– PANTHÉON - SORBONNE –
UNIVERSITÉ PARIS 1

Documents de Travail du
Centre d'Economie de la Sorbonne

CES Working Papers

Atmospheric Pollution, Environmental Justice and Mortality Rate : a Spatial Approach

Emmanuelle LAVAINE

2010.72

Maison des Sciences Économiques, 106-112 boulevard de L'Hôpital, 75647 Paris Cedex 13
http://ces.univ-paris1.fr/cesdp/CES-docs.htm
ISSN : 1955-611X

Atmospheric Pollution, Environmental Justice and Mortality Rate: a Spatial Approach

Emmanuelle LAVAINE*
Université Paris 1 Panthéon Sorbonne, Paris School of Economics

September 2010

Abstract

This paper presents the first study of environmental inequality related to health in France at the national scale. Through an econometric analysis based on a panel data from 2000 to 2004 at a department level, we investigate total mortality rate in relation to socioeconomic status and air pollution. Concentration level of CO, SO_2, NO_2, NO, O_3 and PM_{10} are estimated by spatial interpolation from local observations of a network of monitoring stations. By running a multivariate model, we first investigate the relationship between socioeconomic factors and total mortality rate; then, we make the link with environmental air quality measured within the department. Unemployment plays an important role in affecting the mortality rate. Pollutant concentration level are divided into two risk categories (low and high) at the median. We find a positive and significative relationship between NO_2 and mortality rate especially at high concentration level of NO_2 with a relative risk more important for women. Besides, NO_2 level tends to modify the effect of unemployment on mortality rate. These results not only confirm the existence of short term relationships between current air pollution levels and mortality but also raise questions about environmental justice in France.

Keywords: Inequality, Air pollution, Air quality, Environmental Economics, Environmental Health and Safety, Environmental Impact, Environmental Equity, Mortality rate, Spatial Autocorrelation.

JL classification: R12, Q5, I12, R15, C1

---

*CES, Maison des sciences Economiques, 106 112 boulevard de l'hôpital, 75013 Paris cedex 13, France. Email: emmanuelle.lavaine@univ-paris1.fr

1 Introduction

Many pollutants are declining throughout the industrialized world. However, exposure to air pollution, even at the levels commonly achieved nowadays in European countries, still leads to adverse health effects. In this context, there has been increasing global concern over the public health impacts attributed to environmental pollution.

Multilevel modelling has been previously used to assess the negative correlation between pollution exposure and socioeconomics status, such as unemployment, education, and working class in Canada (Premji & al. [2007]), ethnic group, and income in England (Mc Leod & al. [1999]) and in the US (Grineski & al. [2007], Morello-Frosch & al. [2002]) where the concept of environmental justice has been the object of increasing attention. Lucie Laurian [2008] emphasizes that towns with high proportions of immigrants tend to host more hazardous sites even controlling for population size, income, degree of industrialization of the town, and region. In Germany, Schikowski & al. [2008] show the existence of social differences in respiratory health among women population and Kolhuber & al. [2006] acknowledge social inequality in perceived environmental exposures in relation to housing conditions. Pearce & al. [2007] for New Zealand point out that industrial pollution is more important in wealthy places, whereas overall pollution takes place in poorer zones.

In addition, multiple models also estimate the relation between health and pollution, showing the impact of outdoor air pollution on mortality rate in England (Kunzli & al. [2000], Janke & al. [2009]), on allergic sensitization on primary schoolchildren in France (Maesano & al. [2007]), on asthma (Wilhelm & al. [2009]), or on cancer risks among schoolchildren in the US (Morello-Frosch & al. [2002]). Finally, Finkelstein & al. [2003] point out that mean pollutant levels tend to be higher in lower income neighbourhoods in Ontario and both income and pollutant levels are associated with mortality differences.

Besides, we observe a growing epidemiologic literature about air pollution effects on health by sex. The most recent study for gender analysis from Clougherty [2010] shows that most of studies for adults report stronger effects among women, particularly where using residential exposure assessment. For instance, Marr [2010] evaluates marathon race results, weather data and air pollution concentrations for seven major U.S. marathons in cities such as New York, Boston and Los Angeles, where pollution tends to be highest. Higher levels of particles in the air — also known as smog — were associated with slower performance times for women. Men, however, showed no significant impact from pollution. Smaller size of the trachea has been argued to be a reason which makes women more sensitive to particulates in the air. Franklin & al. [2007] studied 130,000 respiratory deaths in 27 U.S. communities and found that community air pollution better predicted death among women than among men. However, it remains unclear whether observed modification is a result of sex-linked biological differences (e.g., hormonal complement, body size) or gender differences in activity patterns, socially derived gender exposures. The meta-Analysis of Annesi-Maesano [2003] points out that among 14 studies, eight conclude to a risk more important for women than for men.

Our analysis offers several contributions to the existing literature. Most of international empirical economic studies estimate either the relation between health and pollution or correlation between pollution exposure and socioeconomics status. We aim to gather both literatures to assess the impact of air pollution on health according to the social status. To our knowledge, environmental factors affecting health, such as exposure to atmospheric air pollution have not been yet studied in France at a national scale in the context of social inequalities. Laurent & al. [2007] emphasize the importance of continuing to investigate this topic due to the tendancy to show greater effects among the more deprived. Furthermore, we examine recent relationships between pollution and health for the entire country. We also account for unobserved confounders using fixed effects suggesting that the previous epidemiologic French literature may have mistaken the true health effects of atmospheric pollutants.

This paper investigates the relationship between ambient air pollutant concentrations, social class, and population mortality at the scale of the department in France. The French air quality monitoring system is composed of 38 air quality control organizations (AASQA) certified by the ministry of urban and rural planning and the environment (ADEME) with a regional, departmental or district competency. The common air pollutant Ozone (O_3), Carbon monoxide (CO), Nitrogen monoxide (NO), Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2) and Particles of less than 10 micrometers in aerodynamic diameter (PM_{10}) are subject to their control, so that we consider the distribution of those pollutants to construct our dataset. We estimate a multi-level model to allow regression coefficients to be examined simultaneously at several spatial scales. First, we consider a standard model considering the main determinants of all causes mortality. Second, we study the impact of atmospheric pollutants on mortality rates by also estimating a model comparing gender. Finally, we will focus on the interaction between air pollution and socioeconomic status. This study takes part of a new research about environmental justice, and provides an overview about the distribution of environmental risks focusing mainly on NO_2.

Results for NO_2 are particularly robust especially at high concentration level of NO_2 with a relative risk more important for women. Besides, NO_2 level tends to interact with socioeconomics factors. Unemployment has a positive and significative impact on mortality rate.

2 Data

We use data on concentration of pollutants and mortality rates available at a local level for all the French territory.

Detailed data on atmospheric pollution come from the information system of air quality measure of the French Environment and Energy Management Agency (ADEME). The contamination of the atmosphere by pollutants at the local and regional level is the result of three processes: emission, transmission, and air pollution concentration. Pollutants are first released at the source. Then, pollutants emitted are dispersed, or sometimes they can be chemically transformed in the atmosphere, creating new, secondary pollutants (transmission); Ozone is an example of this process as it is formed when Hydrocarbons (HC) and Nitrogen oxides (NO_X) combine in the presence of sunlight. Having combined with air and become diluted, atmospheric pollutants are finally inhaled by humans, animals and plants, thus completing the cycle. The L.A.U.R.E (Law on Air and Rational Use of Energy) and the different European directives give priority to control common air pollutants. ADEME gathers information coming from the 38 associations (AASQA) which control the quality of air united within the ATMO federation. A large number of monitoring stations compose the federation[1]. The French nomenclature identifies seven classes of stations, consistent with the various classification defined on the European level : roadside, urban, industrial, near city background, national rural, regional rural, specific observation at a number of 84, 286, 119, 138, 10, 62, 13, and 12 respectively. Most of the monitoring stations take place where the density of population is significant, apart from rural national monitoring stations. The measure taken into consideration in our study is the annual mean of concentration for pollutant within a civil year (1st of January to the 31st of December) calculated by each AASQA for each captor and measured in micrograms per cubic metre of air. This unit of concentration is mostly used to control for outdoor air quality[2].

