Health damage of air pollution: an estimate of a dose-response relationship for The Netherlands [1]

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ABSTRACT

This paper estimates the dose-response relationship between air pollution and the number of work loss days for The Netherlands. The study is based on illness data (work loss days) for the Dutch labor population and average year concentrations of air pollution in 29 districts. The dose-response relationship has been estimated by means of two different techniques: the ordinary least squares method (OLS) and the one-way fixed-effects method (OWFEM), which we consider to be more adequate. In general health effects are much smaller when OWFEM is applied than if OLS is used.

With OWFEM a significant relationship is found between sulphate aerosol (SO_4), ammonia (NH_3) and the number of work loss days (WLD's). Particulates (TSP), O_3 and SO_2 have no significant effect on the number of WLD's. These results differ from those

[1] We wish to thank Shelby Gerking (University of Wyoming, U.S.A.) for his advice on the application of the one-way fixed-effects method. We are very indebted to Che Wah Lee, who did the computerwork. (In the period he worked at the University of Groningen.)

obtained in studies in the United States, which indicate that particulates (TSP) and other small particles, ozone (O_3) and to a lesser extent SO_4 and SO_2 significantly influence the number of WLD's.

1. INTRODUCTION

To calculate the monetary health benefits of reducing air pollution one needs firstly an estimation of the relationship between the pollutant and its physical impacts; secondly a translation of physical effects in money terms. This paper concentrates on the first part of the problem. It discusses the physical impacts of a number of air pollutants on potential output, in particular labor input. We do this by estimating the dose-response relationship (DRR) between air pollution and the number of work loss days owing to illness of respiratory organs for The Netherlands. Studies of this type have been done in the US since the early seventies. They have identified a significant relationship between specific air pollutants and morbidity (and also mortality) in a number of cases.

Until now no DRR has been estimated on the basis of Dutch data. Only a few rough estimates have been made, in which relationships found in the US were applied to calculate the health impacts of SO_2 concentrations in The Netherlands. This means that it was assumed that relationships which were estimated for the United States also held true for The Netherlands. Of course, this is very dubious. This study is original in the sense that we have estimated a DRR purely on the basis of Dutch data. A second interesting element is that we compare the results obtained with the ordinary least squares method with a more advanced method: the so-called one-way fixed-effects method.

The paper is structured as follows. In section 2 a review of the research literature is given. Subsequently, section 3.1 explains which DRR is used for The Netherlands. The data used in this study are described in section 3.2. Then section 3.3 describes the estimation method, namely the one-way fixed-effects method. Subsequently, the empirical results are presented in section 3.4. Finally some conclusions are drawn in section 4.

2. REVIEW OF THE RESEARCH LITERATURE

Ideally the DRR should be based on a health model that specifies the factors that determine the health situation of a person. Clearly, health status is affected by many factors; see, among others, Zuidema [1992, paper 27.06].

A DRR can be presented by the following formula:

$$WLD = f(P_1, \dots, P_N, X_1, \dots, X_M) \qquad [1]$$

WLD = annual work loss days;

P_i = air pollutant i;

Xj = other variables j.

In the literature on the health impacts of air pollution, a DRR is usually a function of a large number of variables, such as air pollution: nitrogen oxides, sulphur dioxide, sulphate aerosol, black smoke, particulates, ozone and ammonia. In addition to these variables, the number of WLD's is influenced by other variables as well. The literature on epidemiology mentions, among others: education and occupation, income, job situation (employed or not), race, sex, age, and habits such as drinking and smoking.

For empirical research we have to confine ourselves to an equation with a small number of variables, because only then the relationship can be estimated. In the literature on research in the US the emphasis lies on the estimation of the relationship between air pollution and the number of WLD's. Air pollution, however, can also result in an increase in mortality. Research in this field has been conducted, for example by, Lave and Seskin [1971; 1977]; Mendelsohn and Orcutt [1979], Chappie and Lave [1982], and Lipfert [1984]. In this article and survey of the literature we shall not deal with mortality but concentrate on morbidity (=WLD's).

The research for the estimation of DRR's has mainly been done for the US. Table I classifies the seven major studies of a number of air pollutants for the United States. It shows that the DRR's have been estimated by applying different techniques. Apparently, no standard technique exists for the estimation of a DRR. The studies were published in the eighties and early nineties, but refer to different regions in the U.S. in the seventies. The types of pollutants that have been distinguished and the other explanatory variables are shown in table II. The variable measuring WLD's is based on the response to the survey question asking how many days in the past 2 weeks did illness prevent one from working. Other data on background variables has been obtained from the same set of panel data.

