being 15 and 162, respectively. Thus, at all reasonable significance levels, we reject the restriction of equal parameters across the first and all other time periods. The Chow tests' F statistics (with probability values in parentheses) for the 2nd and 3rd break points are 0.74 (0.743) and 1.05 (0.412), respectively. Thus, we are unable to reject the restriction of equal parameters across the 2nd, 3rd, and 4th periods. However, when comparing the data for periods 2 and 3 with those for period 4, the Chow F statistic and probability value are 2.38 and 0.004, respectively, with numerator and denominator degrees of freedom 15 and 142, respectively. These results imply that, subsequent to introducing Magna in place of Extra and again following the removal of leaded gasoline, Nova, from the market, there were significant structural changes in the pollution regression equation.

For model (M1), F tests of the restrictions (R1), (R2), and (R3) produce F statistics (with probability values in parentheses) of 5.4 (0.021), 1.15 (0.286), and 0.03 (0.874), respectively, with all F statistics having numerator and denominator degrees of freedom of 1 and 163, respectively. Thus, we fail to reject (R2) and (R3) at any reasonable significance levels and we fail to reject (R1) at the 1 percent significance level. The failure to reject (R2) and (R3) is consistent with the Chow test results above, which imply that there is no need to allow for any change in the parameter estimates from the 2nd to the 3rd and to the 4th periods; it seems that a linear time trend fits the data well throughout and across these time periods. However, as pointed out above, the Chow test provides evidence of structural change at the 1st and 3rd break points, and this F test of restrictions suggests that forcing the regression function to be continuous at this first break point is unnecessary.

[13] For (M1), the Durbin-Watson statistic for 9th order serial correlation is 1.686, with a probability value for the test for positive autocorrelation of 0.044. Thus, we correct the standard errors for 9th order positive serial correlation. For (M2), we find similar results; the Durbin-Watson statistic for 9th order serial correlation is 1.695, with a probability value for the test for positive autocorrelation of 0.047.

[14] We also experimented with using the natural log of the quantity of gasoline sold as an additional control variable, but this weakened the fit of the models.

We applied Ramsey's RESET test to (M1). The F statistic for this test (with numerator and denominator degrees of freedom equal to 2 and 172, respectively) was 0.82 with a probability value of 0.442. Applied to (M2), this test produces an F statistic of 2.41 with a probability value equal to 0.093. Thus, both models seem to be well specified. However, on the basis of this test, (M1) seems to be preferable to (M2), consistent with results of the F tests of restrictions. Nevertheless, we discuss the results from both models below.

The 3rd column of table 3 presents the parameter estimates for M1. The fitted values are graphed in figure 1. For simplicity, these are the fitted values for when all control variables (natural log of oil prices, the economic crisis and month dummy variables) have been set to zero. From these, we can see that pollution seems to have fallen significantly over the first period at a rate of approximately 2 percent per month. Note that the change in the fitted value for pollution at the break point T_1, the point in time when Magna replaced Extra, is $\alpha_2 + \alpha_5 T_1$, where T_1 is observation number 20. The point estimate for this term is -0.229 and it is statistically significant at the 5 percent level.[15] Thus, we can conclude that air pollution fell significantly at this point in time. For the second period, the slope with respect to time is $\alpha_1 + \alpha_5 = 0.0012$ and it is not significantly different from zero.[16] That is, pollution remains flat during this second time period. The model predicts that, following the introduction of Premium at point T_2, observation number 95 in our data set, the fitted pollution value changes by $(\alpha_2 - \alpha_3) + (\alpha_5 - \alpha_6)T_2 = -0.033$. However, this is not significantly different from zero and the slope with respect to time in this period, $\alpha_1 + \alpha_6 = -0.018$, is not statistically significant either.[17] Finally, when leaded gasoline is eliminated at point T_3, observation number 105 in our data set, the fitted pollution value changes by $(\alpha_3 - \alpha_4) + (\alpha_6 - \alpha_7)T_3 = -0.042$. Again, this change is not statistically significant. The slope becomes significantly negative, with a point estimate of –0.006, but this is not significantly different from the slope of the first period.[18]

Summarizing the regression results for model M1, we find evidence that pollution had been falling over time prior to the introduction of Magna, that it dropped by a little more than 20 percent with the introduction of Magna and then remained unchanged up until the elimination of leaded gasoline, at which point it returned to a significantly negative trend. These results suggest that, while initially causing an improvement in air quality, the introduction of unleaded gasoline products and catalytic converters do not result in persistent improvements as long as cheaper leaded gasoline remains available. While it does not seem that the introduction of the relatively expensive unleaded gasoline

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[15] The F statistic for the test that this change in the fitted pollution value is zero equals 5.4 with a probability value of 0.021, with numerator and denominator degrees of freedom equal to 1 and 162, respectively.