For spatial interpolation between monitoring stations, we use Universal Kriging, a stochastic geostatistical method that takes into account spatial dependence. Following Currie & Neidell [2005] and Janke and al. [2009], we assign annual pollutant concentrations to the 95 French departments. We consider a model with spatial dependence and express this dependence by constructing a contiguity matrix. The contiguity matrix is based on the distance between two entities. Using the geographical coordinates of the headquarters of a

---

[1] See appendix 9

[2] Air pollutant concentrations do not necessarily produce accurate predictions of exposure levels. People may be resident in one area, they may work in another. Nevertheless, the geographical level used in this article reduces the bias related to population mobility. The department surface represents an average of 570 000 hectares and we know from INSEE data that the average distance between the place of residence and the place of work is nearby 20km, so the accuracy of the exposure levels seems reasonable. It is also important to emphasize that death is registered in the commune of birth although most of people do not live in their place of birth.

local authority, we calculate the distance between the headquarters (prefecture) and all monitoring stations. This distance is given as the great-circle distance between the two points that is, the shortest distance over the earth's surface giving an 'as-the-crow-flies' distance. Let (L_i,N_i) be the latitude and longitude in degrees of monitoring station i and (Lj, Nj) of headquarters j. The distance between the monitoring station i and the headquarter j is given by:

$$d_{ij} = arccos(G_{ij})R \tag{1}$$

where R is the radius of the earth, measured around the equator ($R = 6378$) and

$$G_{ij} = sin(aL_i)sin(aL_j) + cos(aL_i)cos(aL_j)cos(aN_j - aN_i) \tag{2}$$

with $a = \pi/180$

From this distance we calculate a weighted mean of pollutant concentration. The weight attributed to a monitoring station corresponds to the inverse of the distance between the prefecture and the station so that every elements C_{ij} of the distance matrix C is given by:

$$C_{ij}{=}\frac{1/d_{ij}}{\sum_{i=1}^{n} 1/d_{ij}} \tag{3}$$

Matrix C is a stochastic matrix of size N×N where elements in the main diagonal are zero. It is normalized in order to have each row summing to 1. Such normalization allows considering the relative distance instead of the absolute one. Then, we calculate the average weighted mean of pollutant concentration $\bar{P}$ within the entire department:

$$\bar{P}{=}\sum_{i=1}^{n} C_{ij} P_{iu} \tag{4}$$

P_{iu} corresponds to the annual mean concentration measured by the monitoring station i for the pollutant u.

The top panel of Table 1 presents descriptive statistics for pollution data. It is important to stress that air pollutant concentration used to be below the limit value fixed by European and national institution over which health can be harmed. And the average concentration from our measure is lower than the level used by studies in United States and even lower than in England where it is already considered to be quite low to harm health. However, E.R.P.U.R.S project [2003] in France shows recently that NO_2 and PM_{10} have a negative impact on health, even at low air pollutant concentration, considering hospitalization number as the explicative variable. Pascal & al. [2009] in France obtain similar results considering also different mortality rates in nine polluted cities.

NO, NO_2 and PM_{10} are positively correlated with correlation coefficients between 0.5 and 0.8. They are negatively correlated with O_3 which may be due to the fact that Ozone is rapidly destroyed to form NO_2 within cities. In addition, correlation between both NO_2 and NO is high (0.85), so that we choose to keep NO_2 as an explanotory variable and drop NO to prevent from autocorrelation. We do not include observations for SO_2 and CO as few monitoring stations measure those pollutants. Other pollutants are also likely to be associated with differences in mortality, but data were unavailable to perform intra urban interpolations for these pollutants.

The second panel of Table 1 presents mortality rates. A large range of pollutants are responsible for outdoor air pollution, so that it is difficult to assign them a specific health effect that's why we use all causes mortality rate. Data on health come from the national federation of regional health observatories (ORS). We use directly age standardized rates to control for different population age structures across department. The year corresponds to mid-year of the triennial period used. Data on mortality are available from 1980 to 2004 whereas data on pollution from 1985 to 2005 with very few values before 2000, so that we consider a period of 5 years (2000-2004). The standard deviation is quite high showing us that our data are spread out over a large range of values[3]. In addition, the variation within each department is significative as well as for pollutant concentration [4].

The third block describes the control variables. Data on weather come from Meteo France through the French Institute of the Environment (IFEN). Smoking rate fell by 35% between 2000 and 2004, probably due to the "Loi Évin" since 1991 and the tax increase (INSEE 2006). Road accident rate fell 29% according to the data from the national federation of regional health observatories (ORS). We also collect from the ORS, the number of people per 1 hospital bed to measure health care system and the availability of medical care resources in a particular department from 2000 to 2004. We add the share of industry to control for industrialization, as a time invariant variable for each department coming from the 2005 census of the French Institute of Statistics (INSEE).

The fourth panel shows the socioeconomic variables: education and unemployment coming from the 2007 census of (INSEE) and the French Ministry of Labour (DARES). Definitions of the variables are given in the Appendix 3.

Finally, the last row of descriptive statistics corresponds to an air pollution Index. To capture peaks of pollution, we use the ATMO index calculated by the AASQA. The Atmo outlook varies daily according to

---

[3] The degree of dispersion (spread) and skewness in the data are presented graphically in Appendix 2.

[4] We do not include in this paper specific cause of mortality due to the weak variability of these data in France for the 2000 - 2004 period which does not allow any estimation.

air quality using a scale of 1-10 (1 = very good air quality, 10 = very bad air quality). This index takes into consideration the concentration of four subindexes characterizing Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), Particles in suspension (PS) and Ozone (O_3). It considers pollution measured only by urban and industrial monitoring stations for main agglomerations for a period from 2000 to 2003. After 2003, the construction of the index has been changed, so that we cannot consider it for 2004. We retain 41 agglomerations and we are associating each one to a department. We construct a yearly variable summing the number of days above indices 8, 9 and 10 which corresponds to a poor air quality according to the definition of Atmo index[5].

This index variable is positively correlated with the previous measure of NO_2, NO, PM_{10} and O_3. In other words, peaks of pollution are correlated positively with ambient air pollution which gives more credence to our measure. However, we will prefer further on in our estimation to use real concentration of pollution instead of indices. Few days correspond to peaks of pollution, and fixing a threshold below which pollution does not have any impact is highly arguable. Pollution is indeed fluctuating, low level can be active and the toxic level of perception is variable even among healthy population. Within a population, some people are more sensitive than others and will suffer from atmospheric pollution even at really low level - level which does not go beyond the actual threshold fixed by public authorities.

Variable	Mean	Std. Dev.	Min	Max	Between department Std. Dev.	Within department Std. Dev.	Mean in 2000	Mean in 2004
Pollutants								
PM10 (µg/m3)	21.46066	5.507876	8.817638	57.38416	3.56479	4.226236	20.66536	22.9148
NO2(µg/m3)	31.71435	11.37481	12	74.04559	10.53944	4.509464	32.39159	29.79553
NO(µg/m3)	23.11989	18.70101	3.62616	145.7256	15.84246	10.16506	22.66962	27.73054
O3 (µg/m3)	53.02869	15.39018	30.60137	99.65313	6.579284	13.94135	43.26784	78.57994
All causes mortality rates								
All causes mortality rate (per 100 000)	819.7591	64.61492	620	1000	63.91677	12.82	835.75	806.9091
Male mortality rate (per 100 000)	1092.595	96.55129	792	1393	93.63266	26.74333	1127.659	1058.75
Female mortality rate (per 100 000)	626.5364	47.62308	499	756	46.77091	10.97244	631.0227	626.2727
Control variables								
industry (%)	16.17478	4.77803	5.930366	24.47606	4.822272	0	16.17478	16.17478
Smoking rate (per 1000)	1218.513	274.1815	483.5	2298.7	192.2561	197.2009	1372,991	883,8295
Accident (per 100 000)	12.05455	4.106652	3	22	3.765045	1.716958	13,77273	9,75
PPHB	136.1738	37.84015	71.69604	268.8203	38.15236	1.691371	134.3395	137.9933
Precipitation (mm)	2.211417	.5709846	.854918	3.865206	.4134218	.3969113	2.434172	1.984284
Sun (C°)	5.422066	.9889944	3.736066	8.115891	.8865025	.446114	5.194088	5.397749
Socioeconomics variables								
Unemployment (%)	8.436023	2.033194	4.575	14.625	1.976955	.5448954	8.753409	8.867045
Education (%)	15.67797	5.044896	10.24137	37.48089	5.087249	.2087244	15.89803	15.4632
Others								
Atmo index 8 to 10	3.524096	5.531948	0	28	3.639727	4.184507	.	.