Table I. Estimation techniques, place and period in studies about morbidity

Studies	Estimation techniques	Place[1]	Period
Cropper [1981]	- Tobit model	US	1970, 1974 en 1976
Krupnick, Harrington and Ostro [1990]	- logit estimation procedure	Los Angeles	1978 en 1979
Ostro [1983a]	- OLS[1]; - Tobit model; - logit linear combination	US	1976
Ostro [1983b]	- OLS; - logit linear combination	US	1976
Ostro [1987]	- Fixed-effects method by using a Poisson distribution	US	1976-1981
Ostro [1990a]	- logit estimation	US	1979-1981
Portney and Mullahy [1986]	- maximum likelihood method by using a Poisson distribution	US	1979

[1] OLS = ordinary least squares method

Table II. Dose-response relationship for morbidity[1]

Studies	Pollutants								Health Situation	Socio-economic variables		Demographic variables				Habits	Other variables
	NO2	SO_2	SO_4	O_3	TSP[2)]	IP[2)]	FP[2)]	COH[2)]	existence of chronic condition	income	educa tion	age	marital status	race	sex	smoking	population density
Cropper [1981]		*							-	-	-		-	-			
Krupnick, Harrington and Ostro [1990]	-	-		*				*	*		*	*		-	*	*	
Ostro [1983a]			-		*				*	-		*	-	-	*	-	-
Ostro [1983b]			-		*			*	-		*	-	-		-		-
Ostro [1987]							*		*	*	*	*	*	*	*		
Ostro [1990a][4)]			*		*[3)]	*[3)]	*[3)]										
Portney and Mullahy [1986]			-	*					-	*	-	-		*	-	-	

1) * = significant;
- = in significant;

2) TSP = total suspended particulates;
IP = inhalable particles;
FP = fine particles;
COH = coefficient of haze (= a surrogate for fine particles);

3) Only significant if lagged by one 2-week period

4) Several socio-economic and demographic variables are included in the DRR. It is, however, not known which variables are significant.

Table II shows that the variables included in DRR's can differ between the studies. Which variables are actually taken into account is to a large extent determined by pragmatic reasons, such as the availability of data.
The pollutant NO_2 is only examined in the study by Krupnick et al. [1990], but it is not statistically significant. SO_4 is significant in only one of the four cases. Statistically significant in all cases are ozone, total suspended particulates and the coefficient of haze. The conclusion can be drawn that the most important variables are ozone and the four types of particulates.
It appears from table II that the variables chronic condition, education, age, and sex are usually statistically significant. Smoking is only significant in one of the three studies.
Next, the figures about air pollution are presented in table III.

Table III. Air pollution concentration[4]

Studies	Pollutants							
	NO_2	SO_2	SO_4	O_3	TSP	IP	FP	COH
Cropper [1981]		- [3)]						
Krupnick, Harrington and Ostro [1990]	$O < NO_2 < 31$ pphm[1)]	$O < SO_2 < 6$ pphm		$2 < O_3 < 43$ pphm				$4 < COH < 26$ μ gm -3
Ostro [1983a]			8 μ gm $^{-3}$		78 μ gm $^{-3}$			
Ostro [1983b]			-		-			
Ostro [1987]							22 μ gm $^{-3}$	
Ostro [1990a]			8 μ gm $^{-3}$		69 μ gm $^{-3}$	44 μ gm^{-3}	24 μ gm $^{-3}$	
Portney and Mullahy [1986]			11 μ gm^{-3}	0,042 ppm [2)]				

1) pphm = parts per hundred million;
2) ppm = parts per million;
3) - = the study does not present the figures.
4) Krupnick et al. present minimum and maximum concentrations. The other studies present average values.

It is important that studies present data about the interval of air pollution concentration for which the DRR is estimated. This is done only by Krupnick et al. Most other studies mention only the average pollution and Ostro [1983b] does not even mention this. The authors hardly ever compare their results with the results of other studies. As Ostro has done a substantial amount of the research, it would have been interesting if he had examined why SO_4 is statistically significant in Ostro [1990a], but not in Ostro [1983a] and [1983b]. The influence of the estimation technique on the empirical results is not discussed in the various studies. This effect can be very large, however, as will be shown in section 3.