[16] The F statistic for the test that this slope with respect to time is zero equals 0.43 with a probability value of 0.512, with numerator and denominator degrees of freedom equal to 1 and 162, respectively.

[17] The F statistic for the statistical significance of this intercept change at T_2 is 0.05 with a probability value of 0.826. The numerator and denominator degrees of freedom are 1 and 162, respectively. The F statistic for the significance of this slope estimate is 0.52 with a probability value of 0.470 and the same degrees of freedom as the former test.

[18] The F statistic for the test that this change in pollution at T_3 is zero is 1.11 with probability value 0.293. The F statistic for the test that this slope is zero is 35.09 with probability value <0.0001. The numerator and denominator degrees of freedom for both of these statistics are 1 and 162, respectively.

caused an increase in air pollution, we do find that evidence that it counteracts the influence of whatever pre-existing forces that had already been improving air quality. While we cannot pinpoint what those forces are, they are likely to include, for example, gradual improvements in the lead content of leaded gasoline, the extension of nonpolluting urban electric transportation, the conversion of state-owned buses to run on low-emission engines, and the relocation of polluting industries outside the MCMA.[19]

The model suggests that if pollution had continued to fall at the same rate as in the first period (approximately 2 percent per month) from September 1990 (T_1) up to December 1998 (T_3), instead of flattening out through this period, pollution levels would have been lower by $(\alpha_4\text{-}\alpha_2)+\alpha_7 T_3$ = 1.727, over 400 percent lower.[20]

Table 3 and figure 1 also present the results for the spline regression model, (M2). While, by construction, this model does not predict a significant drop in pollution levels at T_1 that is predicted by the model M1, it's fitted regression line follows a pattern that is not significantly different from that of M1; fitted pollution falls significantly during periods 1 and 4 and remains flat throughout periods 2 and 3.

Finally, figure 2 presents the results of (M1) and (M2) for the case where the dependent variable is the natural log of pollution per thousand barrels of gasoline sold.[21] The rationale is that by focusing on total pollution, we may miss significant changes in the rate of emissions per unit of gasoline. However, we find that resulting patterns for pollution per unit of gasoline that are predicted by these models are essentially the same as the patterns for total pollution.

6. Conclusion

This paper examines how the trend in air pollution in Mexico City differs with the set of gasoline products that are available for use. We hypothesize that the introduction of a new unleaded gasoline product will have adverse effects upon air quality if leaded gasoline continues to be sold and at a lower price; the ability to substitute to the cheaper and dirtier gasoline could cause increases in pollution if it is used with automobiles that are designed to use only unleaded gasoline. We find statistical evidence of a structural break in the time trend of pollution that coincides with the introduction of an unleaded gasoline product. At that point, the trend switches from being significantly negative to being flat. It is not until the cheaper leaded gasoline is eliminated from the market that the trend reverts to being negative again. While it is reasonable that gasoline consumers should be allowed to adjust gradually to using solely unleaded gasoline, eight years passed between the introduction of the first unleaded gasoline, in September 1990, and the elimination of all leaded gasolines from the Mexico City gasoline market, in December 1998. This presented substitution possibilities for consumers that are estimated to have significantly large negative effects on air quality.

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[19] For further details on these and other efforts to improve air quality in the MCMA during this period of time see Molina and Molina (2002).

[20] This figure of over 400 percent comes from noting that 1.727 is a predicted difference in the fitted natural log of pollution, $\ln(P_2)-\ln(P_1)=\ln(P_2/P_1)$. To use this figure to get an estimate for the predicted *percentage* difference in pollution levels, $(P_2-P_1)/P_1$, we note that $\exp[\ln(P_2/P_1)]-1=(P_2-P_1)/P_1$. Thus, the estimated percentage difference in pollution levels associated with an estimated difference in the natural log of pollution of 1.727 is exp(1.727)-1=4.621. A similar transformation is applied to all of the parameter estimates.

[21] In the interests of space, the parameter estimates for this case are not reported here.

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Table 1. Comparison of IMECA and the United States NAAQS

IMECA	IMECA DESCRIPTION	NAAQS DESCRIPTION
0 - 100	Conditions favorable for all types of outdoor activities	Below NAAQS
101 - 200	Increase in minor problems among sensitive groups	Above NAAQS
201 - 300	Increased problems and inability to engage in outdoor activities among persons with respiratory or cardiovascular conditions, minor problems among the general population	Alert
301 - 500	Appearance among general population of varied symptoms and inability to engage in outdoor activities	Warning (301-400) Emergency (401-500)
501+	Not described	Significant harm