Table 1 : Descriptive statistics for the estimation sample (n = 220, groups = 44)

---

[5] See appendix 6

3 Model and Econometrics Issues

3.1 Specification

The focus of this study is the relationship between average pollution, socioeconomic status, and mortality. Our unit of analysis is the department, which is the main administrative unit below the national level. There are 95 departments in France with an average population of 620 000 people, ranging from over 70 000 to over two million. Departments are grouped over 22 metropolitan known as region.

In the analysis, we start by estimating a standard model with total mortality rate as the explicative variable without consideration of environmental quality. After doing preliminary regression for various functional form and following the result from overall normality test based on skewness and on kurtosis for each of them, we estimate an equation of the following form to ensure that errors are normally distributed[6] $\varepsilon \sim N(0, \sigma^2)$:

$$X_{it}^k = \alpha_k + Socioeconomic_{it}\beta_k + PPHB_{it}\gamma_k + Industry_i\zeta_k + Lifestyle_{it}\eta_k + \varepsilon_{it}^k \tag{5}$$

where i indexes the local authority, t indexes the year, k the kind of mortality rate. X_{it}^k is a vector of all causes mortality rates (overall mortality rate, male and female mortality rate). Socioeconomic variables such as unemployment rate and education are included as the main explanatory variables. An individual's living situation and quality of life have a very high degree of correlation with whether or not he or she is employed (Lin [2009]). There is also, most likely, a direct positive effect of education on health (Groot & Maassen van den Brink [2007]). While the exact mechanism underlying this link is unclear, the differential use of health knowledge and technology is almost certainly important parts of the explanation. Due to multicollinearity issue [7], we were not able to include both the average revenue and education. The number of people per 1 hospital bed $PPHB_{it}$ in each department, was included as a proxy to measure the health care system and the availability of medical care resources in a particular department. We also include the % of industry added value over the total added value $Industry_i$ for each department as a time invariant variable. The vector $Lifestyle_{it}$ accounts for lifestyle which refers to the regular activities and habits a person has that could have an effect on its health. We include accident and smoking rate variables. ε_{it} is the error term.
To address the possibility that omitted variables account for some of the heterogeneity among French de-

---

[6] There is no evidence that the log transform is the best fit for mortality time trends (Bishai & Opuni [2009]).

[7] The squared correlation between education and the average revenue is above 0.8.

partments, an error component model is estimated:

$$\varepsilon_{it} = c_i + \delta_t + u_{it} \tag{6}$$

c_i and δ_t are residual differences where c_i is a department effect which accounts for differences across departments that are time-invariant (e.g lifestyle differences that we cannot take into account), δ_t is a year effect which controls for factors that vary uniformly across departments over time, and u_{it} is the remaining error term. We weight all of our observations by the square root of mid year population estimates. We consider that this weight takes also into account the land surface, knowing the high correlation between both land area and average population. Ramsey test confirms the robustness of our specification.

The next step of our empirical work is to choose the right estimation model. It is likely that population's health affects unemployment through productivity, education and other factors. This potential simultaneity can be a source of endogeneity, making standard estimators inconsistent. We need to test this hypothesis so that we consider the lag of the endogenous variable, unemployment, as an instrument. The F-test on the excluded instruments in the first stage regression confirms the validity of the instrument [8]. Then, Hausman test rejects the endogeneity of the model[9]. However, OLS estimator is not consistent due to unobserved factors f_{it} which determine both X_{it}^k and P_{it} with:

$E(P_{it}; f_{it}) \neq 0$ and $E(\varepsilon_{it}; f_{it}) \neq 0$ such that $E(\varepsilon_{it}; P_{it}) \neq 0$.

Thus, a next decision in performing a multilevel analysis is whether the explanatory variables considered in the analysis have fixed or random effect. Independent variables have explained most of differences about department and year, but there is probably some unmodeled heterogeneity. Hausman test considers the null hypothesis that the coefficients estimated by the efficient random effects estimator are the same as the ones estimated by the consistent fixed effects estimator. By running this test, and apart when we consider the sample below the median of pollution for NO_2, fixed effect model appears to be the most efficient one. In fact, we think about each department as having its own systematic baseline. We also calculate robust variance estimator in order to prevent for heteroskedasticity that we found by running Breush-Pagan test: this test checks if squared errors are explicated by explanatory variables. Our estimation will also take into account autocorrelation because Wooldridge test shows that disturbances exhibit autocorrelation, with the values in a given period depending on values of the same series in previous periods.

---

[8] To avoid the weak instruments pathology, we look at the F-test on the excluded instruments in the first stage regression and check whether the test statistic is larger than 10. F(1,192) = 28.91

[9] P=0.810

In the second model, mortality rate is expressed as a function of environmental variables added to the previous variables. We will estimate the model :

$$X_{it}^{k} = \lambda_k + P_{it}\theta_k + Socioeconomic_{it}\psi_k + PPHB_{it}\varsigma_k + Industry_i\mu_k + Lifestyle_{it}\sigma_k + Z_{it}\phi_k + \varepsilon_{it}^{k} \qquad (7)$$

P_{it} is a vector of air pollutants concentration for O_3, NO_2 and PM_{10}. We also include a vector of weather variables at department level Z_{it} as a control for average pollution levels. We consider the annual mean of precipitation to capture the effect of very wet years and the annual mean of the daily maximum temperature as time varying control. In this model, the main coefficient of interest is θ representing the mean parameter estimates for all 95 departments for explanatory variables P_{it}. It also represents the effect of air quality on the health outcome. We will again use the fixed effect estimator to control for heterogeneity between departments. The fixed effects are contained in the error term, ε_{it}, in equation (7), which consists of the unobserved department-specific effects, c_i, the year effect δ_t, and the observation-specific errors, u_{it}:

$$\varepsilon_{it} = c_i + \delta_t + u_{it} \qquad (8)$$

Finally, we will add an interactive term $P_{it}Socioeconomic_{it}$ between socioeconomics and environmental quality to provide a better description of the relationship between the mortality rate and the independent variables such that:

$$\begin{aligned} X_{it}^{k} &= \lambda_k + P_{it}\theta_k + Socioeconomic_{it}\psi_k + P_{it}Socioeconomic_{it}\varpi_k + PPHB_{it}\varsigma_k + Industry_i\mu_k + Lifestyle_{it}\sigma_k + Z_{it}\phi_k + \varepsilon_{it}^{k} \qquad (9) \\ &= \lambda_k + (\theta_k + Socioeconomic_{it}\varpi_k)P_{it} + Socioeconomic_{it}\psi_k + PPHB_{it}\varsigma_k + Industry_i\mu_k + Lifestyle_{it}\sigma_k + Z_{it}\phi_k + \varepsilon_{it}^{k} \end{aligned}$$

where $(\theta_k + Socioeconomic_{it}\varpi_k)$ represents the effect of environmental quality on mortality rate at specific level of socioeconomics variable and ϖ_k indicates how much the slope of P_{it} changes as socioeconomic goes up or down one unit.

3.2 Results

3.2.1 Impact of environment quality on health

We start by examining a standard model without consideration of environmental quality. We will then add NO_2, O_3 and PM_{10} in the specification controlling for precipitation and temperature to see if considering pollutant variables improves the global fit of the model. To capture the department effect, both fixed effects and random effects are estimated. Approximately, seventy percent of the variation in the response variable may be attributed to explanatory variables. High R^2 in all fixed effect models confirm the global good fit of the models when considering characteristics of departments. Moreover, the values of Baltagi-Wu LBI and Durbin-Watson are above or close to 2, showing that the autocorrelation is not an issue.