Dutch research

Although the relationship between WLD's and air pollution has not been estimated for The Netherlands, research has been done on health effects of air pollution. Hoek et al. [1990] and [1993] researched the effects of air pollution on children living in The Netherlands. They measure the effect of short term exposure to relatively high concentrations of the air pollutants ozone, sulphur dioxide and total suspended particulates on the pulmonary function of a group of children. The research was conducted in the eighties in a small number of communities in The Netherlands. Hoek et al. found a significant negative association between O_3, SO_2, TSP and the pulmonary function of the children. Our research differs from this approach because we have estimated long run effects of air pollution on work loss days of adults by using aggregated data.

Of a quite different category is the research of Jansen [1974], the OECD [1981] and Ostro et al. [1990b]. They estimated the monetary health damage due to air pollution for The Netherlands. Since an empirical DRR for The Netherlands was not available they applied a DRR which was estimated by Lave and Seskin [1971; 1977] for the US. In another publication, Jansen [1980] used Crocker's so-called Wyoming study. If one takes the American DRR for granted the damage to health in The Netherlands is considerable. According to Jansen [1974] the annual damage is about one billion guilders (1967 prices). However, the estimation of the actual damage is very uncertain, for the OECD [1981] annual estimates range from 100 million to 2.5 billion guilders.

3. A DOSE-RESPONSE RELATIONSHIP FOR THE NETHERLANDS

3.1. The model for a dose-response relationship for The Netherlands

As a starting point for estimating an empirical DRR we have formulated the following health model.

$$WLD = f(P_1, \ldots, P_6, X_1, \ldots, X_4) \qquad [2]$$

WLD = annual work loss days;
P_1 = sulphur dioxide (SO_2);
P_2 = sulphate aerosol (SO_4);
P_3 = black smoke;
P_4 = particulates;
P_5 = ammonia (NH_3);
P_6 = ozone (O_3);
X_1 = unemployment percentage in a region;
X_2 = percentage of labor force in a region receiving a pension under the Dutch Disablement Insurance Act;
X_3 = population density as an indicator for the urbanization rate of a region;
X_4 = average annual gross income per capita in a region.

The choice of explanatory variables is partly inspired by theoretical considerations and partly influenced by availability of data. In this study aggregated cross-sectional data have been used. We would have prefered to use microdata because these data contain person-specific information. Unfortunately no suitable dataset is available in The Netherlands. When compared with the models used in section 2 (table II), it is striking that in equation 2 the following background variables are lacking: chronic condition, age, race, sex, smoking and drinking. The reason for this is that there is no information available on a regional level for The Netherlands. Next, we discuss the variables in equation 2.

Pollutants

The selection of air pollutants has been influenced by availability of information. In further defence of this choice we recall that US studies suggest that the following pollutants may have a significant positive effect on WLD's: SO_2, SO_4, particulates, black smoke and ozone. To this we have added ammonia, which has not been researched in US studies. It, however, is a major air pollutant in The Netherlands.

Work loss days

The question can be asked how WLD's should be defined. Since we are interested in the health impacts of air pollution only WLD's caused by illnesses of the respiratory system, such as chronic bronchitis, asthma and chronic non-specific lung disease (CNSLD) has been used in this research. In the empirical study only the WLD's of employed persons are used. WLD's of the unemployed and disabled are not taken into account.

Unemployment

Four socio-economic variables are used. The first one is unemployment. We expect that with increasing unemployment the WLD's of the employed will decrease. This can be argued in the following two ways:

- When the fear of loosing one's job increases, people will not report themselves sick so readily because they are anxious not to be fired;
- It is possible that unhealthy people are more likely to lose their jobs than healthier people.

Disablement

The percentage of disabled workers might also affect the WLD's of the employed people. Two influences can be distinguished:

- The labor force may become healthier when more people are considered as disabled. This may reduce the number of WLD's of the remaining labor force.
- The disablement percentage can be seen as a health indicator for the labor force: the higher it is the lower the health situation of the labor force may be. In this view a high disablement percentage correlates with a large number of WLD's.

The above-mentioned two influences work against each other. Therefore it is a priori not clear what sign this variable will have in equation 2.

Population density

The labor force in urban areas is different from that in rural areas. The socio-cultural climate is also different. Generally speaking, urban areas have greater problems than rural areas. Therefore we expect a positive relationship between the population density and the number of WLD's.