Table 2. Health-based ambient air standards

POLLUTANT	STANDARD	
	United States	**Mexico**
Carbon monoxide (CO)		
8-hour Average	9 ppm	11 ppm
1-hour Average	35 ppm	
Nitrogen dioxide (NO2)		
Annual Average	0.053 ppm	
1-hour Average		0.21 ppm
Ozone (O3)		
8-hour Average	0.08 ppm	
1-hour Average	0.12 ppm	0.11 ppm
Sulfur dioxide (SO2)		
Annual Average	0.030 ppm	0.030 ppm
24-hour Average	0.14 ppm	0.13 ppm
Particulate matter smaller than 2.5 micrometers (PM2.5)		
Annual Average	15 $\mu g/m^3$	
24-hour Average	65 $\mu g/m^3$	
Particulate matter smaller than 10 micrometers (PM10)		
Annual Average	50 $\mu g/m^3$	50 $\mu g/m^3$
24-hour Average	150 $\mu g/m^3$	150 $\mu g/m^3$
Total suspended particulate matter (TSP)		
Annual Average		75 $\mu g/m^3$
24-hour Average		260 $\mu g/m^3$
Lead (Pb)		
Quarterly Average	1.5 $\mu g/m^3$	1.5 $\mu g/m^3$

Source: http://www.epa.gov/ttncatc1/cica/airq_e.html
ppm is parts per million and $\mu g/m^3$ is micrograms per cubic meter of air.

Table 3. Dependent Variable: Natural log of monthly IMECA

Variable	Parameter	M1 Estimate		M2 Estimate	
Intercept	α_0	5.35	**	5.44	**
		(0.11)		(0.12)	
time	α_1	-0.02	*	-0.03	**
		(0.01)		(0.01)	
d_2	α_2	-0.56	**		
		(0.13)			
d_3	α_3	1.34			
		(2.53)			
d_4	α_4	0.19			
		(0.20)			
time.d_2 (M1), $node_1$ (M2)	α_5	0.02	*	0.02	**
		(0.01)		(0.01)	
time.d_3 (M1), $node_2$ (M2)	α_6	0.00		0.03	**
		(0.03)		(0.01)	
time.d_4 (M1), $node_3$ (M2)	α_7	0.01		0.02	**
		(0.01)		(0.01)	
Natural log of oil price		-0.03		-0.04	*
		(0.02)		(0.02)	
1995 economic crisis		-0.11		-0.07	
		(0.09)		(0.10)	
R-Squared		0.83		0.82	
Adjusted R-Squared		0.81		0.80	
Sample Size		192		192	

Notes: A set of 11 month dummy variables were included in the regression model.

All standard errors have been corrected for 9th order positive serial autocorrelation.

** and * denote statistical significance at the 1% and the 5% levels, respectively.

Figure 1. Fitted natural log of pollution over time, January 1989 to December 2004, Regression Models M1 and M2

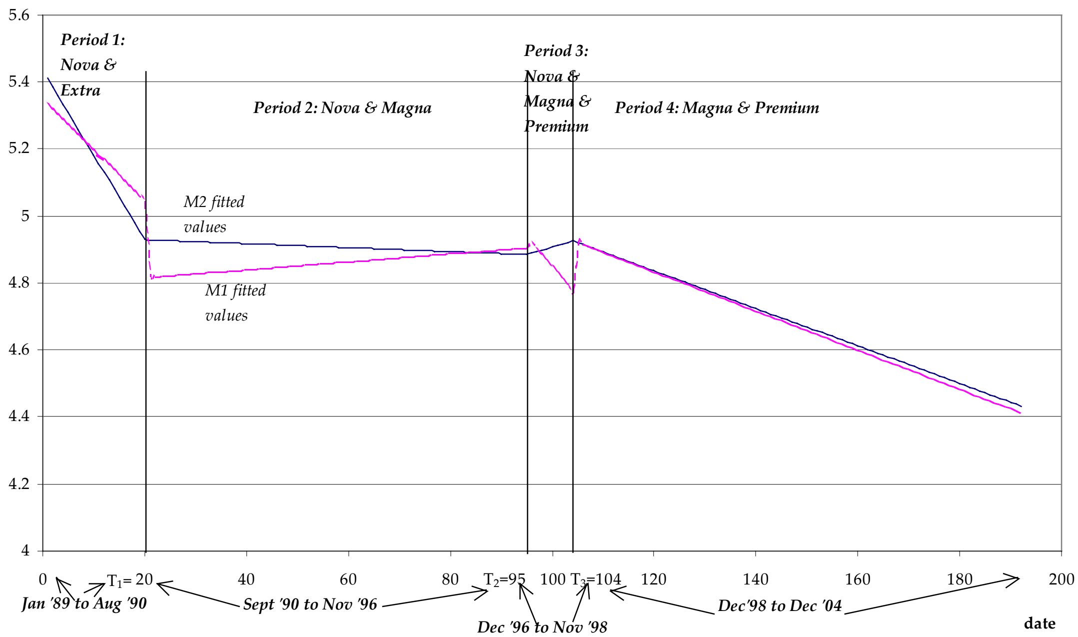

Figure 2. Fitted natural log of pollution per-unit of gasoline over time, January 1989 to December 2004, Regression Models M1 and M2