	OLS	Fixed effect	Random effect
Ed	-10.354***	-0.466	-8.079***
	(11.20)	(0.03)	(6.55)
Accident	-4.665***	-1.975**	-1.045
	(3.79)	(2.49)	(1.38)
Sm	0.058***	0.046***	0.059***
	(4.28)	(5.67)	(7.77)
Industry	4.388***		4.813***
	(6.14)		(3.82)
PPHB	-0.231**	-2.392	-0.351**
	(2.40)	(1.43)	(2.44)
Unemployment	7.274***	5.912***	10.617***
	(3.76)	(3.77)	(7.02)
Constant	867.247***	1,070.844**	768.756***
	(28.28)	(2.38)	(18.41)
Observations	220	220	220
R-squared	0.67	0.98	
DW	1.0691343		
Baltagi-Wu LBI	1.6427049		

*Note: observations weighted by the square root of mid-year population estimates. * significant at 10%; ** significant at 5%; ***significant at 1%. Absolute value of z statistics in parentheses. Robust t statistics in parentheses.*

Table 2 : Estimates of the association between all causes mortality rate and the standard determinants of mortality rate without consideration of environmental quality

We first estimate the standard model with OLS trying to test a most complete model and we observe in the first column from table 2 that all the coefficients of the determinants of mortality are significative. However, we also use the within estimator as we assume that the unobserved factors f_{it} between departments determine both mortality rate and explanatory variables. All the coefficients remain significative when considering fixed effect estimator apart for PPHB and education. This loss of significativity may be due to the correlation between department specific effect and both explanatory variables. Fixed effect imposes time independent effects for each entity that are possibly correlated with the regressors that's why $Industry_i$, time invariant variable, is not taken into account.

We then study the relationship between NO_2, O_3, PM_{10} and mortality rates in both a single pollutant model (table 3) and in a multi-pollutant one (table 4). The multi-pollutant model allows coefficients to be examined at the same time, so as to not overestimate the impact of one pollutant. In addition, we divide our panel in two: departments above and those below the median of air pollutant concentration to compare results when facing high atmospheric pollution.

All the determinants of mortality remain significative when adding the environmental variable in an OLS model. Nevertheless, apart for Ozone, the environmental variables are not significative probably due to multiple correlation existing between explanatory variables. As we explained previously, OLS estimator is not a consistent estimator, so that we need to consider a fixed effect model.

As it is shown in the first two models, coefficients are not significantly different from zero when we consider fixed and random effect for PM_{10} in all specifications. We may think that the impact of PM_{10} on morbidity would be more likely. This result is opposed to the French study by the Sanitary Health Institute (Pascal & al. [2009]) which founds a positive effect of PM_{10} on mortality in a panel of nine different French cities. However, this article does not precise the type of estimator used. Furthermore, Pascal & al. [2009] do not take into account the influence of lifestyle or socioeconomic factors on health as their model strictly includes weather data whereas the robustness of our model is not verified if we take education out. Finally, the average concentration from our measure is probably lower than the level used by the Sanitary Health Institute which considers 9 urban cities.

	NO2			O			PM10		
	OLS	Fixed effect	Random effect	OLS	Fixed effect	Random effect	OLS	Fixed effect	Random effect
NO2	-0.100	0.333**	0.229						
	(0.28)	(2.17)	(1.38)						
O				-0.653***	-0.166	-0.349***			
				(2.81)	(1.23)	(2.69)			
PM10							-0.032	0.154	0.104
							(0.05)	(0.93)	(0.54)
Pr	-14.005***	-0.405	-2.805	-16.033***	-0.586	-2.731	-14.229***	-0.085	-2.714
	(3.11)	(0.15)	(1.11)	(3.49)	(0.21)	(1.11)	(3.14)	(0.03)	(1.06)
Sun	-17.268***	2.631	0.652	-16.021***	1.983	-0.548	-17.436***	3.226	1.039
	(5.46)	(1.23)	(0.35)	(5.52)	(0.86)	(0.29)	(5.77)	(1.50)	(0.56)
Ed	-12.895***	30.908*	-8.878***	-12.806***	36.896**	-8.451***	-12.967***	34.369*	-8.637***
	(14.55)	(1.75)	(7.83)	(17.00)	(2.09)	(7.61)	(15.84)	(1.93)	(7.73)
Accident	-6.808***	0.398	-0.772	-6.572***	0.270	-0.875	-6.694***	0.354	-0.881
	(6.16)	(0.44)	(0.97)	(6.66)	(0.29)	(1.12)	(6.34)	(0.39)	(1.10)
Sm	0.083***	0.038***	0.056***	0.058***	0.030**	0.035***	0.082***	0.040***	0.059***
	(6.66)	(4.34)	(6.81)	(3.95)	(2.42)	(2.99)	(6.87)	(4.34)	(7.09)
Industry	2.058***		4.450***	1.655**		4.181***	1.969***		4.659***
	(2.64)		(3.73)	(2.39)		(3.48)	(2.77)		(3.94)
PPHB	0.191**	3.419	-0.169	0.154**	4.279*	-0.187	0.194**	3.803	-0.176
	(2.42)	(1.45)	(1.00)	(2.00)	(1.83)	(1.10)	(2.50)	(1.60)	(1.04)
Unemployment	10.787***	6.331***	10.655***	11.596***	6.462***	11.194***	10.659***	6.301***	10.752***
	(6.04)	(3.54)	(6.86)	(6.76)	(3.42)	(7.32)	(5.84)	(3.34)	(6.89)
Constant	983.934***	-275.267	757.774***	1,043.919***	-453.933	813.404***	986.288***	-381.116	751.962***
	(32.37)	(0.46)	(18.63)	(27.56)	(0.76)	(17.34)	(31.79)	(0.63)	(18.46)
Observations	205	205	205	205	205	205	205	205	205
R-squared	0.77	0.99		0.78	0.98		0.77	0.98	
DW	.9813505			.93997743			.97930161		
Baltagi-Wu LBI	1.5939381			1.5603009			1.5895372		

*Note: observations weighted by the square root of mid-year population estimates. * significant at 10%; ** significant at 5%; ***significant at 1%. Absolute value of z statistics in parentheses. Robust t statistics in parentheses.*

Table 3 : Estimates of the association between all causes mortality rate and air pollutant concentrations in single pollutant models

Ozone is negatively correlated with mortality rate and it is only significative with fixed effect estimator when considering the sample above the median of air pollutant concentration in a multi-pollutant model. The relationship between Ozone and temperature remains a complex phenomenon and may be the cause of the negative coefficient also pointed out in England by Janke & al. [2009]. Temperature, humidity, winds, and the presence of other chemicals in the atmosphere influence Ozone formation, and the presence of Ozone, in turn, affects those atmospheric constituents. French data show this positive correlation between temperature and Ozone[10]. Using two time-series Poisson regression models, Ren & al. [2008] indicate that Ozone positively modified the temperature associations across different regions in the USA. In addition, both

---

[10] See appendix 7

ambient Ozone and temperature are associated with human health. From an epidemiologic point of view, Sanitary Health Institute [2009] in France insists about the complexity of studying the interaction between Ozone and sanitary variables.

In contrast, NO_2 appears to have a significative and positive effect in both single and multi-pollutant models whether we consider the fixed effect estimator. In addition, the impact is greater with higher significativity when we consider the sample above the median of pollution in the multi-pollutant model. We observe from the OLS estimator that the effect of NO2 on mortality rate tends to lead to erroneous conclusion if the fixed-effects problems are neglected. As a result, we give more credence to fixed and random effect estimators for the rest of the study and we will focus on the unique pollutant, NO_2, as it has a relevant significativity in both models.