Income

It is well known that people who are well educated and belong to the higher occupations have fewer WLD's than people who belong to the lower classes. Income can be considered as an indicator of the schooling and occupational level. Therefore we expect a low average regional income per capita to have a negative influence on the number of WLD's.

The empirical results will show whether these hypotheses are falsified or not.

3.2. Data

The following data are used for the estimation of the DRR: work loss days, air pollution, and socio-economic figures.

Work loss days

The Netherlands consist of 29 administrative health districts. For each district we have information on WLD's of employed persons due to illnesses of the respiratory system for the years 1987, 1988 and 1989. This means that aggregated data (cross-sectional and time series) had to be used and we lack the person-specific information (smoking habits, age, sex, etc.) that are contained in microdata that have been used in the US studies. On the other hand our sample contains the complete employed labor population and the whole territory of The Netherlands. The US studies lack this scope. For estimation purposes WLD's per district have been expressed as a percentage of the district's employed labor population. Its variation between district's is large with the maximum more than three times the minimum.

Air pollution

The data refer to outdoor air pollution. Although the influence of occupational exposure on the health situation of people is possible, this influence is not included in the DRR. The reason for this is that there is no data set available.

Data about outdoor air pollution come from the annual reports of the National Institute of Public Health and Environmental Protection (RIVM) for 1987, 1988 and 1989. Air pollution is monitored at a number of monitoring sites. The air pollution in a "district" is estimated by taking an average of the air pollution at the monitoring sites in that "district". We use annual averages since WLD's have also been measured on a per year basis.

The pollutants SO_2, SO_4, BS, Part., and O_3 are measured in μgm-3 and NH_3 in mol ha-1. Figures on concentration are presented in table IV. They show that differences across the regions are considerable. The maximum concentration is about two to three times higher than the minimum value. In general the northern part of The Netherlands is the least polluted and the southwestern part the most.

Table IV. Minimum and maximum concentration of air pollution in The Netherlands

(measured in μg m-3, except NH_3 (mol ha^{-1}))						
	year					
air pollution	1987		1988		1989	
	min.	max.	min.	max.	min.	max.
SO_2	10	36	7	24	7	26
SO_4	7	9	4	6	7	10
BS	11	30	7	24	10	28
Part.	42	57	33	55	36	61
NH_3	570	1190	320	1060	490	1000
O_3	27	56	26	57	28	58

Part. = particulates;
BS = black smoke;
NH_3 = ammonia;
min. = region with lowest annual pollution;
max. = region with highest annual pollution.

A comparison with air pollution concentration of the US studies, as shown in table II, reveals that the concentration of SO_4 in The Netherlands in the late eighties is between 4 and 10 μg m^3 and in the areas in the US between 8 and 11 μg m^3 during the seventies. The concentration of particulates in The Netherlands is lower than the concentration in the study by Ostro [1983a] and in the range of Ostro [1990a].

Socio-economic data

The socio-economic data on unemployment percentages, disablement percentages, population density and average gross nominal income per capita come from the Dutch Central Statistical Office. These figures are available for 40 areas, the so-called "Coropregions", which differ from the health districts. Therefore all socio-economic data about Coropregions had to be assigned to the 29 health districts. In doing this the number of inhabitants per Corop region has been used as weights.

The unemployment and disablement percentages are calculated as percentages of the labor force per district. The population density is calculated by dividing the population of a district by the number of square kilometers. The variance of the population density, however, is very large. Amsterdam has more than 4000 inhabitants per km^2 and Assen has less than 170. The variance in the unemployment and disablement percentages across the regions is considerable. The variance of the incomes across the regions is small. The maximum income is about 10 percent higher than the minimum income.

3.3. Estimation technique: ordinary least squares method versus one-way fixed-effects method

We have estimated the DRR both by application of the least squares method (OLS) and by the so-called one-way fixed-effects method (OWFEM). It is not necessary to explain OLS, but this may be necessary for OWFEM, because this method is not so widely known.

The DRR for The Netherlands is estimated by means of data that refer to 29 regions in The Netherlands. When the relation is estimated by application of the ordinary least squares method it is actually assumed that the same DRR holds for each region. This is, however, very unlikely. Some regions may have a specific population composition which influences the number of WLD's. Urban areas could therefore have health models that differ from those for rural areas. If these differences are not taken into account the effect of air pollution on the number of WLD's cannot be estimated in an unbiased way. A method which can take into account the fact that the DRR's differ across the regions is the *one-way fixed-effects method* (OWFEM), see, among others, Judge et al. [1988,chapter 11.4] and Greene [1990, chapter 16.4]. The essential difference between the least squares method and OWFEM is that in the latter method the intercepts are different across the various regions while in the former method they are all equal. On the other hand, it is assumed that the independent variables and their impacts on health are the same for the various regions. Because specific regional differences in the WLD's are reflected in the intercepts it is not necessary to use different DRR's for the various regions.[2] The method is called fixed-effects because the differences across the regions

[2] Besides the one-way fixed-effects method there is also a two-way fixed-effects method. In the two-way the intercepts differ both across the regions and across time intervals. Because the data are related to a short period, namely three years, it is not likely that the DRR's will

can be considered as shifts of the functions.

The computer program LIMDEP 6.0 has been used for the estimation of the equations, see Greene, [1991]. Assuming we have i=1,2,..., N regional observations and t = 1,2,..., T time-series observations, the (i,t) observation can be written as:

$$Yit = \beta 1i + \sum_{k=1}^{K} \beta k.\ Xkit + eit \qquad [3]$$

K = number of explanatory variables;

The fact that each region has a different DRR can be adequately captured by specifying a different intercept coefficient for each region. All the information is used in estimating equation 3. Output consists of X-effects (that is β2,...,βk) and the N values for intercepts β1. Only when the intercepts differ significantly is there a basis for applying the fixed-effects method. The testing is as follows:

Hypothesis 0: β11 = β12 = ... = β1N

The null hypothesis can be tested by calculating the following value for F.

$$F = \frac{(e'e - \hat{e}'\hat{e}) / (N-1)}{\hat{e}'\hat{e} / (NT - N - K')} \qquad [4]$$

e'e = the residual sum of squares from the restricted model. This is the model in which all the intercepts are equal.

ê'ê = the residual sum of squares from the unrestricted model. This is the model that is used here, which means that the intercepts are not equal.

K'= K -1

Under the null hypothesis the statistic in [4] has the F distribution with [(N-1),(NT-N-K)] degrees of freedom. The critical value of F can be found in a table.

It is also of interest to examine which part of the variance is explained by the explanatory variables. This is done by means of an analysis of variance. Total variation

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differ over the various years. In addition to the fixed-effects method there is also a random-effects method. In the One-way Random-effects method it is assumed that the intercepts are randomly distributed across the regions. We can use OWFEM because we do not assume this.

is equal to the sum of within group variation and between group variation. The explanatory variables only give an explanation of the variance within the regions. The differences between the regions are caught by the differences between the constants. Before presenting the empirical research, an analysis of variance is given for the dependent variable, that is the number of WLD's for each of the pollutants. Total variation is equal to the sum of within group variation and between group variation. Systematic differences between the regions that cannot be related to differences in explanatory variables are caught by the differences in the intercepts. Although the number of WLD's per region is the same each time, there are important differences because the available information is different. For SO_4, for instance, data on air pollution exist for only 9 out of 29 regions, so use can be made of the information concerning the number of WLD's in these 9 regions only. The result is that the analysis of variance shows differences.

Table V. Analysis of variance

N		variance within regions	variance between regions	total variance
29	SO_2	460.23	9436.71	9896.94
9	SO_4	97.82	2440.51	2538.33
14	BS	261.51	5180.98	5442.49
5	Part.	48.38	1738.95	1787.32
11	NH_3	136.73	3588.56	3725.29
20	O_3	349.21	6428.11	6777.32

Table V shows that total variance of the number of WLD's consists, for more than 95 %, of variance between the regions. This means that the explanatory variables explain only a small part of the total variance in the number of WLD's. This indicates that it is especially useful to apply a technique like the fixed-effects method in which this is taken into account.

3.4. Empirical results

The DRR's for The Netherlands are estimated, with each equation containing only one pollutant variable. The reason for this is that multicollinearity exists between the various pollutants. A consequence of this estimation procedure, however, is that the effect of a specific air pollutant on the number of WLD's may be overestimated.

Firstly, empirical results which were obtained by application of OLS and subsequently by means of OWFEM are given. We first estimate a simple model with pollution as the only explanatory variable and then a model with more explanatory variables.