	Overall panel			Above the median of pollution		
	OLS	Fixed effect	Random effect	OLS	Fixed effect	Random effect
NO2	-0.377	0.361*	0.234	-0.096	0.860***	0.865**
	(1.01)	(1.73)	(1.08)	(0.11)	(2.82)	(2.06)
O	-0.711***	-0.158	-0.349***	-1.047***	-0.362*	-0.569**
	(3.02)	(1.15)	(2.65)	(2.66)	(1.82)	(2.52)
PM10	0.491	-0.052	-0.006	0.030	-0.148	-0.469
	(0.78)	(0.27)	(0.02)	(0.04)	(0.38)	(1.00)
Pr	-15.212***	-0.779	-2.783	-25.794***	-6.608*	-6.702*
	(3.30)	(0.28)	(1.13)	(2.99)	(1.68)	(1.71)
Sun	-15.641***	1.402	-0.993	-20.229***	-8.333**	-9.719***
	(4.98)	(0.60)	(0.51)	(4.22)	(2.18)	(2.87)
Ed	-12.595***	32.763*	-8.752***	-12.728***	3.102	-10.223***
	(15.09)	(1.85)	(7.70)	(9.45)	(0.10)	(6.24)
Accident	-6.869***	0.329	-0.782	-3.150	-1.475	-2.237
	(6.57)	(0.36)	(0.99)	(1.55)	(0.65)	(1.42)
Sm	0.061***	0.029**	0.033***	0.021	0.025	0.028
	(4.07)	(2.39)	(2.82)	(0.95)	(1.55)	(1.38)
Industry	1.876**		3.934***	-0.832		1.351
	(2.47)		(3.23)	(0.53)		(0.71)
PPHB	0.148*	3.808	-0.176	0.060	-0.191	-0.107
	(1.87)	(1.62)	(1.03)	(0.38)	(0.04)	(0.40)
Unemployment	11.948***	6.457***	11.019***	9.365***	4.784	8.926***
	(6.94)	(3.59)	(7.18)	(3.04)	(1.62)	(3.52)
Constant	1,035.776***	-330.199	818.452***	1,199.314***	750.746	970.668***
	(27.06)	(0.55)	(17.34)	(11.51)	(0.59)	(10.47)
Observations	205	205	205	74	74	74
R-squared	0.78	0.99		0.88	0.99	
DW	.96615973			1.2117275		
Baltagi-Wu LBI	1.5807708			1.9954329		

*Note: observations weighted by the square root of mid-year population estimates. * significant at 10%; ** significant at 5%; ***significant at 1%. Absolute value of z statistics in parentheses. Robust t statistics in parentheses.*

Table 4 : Estimates of the association between all causes mortality rate and air pollutant concentrations in multi-pollutant models

Nitrogen oxides (NOx) is the main indicator of transportation vehicles and stationary combustion sources, such as electric utility and industrial boilers contamination[11]. NOx forms when fuels are burned at high

---

[11] The spatial distribution of NO_2 is generally not homogeneous within individual metropolitan areas. The primary reason for the observed heterogeneity in concentrations across an urban area is the substantially higher concentrations of NO_2 near sources, such as roadways. [Electric power research institute 2009].

temperatures and includes various Nitrogen compounds like Nitrogen dioxide (NO_2) and Nitric oxide (NO). These compounds play an important role in the atmospheric reactions that create harmful particulate matter, ground-level Ozone (smog), acid rain, and eutrophication of coastal waters. NO_2 is produced by chemical transformation with NO and Ozone ($NO + O_3 = NO_2 + O_2$). Not only particle filters but also the rise of Ozone in the atmosphere, increase NO_2 emissions (AFSSET [2009]). As a consequence, NOx is a powerful oxidizing gas, linked with a number of adverse effects on the respiratory system (EPA [2010]).

Then, we divide our panel in the departments above and those below the median of NO_2 as shown in table 5. The within group and the long difference estimates are quite similar although we prefer fixed effect model for the reason we described previously. The first block presents the panel below the median of pollution for NO_2. The association is no significant, whereas when we consider departments above the median of pollution for NO_2, the coefficient remains significantly positive with fixed and random effect. We confirm results found with previous models. The fixed effect estimate suggests that per 1 $\mu g/m^3$ increase in NO_2, there is almost one more death a year. Concentration of NO_2 varies from 12 to 74 $\mu g/m^3$ suggesting a difference of nearby 50 deaths a year according to the department. This result confirms in France the existence at a high level of pollution of a short-term relationship between current air pollution levels and mortality.

	Below the median of pollution for NO2			Above the median of pollution for NO2		
	OLS	Fixed effect	Random effect	OLS	Fixed effect	Random effect
NO2	-0.125	-0.532	0.038	0.374	0.771***	0.625**
	(0.17)	(1.70)	(0.07)	(0.60)	(3.89)	(2.03)
Pr	-7.231	5.282	0.641	-22.886***	-5.002	-9.151**
	(1.05)	(1.47)	(0.14)	(3.11)	(1.42)	(2.30)
Sun	-14.130**	7.722***	2.228	-20.084***	-3.366	-7.933**
	(2.48)	(3.12)	(0.73)	(4.89)	(1.09)	(2.52)
Ed	-16.136***	54.712	-12.453***	-12.254***	-4.456	-9.281***
	(8.37)	(1.62)	(4.36)	(10.18)	(0.17)	(6.28)
Accident	-9.241***	1.185	-2.375**	-4.192**	0.570	-1.286
	(7.07)	(1.02)	(2.17)	(2.30)	(0.34)	(0.91)
Sm	0.127***	0.043***	0.063***	0.064***	0.039***	0.062***
	(6.88)	(3.81)	(4.60)	(3.56)	(3.47)	(4.62)
Industry	3.886***		4.873***	1.394		3.914**
	(3.02)		(3.38)	(1.04)		(2.33)
PPHB	-0.057	8.059**	-0.231	0.316**	-1.628	-0.013
	(0.48)	(2.27)	(1.05)	(2.43)	(0.38)	(0.05)
Unemployment	11.665***	15.973***	13.208***	10.158***	4.908**	9.620***
	(5.76)	(5.86)	(5.40)	(3.60)	(2.32)	(4.19)
Constant	976.640***	-1,226.252	790.633***	985.378***	1,001.842	803.099***
	(19.01)	(1.33)	(13.40)	(16.07)	(0.95)	(11.47)
Observations	106	106	106	99	99	99
R-squared	0.64	0.99		0.83	0.99	
DW	1.0747863			1.350698		
Baltagi-Wu LBI	1.6960147			2.0349193		

*Note: observations weighted by the square root of mid-year population estimates. * significant at 10%; ** significant at 5%; ***significant at 1%. Absolute value of z statistics in parentheses. Robust t statistics in parentheses.*

Table 5 : Estimates of the association between all causes mortality rate and NO2 for different level of air pollutant concentration

Gender Analysis Hence, we consider male and female mortality rates as explicative variables related to NO_2. We observe a significative effect for female as we do not find any for male. Road accident, smoking rate and unemployment have a significative and positive effect on male mortality rate. Lifestyle seems to be more prevalent than air pollution concentration on male mortality rate. The female fixed effect estimate suggests that per 2 $\mu g/m^3$ increase in NO_2, another death for women is registered suggesting a difference of 30 deaths a year for women between departments.

	Ms			Mr		
	OLS	Fixed effect	Random effect	OLS	Fixed effect	Random effect
NO2	0.150	0.513***	0.369**	-0.550	0.152	0.096
	(0.41)	(2.95)	(2.44)	(1.35)	(0.65)	(0.37)
Pr	-14.290***	-1.158	-2.435	-12.294*	0.738	-5.118
	(3.53)	(0.44)	(1.05)	(1.91)	(0.18)	(1.28)
Sun	-7.557***	7.407***	5.868***	-34.166***	-6.845**	-11.245***
	(2.74)	(3.47)	(3.43)	(7.33)	(2.08)	(3.86)
Ed	-8.568***	33.133**	-5.471***	-19.415***	28.547	-13.819***
	(11.50)	(2.23)	(5.24)	(14.70)	(1.01)	(8.76)
Accident	-6.162***	-1.106	-1.740**	-9.782***	2.902*	-0.438
	(6.49)	(1.33)	(2.39)	(6.13)	(1.81)	(0.36)
Sm	0.051***	0.008	0.022***	0.141***	0.090***	0.120***
	(4.33)	(1.08)	(2.98)	(8.53)	(6.11)	(9.45)
Industry	2.265***		3.962***	2.620***		5.768***
	(3.09)		(3.59)	(2.62)		(3.55)
PPHB	0.203***	3.976*	-0.036	0.115	3.156	-0.377*
	(2.96)	(1.89)	(0.23)	(0.96)	(0.85)	(1.65)
Unemployment	7.281***	2.596	7.338***	16.599***	11.657***	14.604***
	(4.94)	(1.63)	(5.19)	(6.01)	(4.14)	(6.33)
Constant	717.745***	-521.682	548.218***	1,381.733***	-11.379	1,075.123***
	(25.92)	(1.00)	(14.65)	(34.14)	(0.01)	(18.65)
Observations	205	205	205	205	205	205
R-squared	0.65	0.98		0.81	0.98	
DW	1.1149423			.96666977		
Baltagi-Wu LBI	1.6190883			1.6268575		

*Note: observations weighted by the square root of mid-year population estimates for male and female respectively. * significant at 10%; ** significant at 5%; ***significant at 1%. Absolute value of z statistics in parentheses. Robust t statistics in parentheses.*

Table 6 : Estimates of the association between NO2 and all causes mortality rate according to gender

3.2.2 Interaction between socioeconomic status and environment quality

Hence, we might suspect that exposure to air pollution related to health varies with economic status in France. People with low incomes may be disproportionately exposed to environmental contamination that threatens their health.