Ordinary least squares method

The following equation is estimated for the period 1987-1989:

$$WLD = a.Pi + c \quad [5]$$

WLD = number of work loss days per 100 working persons a year;

P_i = pollutant i.

Table VI. Relationship between air pollution and the number of work loss days (WLD = a.P_i + c) OLS

N		constant	Pi	R^2
29	SO_2	34.363 (12.279)***	0.338 (1.988)**	0.044
9	SO_4	26.142 (3.001)***	0.035 (1.416)	0.074
14	BS	26.442 (4.626)***	0.946 (2.700)**	0.154
5	Part.	20.527 (0.940)	0.337 (0.779)	0.045
11	NH_3	29.918 (4.601)***	0.011 (1.284)	0.051
20	O_3	65.774 (11.074)***	-0.659 (-4.637)***	0.270

t-statistic is in parentheses;

* = coefficient is significant at a 10 per cent level;

** = coefficient is significant at a 5 per cent level;

*** = coefficient is significant at a 1 per cent level;

N = number of regions.

Table VI gives the results of the ordinary least square method with only one pollutant as explanatory variable. The following conclusions can be drawn:

1. The coefficient that shows the influence of air pollution on WLD (a) is positive, except for ozone which has a negative impact;
2. The coefficient a differs significantly from zero in three cases;
3. The constant c is significant at a 1 per cent level in five of six cases.

One can try to improve these results by adding socio-economic variables to explain differences in WLD's. Table VII presents results with population (Pd) and unemployment percentage (u) added. The disablement percentage has been left out since adding it did not improve empirical results. For the same reason average income per capita was left out. The reason for it is the small variation of this variable across the regions.

Table VII. Relationship between the number of work loss days and air pollution, population density and unemployment. (WLD = a.Pi + b. Pd + d.u + c) OLS

N		constant	Pi	u	Pd	R2
29	SO_2	30.849 (7.905)***	0.337 (1.869)*	0.372 1.299	-0.000,12 (-0.163)	0.063
9	SO_4	23.799 (2.662)**	0.031 (1.191)	-0.048 (-0.081)	0.005,72 (1.631)	0.174
14	BS	19.108 (2.569)**	0.955 (2.676)**	0.668 (1.392)	0.000,60 (0.363)	0.214
5	Part.	11.365 (1.239)	0.193 (1.144)	-0.188 (-0.477)	0.015 (7.564)***	0.880
11	NH_3	19.900 (2.505)**	0.019 (2.147)**	-0.218 (-0.477)	0.009 (2.426)**	0.216
20	O_3	71.336 (8.837)***	-0.74 (-4.669)***	-0.019 (-0.063)	-0.002 (-1.219)	0.290

The following conclusions can be drawn from table VII:

1. As in table VI, the effect of air pollution (a) is in most cases positive, except for ozone.
2. Adding u and Pd in the DRR does not substantially change the effects of air pollution as a comparison of the columns under Pi in table VII and VI shows. The difference is that next to SO_2 and BS, ammonia has a positive significant effect on the number of WLD's.

3. The influence of the population density (Pd) is also usually positive (as expected).
4. The influence of unemployment is usually negative (as expected), but it is never significant.
5. In general R^2 is hardly improved by adding u and Pd. The exception is the equation for particulates. This may be caused by the effect of Pd.

One-way fixed-effects method

The simple equation, similar to 5, is now estimated by means of fixed-effects. The constants - as many as there are regions and for each pollutant - are not shown in this publication, but they differ considerable, with a minimum of 24 for SO_2 for region 7 and a maximum of 62 for SO_2 in region 19. These base levels are influenced by variables which are not included in the model. The test of whether the regional constants differ significantly is done on the basis of F-values. If the hypothesis is rejected, application of fixed-effects is not useful. If the F-value exceeds the critical value, the hypothesis is accepted. The highest critical value holds for particulates, namely 6.42, at a significance level of 1 per cent. Since all F-values from table VIII are much higher than 6.42 it is even more than 99 % certain that the constants (the intercepts for various regions) differ significantly.

Table VIII. Relationship between work loss days and air pollution
(WLD = a. P_i + c) OWFEM

N		Pi	R^2	F-value
29	SO_2	0.054 (0.803)	0.954	40.27
9	SO_4	0.007 (1.101)	0.964	52.57
14	BS	0.221 (1.445)	0.955	37.31
5	Part.	0.005 (0.031)	0.973	77.18
11	NH_3	0.001 (0.315)	0.963	52.48
20	O_3	-0.067 (-0.633)	0.949	27.31

Table VIII shows:

1. Just as in the ordinary least squares method, the effect of air pollution on the number of WLD's is positive for all pollutants except ozone (column 3);
2. The value of the coefficient, however, is much lower than the same coefficient in table VI. This can be explained by the fact that in the one-way fixed-effects method, the other influences on the number of WLD's are represented in the constants. Owing to this, the estimation of the effect of air pollution is improved.
3. Finally it appears that R^2 is now much higher. In table VI the correlation coefficient R^2 was usually less than 0.1.

The explanation for the high R^2 is that the regional constants explain a large part of the differences between regions. The variance that is left can be associated largely with differences in air pollution between the regions. It should, however, be admitted that the impacts of air pollution on the number of WLD's does not differ significantly from zero in table VIII for each pollutant.

Next, equation 6 is estimated by application of the one-way fixed-effects method.

$$WLD = a.Pi + b.Pd + d.u + c \quad [6]$$

Table IX: Relationship between number of work loss days and air pollution, population density and unemployment
(WLD = a. Pi + b. Pd + d. u + c) OWFEM

N		Pi	Pd	u	R^2	F-value
29	SO_2	0.081 (1.207)	0.017 (0.676)	-0.185 (-1.975)*	0.958	42.18
9	SO_4	0.021 (3.456)***	0.322 (2.850)***	-0.149 (-1.166)	0.982	86.60
14	BS	0.203 (1.206)	0.024 (0.815)	-0.125 (-0.731)	0.959	35.06
5	Part.	-0.186 (-0.903)	-0.202 (-0.977)	-0.551 (-1.705)	0.982	9.63
11	NH_3	0.007 (1.880)*	0.267 (1.848)*	-0.187 (-1.272)	0.975	58.53
20	O_3	-0.189 (-1.639)	0.015 (0.577)	-0.251 (-1.986)*	0.955	29.03

The results are presented in table IX and the following conclusions can be drawn.

1. The influence of air pollution is usually positive, as in table VIII. The exception is again ozone, and this time also particulates: both have a negative coefficient (but neither of them is significant).

   The main difference with table VIII is that two pollutants are now significant: SO_4 and NH_3. The t-values have improved for all the pollutants compared with the simple model presented in table VIII.

2. The effect of population density on work loss days is usually positive.

3. Just as in table VII the effect of unemployment is negative and confirms our expectation that higher unemployment is associated with lower WLD's.
4. R^2, which was already high in the simple specification of OWFEM (table VIII) has improved slightly.

It is interesting to compare the results obtained by OLS with those by OWFEM by comparing the tables VII and IX. The following conclusions can then be drawn.

1. The effect of air pollution on health is in the fixed-effects method much lower than in the least squares method. The reason for this is that the intercepts explain a large part of the WLD's. The estimated effect of air pollution is then lower.
2. With OLS the pollutants SO_2, BS, NH_3 and O_3 are statistically significant, but with OWFEM SO_4 and NH_3 are statistically significant.

4. A COMPARISON WITH OTHER STUDIES AND CONCLUSIONS

In our quest for a DRR between air pollution and diseases of the respiratory system it has been shown how much the results are influenced by the specification of the model and the statistical method that is applied. As to the statistical method: if one were to simply look at t-values, the least squares method is better than OWFEM, but as we explained, it tends to overestimate the health impacts of air pollution. OWFEM is the most advanced method and its results are more reliable. It has appeared from the analysis of variance and from the calculated F-values that each region has its own health model. This fact is taken as a starting point in OWFEM.

By not taking into account these structural regional differences, the estimation of the health effects of air pollution is too high when the least squares method is used. Therefore we consider OWFEM with multiple explanatory variables as presented in table IX to give the most reliable results.

The empirical results of this study show important differences with results of research in the US. As table II shows, the significant pollutants in the US are: TSP and other small particles, O_3 and to a lesser extent SO_4 and SO_2. In our OLS version for The Netherlands

SO_2, BS, O_3 and NH_3 are significant, but in OWFEM only pollutants SO_4 and NH_3 significantly influence the number of WLD's.