Thus, to be more precise, we want to analyze whether the effect of the socioeconomic variables has been moderated or modified by the introduction of the environmental variable. To do so, we include an interaction variable to look at the unemployment and NO_2 interact. Critics assert that increased level of collinearity in models including a multiplicative term distorts the beta coefficients. To reduce multicollinearity, we subtract the mean from each observation of unemployment and NO2 so that the new mean is equal to zero (Cronbach [1987]).

The effects of unemployment rate on health status with consideration of NO_2 are summarized in table 7. Coefficients for unemployment, NO_2 and the interactive variable are significative with both explicative variables "all causes mortality rate" and female mortality rate when using the within estimator. The significativity of the interaction coefficient suggests that the the effect of unemployment has been modified by the environmental variable. In other words, the effect of NO_2 $(\theta_k + Socioeconomic_{it}\varpi_k)$ at some value of unemployment $Socioeconomic_{it}$ has a significant effect on the mortality rate. If unemployment is positive, the effect of NO_2 on mortality rate is also positive.

We want to check the robustness of our previous result about gender, so that we consider separately female and male mortality rate as it is shown in the two last blocks. Unemployment and NO_2. are again positively and significatively correlated with female mortality rate with the fixed effect estimator. Unemployment has a positive and significative impact on the three different types of mortality rates. In contrast, the coefficient of NO_2 does not appear significative when considering male mortality rate. We also notice an higher coefficient of unemployment for men than for women which suggests a relative impact of having a job on health, more important for men. This result leads us to think about the significance of taking into account the individual degree of exposure including demographics, type of activities or personal health situation.

	All causes mortality rates			Ms			Mr		
	OLS	Fixed effect	Random effect	OLS	Fixed effect	Random effect	OLS	Fixed effect	Random effect
Unemployment_ct	10.693***	7.209***	10.742***	7.300***	3.510**	7.433***	16.658***	12.526***	14.712***
	(6.17)	(4.04)	(6.91)	(5.10)	(2.13)	(5.25)	(6.39)	(4.54)	(6.36)
NO2_ct	-0.105	0.469**	0.335*	0.151	0.654***	0.482***	-0.547	0.288	0.212
	(0.30)	(2.59)	(1.80)	(0.41)	(3.43)	(2.85)	(1.35)	(1.11)	(0.72)
NO2_ct *Unemployment_ct	0.030	-0.115*	-0.084	-0.006	-0.119**	-0.088	-0.019	-0.114	-0.096
	(0.30)	(1.78)	(1.23)	(0.06)	(2.13)	(1.42)	(0.13)	(1.01)	(0.90)
Pr	-13.984***	-0.891	-3.190	-14.294***	-1.663	-2.832	-12.307*	0.257	-5.507
	(3.09)	(0.33)	(1.25)	(3.51)	(0.63)	(1.21)	(1.91)	(0.06)	(1.36)
Sun	-17.262***	2.381	0.314	-7.558***	7.148***	5.557***	-34.170***	-7.094**	-11.590***
	(5.46)	(1.09)	(0.17)	(2.74)	(3.29)	(3.22)	(7.33)	(2.14)	(3.94)
Ed	-12.883***	27.495	-9.066***	-8.570***	29.557**	-5.659***	-19.423***	25.195	-14.010***
	(14.51)	(1.60)	(7.96)	(11.53)	(2.11)	(5.39)	(14.70)	(0.88)	(8.81)
Accident	-6.812***	0.440	-0.778	-6.161***	-1.063	-1.739**	-9.780***	2.944*	-0.423
	(6.16)	(0.49)	(0.97)	(6.48)	(1.28)	(2.40)	(6.10)	(1.83)	(0.35)
Sm	0.083***	0.038***	0.056***	0.051***	0.009	0.022***	0.141***	0.090***	0.120***
	(6.59)	(4.36)	(6.82)	(4.30)	(1.16)	(2.97)	(8.48)	(6.09)	(9.43)
Industry	2.064***		4.331***	2.264***		3.841***	2.616***		5.644***
	(2.64)		(3.63)	(3.08)		(3.48)	(2.61)		(3.47)
PPHB	0.193**	3.070	-0.170	0.203***	3.610*	-0.038	0.114	2.815	-0.380*
	(2.42)	(1.33)	(1.01)	(2.92)	(1.82)	(0.25)	(0.94)	(0.75)	(1.66)
Constant	1,071.287***	-107.263	863.210***	784.020***	-374.311	630.267***	1,504.627***	193.743	1,209.984***
	(31.07)	(0.18)	(22.06)	(24.83)	(0.76)	(17.48)	(32.26)	(0.20)	(21.83)
Observations	205	205	205	205	205	205	205	205	205
R-squared	0.77	0.99		0.65	0.98		0.81	0.98	
DW	1.0204769			1.145104			.99439627		
Baltagi-Wu LBI	1.6209387			1.6414211			1.6460637		

Note: observations weighted by the square root of mid-year population estimates. * significant at 10%; ** significant at 5%; ***significant at 1%. Absolute value of z statistics in parentheses. Robust t statistics in parentheses.

Table 7: An interaction model

4 Conclusion

The objective of this paper has been first to investigate whether both department's environmental quality and socioeconomic status relative to its neighbors have an impact on its mortality rate. The second purpose has been to analyze the link between inequalities and air quality between departments. We test these hypothesis by using a multivariate model and taking fixed effects into account.

Results are strongly supportive of the hypothesis that NO_2 has a positive impact on mortality with the effect being larger when considering the subsample with the highest level of pollution. In addition we show that even relatively low concentrations of air pollutants are related to a range of adverse health effects. We also find that higher inequality and unemployment rate in a department are associated with more uncontrolled air pollution in a given department.

Finally, we point out that women health is more impacted than men health by NO_2.

This finding is consistent with the results of international studies that have examined the relationship between economic inequality, environmental quality and health. It also confirms the importance of ambient air pollution and reinforces the need for politics to take into account environmental justice in France.

Our paper suggests that further research on environmental inequality in France focusing on smaller geographical level and individual characteristics is essential. It would be consistent to examine the impact of atmospheric pollution focusing on a individual-level data. It would also be interesting to dispose of morbidity data, especially professional diseases to shed light on productivity loss implications.

References

[1] Besson D. (2006) "Consommation de tabac : la baisse s'est accentuée depuis 2003", division Synthèses des biens et services, INSEE Première 1110.

[2] Clougherty, J. E. (2010) "A Growing Role for Gender Analysis in Air Pollution Epidemiology", Environmental Health Perspectives 118 (2)

[3] Cronbach, L. J. (1987) "Statistical Tests for Moderator Variables: Flaws in Analyses Recently Proposed", Psych. Bull 102 (3):414-417.

[4] Currie, J. ; Neidell, M. and Schmieder, J. F. (2009). "Air Pollution and Infant Health: Lessons from New Jersey," Journal of Health Economics, 28(3): 688-703

[5] Finkelstein, M M.; Jerrett, M.; Deluca, P.; Finkelstein, N.; Verma, D. K.; Chapman, K.; Sears, M. R.(2003)" Relation between Income, Air Pollution and Mortality: a Cohort Study", Canadian Medical Association, 169 (5): 397-402

[6] Grineski, S.; Bolin, B. and Boone, C. (2007) « Criteria Air Pollution and Marginalized Populations : Environmental Inequity in Metropolitan Phoenix, Arizona », social science quartely 88 (2): 535-554

[7] Harner, J.; Warner, K.; Pierce, J. and Hubert, T. (2002), "Urban Environmental Justice Indices", the professional geographer, 54(3): 318-331

[8] Janke, K.; Propper, C.; and Henderson J.; (2009), “Do Current Levels of Air Pollution Kill? The Impact of Air Pollution on Population Mortality in England”, Health Economics 18 (9): 1031-55

[9] Kolhuber, M.; Mielcks, A.; Weiland, S. K and Bolte, G. (2006) “Social Inequality in Perceived Environmental Exposures in Relation to Housing Conditions in Germany”, Environmental Research 101 (2):246-255

[10] Kunzli, N.; Kaiser, R.; Medina, S.; Studnicka, M.; Chanel, O.; Filliger, P.; Herry, M.; Horak, F.; Puybonnieux-Texier Jr, V.and Quénel, P. (2000), “Public-Health Impact of Outdoor and Traffic-related Air Pollution: A European Assessment” Lancet 356: 795–801

[11] Laurent, O.; Bard, D.; Filleul, L. & Segala, C. (2007) "Effect of Socioeconomic Status on the Relationship between Atmospheric Pollution and Mortality", J Epidemiol Community Health 61: 665-675

[12] Laurian, L. (2008), "Environmental Injustice in France", Journal of environmental Planning and Management, 51: 1, 55-79

[13] Laurian, L. (2008), "The Distribution of Environmental Risks: Analytical Methods and French Data", Population 63 (4): 617-634

[14] Leod, H Mc; Langford, I.H; Jones, A.P; Stedman, A.R.; Day, R.J. and Lorenzoni I. (2000) “The Relationship between Socio-economic Indicators and Air Pollution in England and Wales: Implications for Environmental Justice », Reg environ Change 1 (2): 78-85

[15] Linsey C, Marr and Matthew, E. R.(2010) " Effect of Air Pollution on Marathon Running Performance", Medicine & Science in Sports & Exercise, 42 (3): 585

[16] Maesano, A.; Moreau, D; Caillaud, D; Lavaud, F; Le Moullec Y.; Taytard, A.; Pauli G. and Charpin D. (2007) “Residential Proximity Fine Particles Related to Allergic Sensitisation and Asthma in Primary School Children”, Respiratory Medicine 101 (8): 1721-1729

[17] Morello-Frosch, R.; Pastor, M. J.R and Sadd, J. (2002) « Integrating Environmental Justice and the Precautionary Principle in Research and Policy Making: The Case of Ambient Air Toxics Exposures and Health Risks among Schoolchildren in Los Angeles”, Annals of the American Academy of political and social science 584: 47-68.

[18] Opuni M. and Bishai D. (2009), "Are Infant Mortality Rate Declines Exponential? The General Pattern of 20th Century Infant Mortality Rate Decline" Population Health Metrics, 7:13

[19] Pascal, L.; Blanchard, M.; Fabre, P.l; Larrieu, S.; Borreli, D.; Host, S.; Chardon, B.; Chatignoux, E.; Prouvost H.; Jusot J.F; Wagner, V.; Declercq C.; Medina, S. and Lefranc A. (2009) "Liens à court

terme entre la mortalité et les admissions à l'hôpital et les niveaux de pollution atmosphérique dans neuf villes françaises", Institut de veille sanitaire, bulletin épidémiologique hebdomadaire (5)

[20] Pearce, J. and Kingham, S. (2008) « Environmental Inequalities in New Zealand: A National Study of Air Pollution and Environmental Justice » Public health intelligence NZ 39 (2): 980-993

[21] Premji S; Bertrand F; Smargiassi A and Daniels M. (2007) “Socioeconomic Correlates of Municipal Level Pollution Emissions on Montreal Island” Canadian Journal of Public Health 98(2): 138-42.

[22] Rabl, A. (2003) " Mortalité due à la pollution de l'air: comment interpréter les résultats", Pollution Atmosphérique, 180: 541-550.

[23] Ren, C.; Williams, G. M.; Morawska, L.; Mengersen, K.; Tong, S. (2008),” Ozone Modifies Associations between Temperature and Cardiovascular Mortality: Analysis of the NMMAPS Data” Occup.Environ.Med 65: 255-60

[24] Schikowski,T.; Sugiri, D.; Reimann, V.; Pesch, B.; Ranft, U. and Ursula K. (2008) « Contributions of Smoking and Air Pollution Exposure in Urban Areas to Social Differences in Respiratory Health », BMC public health 8:179

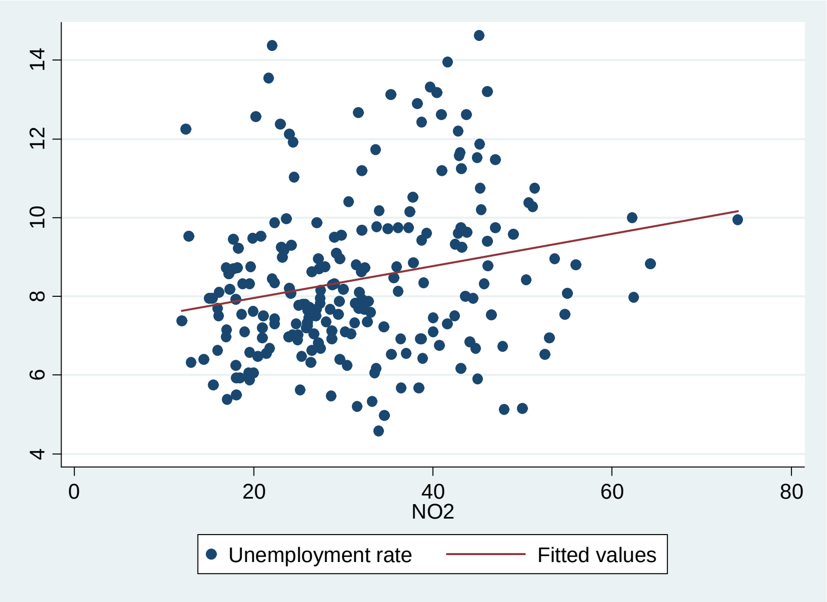
[25] Shin-Jong L. (2009) "Economic Fluctuations and Health Outcome: A Panel Analysis of Asia-Pacific Countries", Applied economics (41): 519-530

[26] Wilhelm, M.; Qianc, L.; Ritz, B. (2009) « Outdoor Air pollution, Family and Neighborhood Environment, and Asthma in LA FANS Children” Health & Place 15: 25-36

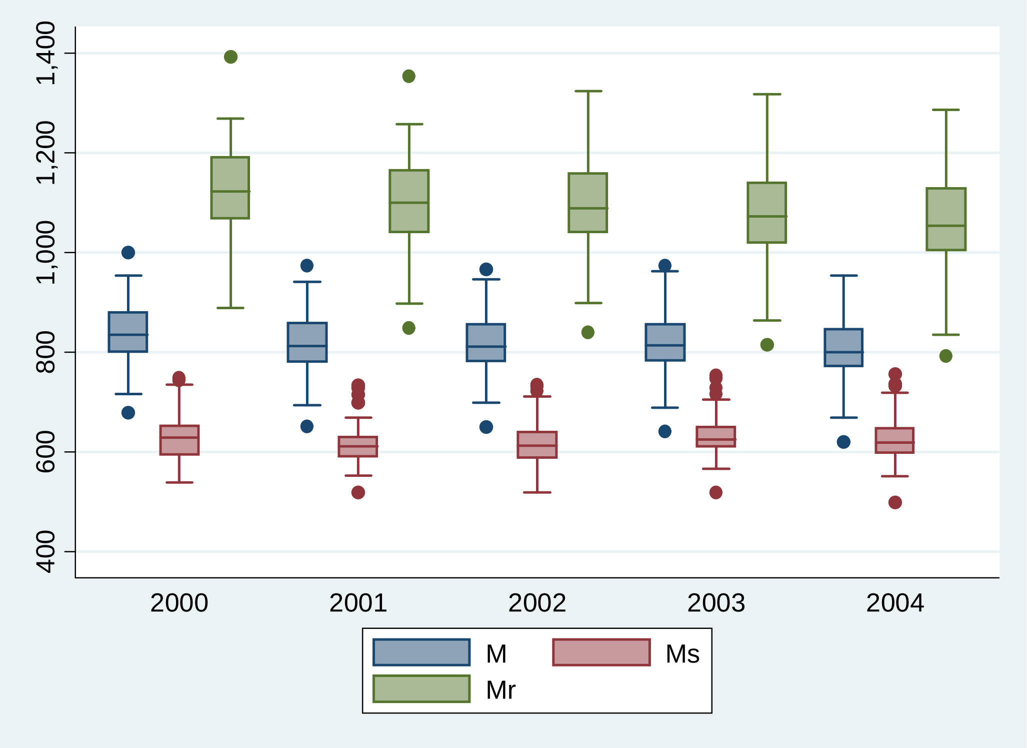
[27] Groot, W. and Maassen van den Brink, H. (2007) "The Health Effects of Education", Economics of Education Review, 26 (2):186-200.

Appendices

Appendix 1 : Correlation between unemployment rate and NO2



Appendix 2 : The yearly distribution of all causes mortality rates for the 2000 - 2004 period, in all departments



Appendix 3 : Definition of variables

Variable	Definition	Sources
M	Total mortality rate, age standardized rates 2000-2004 calculated using data on registered deaths from INSERM, CEPIDc and INSEE. The year corresponds to mid-year of the trienal period used. Unit: per 100 000 people	National federation of regional health observatories (ORS)
Mr	Total male mortality rate, age standardized rates 2000-2004 calculated using data on registered deaths from INSERM, CEPIDc and INSEE. The year corresponds to mid-year of the trienal period used. Unit: per 100 000 people	National federation of regional health observatories (ORS)
Ms	Total female mortality rate, age standardized rates 2000-2004 calculated using data on registered deaths from INSERM, CEPIDc and INSEE. The year corresponds to mid-year of the trienal period used. Unit: per 100 000 people	National federation of regional health observatories (ORS)
NO_2, NO, PM_{10}, O_3	Annual mean of NO_2, NO, PM_{10}, O_3 concentration (µg/m3) respectively 2000-2004	French Environment and Energy Management Agency (ADEME)
Pr	High precipitation totals 2000-2004	Météo France
Sun	Annual mean of the daily maximum temperature 2000-2004	Météo France
Sm	Number of cigarettes sold for 1000 residents 2000-2004	French Monitoring Centre for Drugs and Drug Addictions (OFTD)
Accident	Road accident rate, age standardized rates 2000-2004 calculated using data on registered road accident. Unit: per 100 000 people	National federation of regional health observatories (ORS)
PPHB	Number of people per 1 hospital bed 2000-2004	National federation of regional health observatories (ORS)
Industry	Share of industry in the total value added of a department (in %).	French National Institute for Statistics (INSEE), census 2005
Ed	Population from 15 years (without students) with minimum BAC+2 divided by population within department in 2006	French National Institute for Statistics (INSEE), census 2007
Un	The unemployment rate is the percentage of unemployed people in the labour force (occupied labour force + the unemployed) 2000-2004.	French Ministry of Labour (DARES)

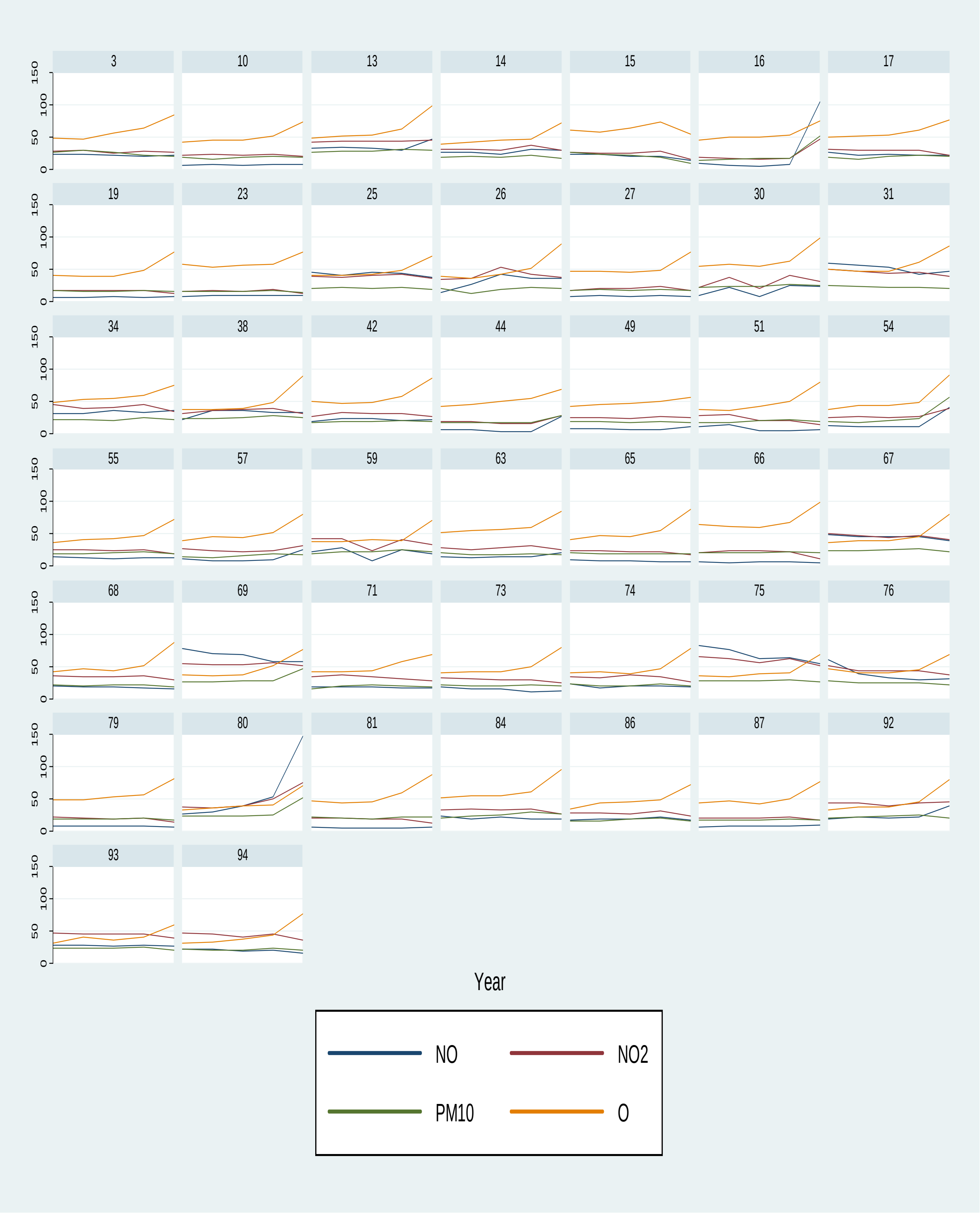
Appendix 4 : Atmo subindex determination grid

		PS scale	NO2 scale	SO2 scale	O3 scale
Index scale	**Subindexes**	**Average of mean daily concentrations for the various sites**	**Average of the hourly maxima for the various sites**		
Very good	1	0 to 9 µg/m3	0 to 29 µg/m3	0 to 39 µg/m3	0 to 29 µg/m3
Very good	2	oct-19	30 - 54	40 - 79	30 - 54
Good	3	20 - 29	55 - 84	80 - 119	55 - 79
Good	4	30 - 39	85 - 109	120 - 159	80 - 104
Moderate	5	40 - 49	110 - 134	160 - 199	105 - 129
Poor	6	50 - 64	135 - 164	200 - 249	130 - 149
Poor	7	65 - 79	165 -199	250 - 299	150 - 179
Bad	8	80 - 99	200 - 274	300 - 399	180 - 209
Bad	9	100 - 124	275 - 399	400 - 599	250 - 359
Very bad	10	125 and more	400 and more	500 and more	240 and more

Appendix 5 : Simple correlation coefficients

	NO2	PM10	O	NO	Atmo index (8-10)	Temperature
NO2	1.0000					
PM10	0.7691	1.0000				
O	-0.1777	0.1226	1.0000			
NO	0.9338	0.6687	-0.2476	1.0000		
Atmo index (8-10)	0.3210	0.5058	0.3229	0.1853	1.0000	
Temperature	0.1711	0.3603	0.6602	0.1268	0.2420	1.0000

Appendix 6 : Quantile plots of annual pollutant concentrations for every department



Appendix 7 : Map of French monitoring stations for NO_2