The pollutant NH_3 does not occur in the US studies because it is of minor importance. For The Netherlands, however, this is different. Ammonia concentrations in specific regions of The Netherlands are very high so it need not come as a surprise that they have a negative impact on health. Ammonia concentrations are caused by the emissions from manure from the intensive cattle-raising sector, which is concentrated in rural areas in the middle, east and south of the country.

The injurious influence of particulates has been proved various times in the United States. The reason that this cannot be found for The Netherlands with OWFEM may be that the number of observations for this pollutant is too low (N = 5; see table IX).

Ozone has a negative influence on the number of WLD's which is highly significant in OLS. As has already been said the results with OLS are not reliable to our opinion. The data show that the level of ozone is highest in the northern part of The Netherlands. This means that the level of ozone is high in areas that are rather clean with respect to other types of air pollution and might explain the negative relationship between ozone and WLD's. With OWFEM the DRR is also negative but not significantly different from zero.

The research in the field of health effects of air pollution has been developing in the past two decades. The results, however, are still rather uncertain and we have shown how sensitive they are to the model specification and the estimation technique. As the results up to now of both US research and of our own study are rather uncertain it is questionable whether the monetary valuation of health damage based on such dose-response relationships makes sense.

REFERENCES

1. Chappie, M. and L. Lave, 1982, The Health Effects of Air Pollution: A Reanalysis, Journal of Urban Economics, 12, Bristol, pp. 346-376.
2. Crocker, T.D., W.D. Schulze, S. Ben-David and A.V. Kneese, 1979, Methods Development for Assessing Air Pollution Control Benefits, Vol.I, Experiments in the Economics of Epidemiology, EPA-600/5-79-001a.
3. Cropper, M.L., 1981, Measuring the Benefits from Reduced Morbidity, American Economic Review, 71, pp. 235-240.
4. Dickie, M. and S. Gerking, 1987, Benefits of Reduced Morbidity from Air Pollution Control: A Survey (paper for congress in Wageningen, The Netherlands).
5. Greene, W.H., 1990, Econometric Analysis, MacMillan, New York.
6. Greene, W.H., 1991, LIMDEP User's Manual and Reference Guide, Version 6.0, New York.
7. Hoek, G. et al., 1990, Effects of Air Pollution Episodes on Pulmonary Function and Respiratory Symptoms, Toxicology and Industrial Health, **6**, pp. 189-197.
8. Hoek, G. et al., 1993, Acute Effects of Ambient Ozone on Pulmonary Function of Children in The Netherlands, American Review of Respiratory Disease, **147**, pp. 111-117.
9. Jansen, H.M.A., G.J. van der Meer, J.B. Opschoor and J.H.A. Stapel, 1974, An Estimate of Damage Caused by Air Pollution in The Netherlands in 1970, Institute for Environmental Problems, Free University of Amsterdam (IvM-VU no. 8a), Amsterdam.
10. Jansen, H.M.A. 1980, Luchtverontreiniging en gezondheid - enige dosis ef-fectrelaties voor gebruik in een economische waardering, Amsterdam (IvM-VU no. 116 and 116 A).
11. Judge, G.J., R. Carter Hill, W.E. Griffiths, H. Lutkepohl and T.C. Lee, 1988, Introduction to the Theory and Practice of Econometrics, second edition, John Wiley & Sons, New York.
12. Krupnick, A.J., W. Harrington and B. Ostro, 1990, Ambient Ozone and Acute Health Effects: Evidence from Daily Data, Journal of Environmental Economics and Management, 18, pp. 1-18.
13. Lave, L.B. and E.P. Seskin, 1971, Health and Air Pollution, Swedish Journal of Economics, 73, pp. 76-95.
14. Lave, L.B. and E.P. Seskin, 1977, Air Pollution and Human Health, Baltimore.

15. Lipfert, F., 1984, Air Pollution and Mortality: Specification Searches using SMSA-based data, Journal of Environmental Economics and Management, 11, pp. 208-243.
16. Mendelsohn, R. and G. Orcutt, 1979, An Empirical Analysis of Air Pollution Dose Response Curves, Journal of Environmental Economics and Management, 6, pp. 85-106.
17. OECD, 1981, The Costs and Benefits of Sulphur Oxide Control, Paris.
18. Ostro, B., 1983a, The Effects of Air Pollution on Work Loss and Morbidity, Journal of Environmental Economics and Management, 10, pp. 371-382.
19. Ostro, B., 1983b, Urban Air Pollution and Morbidity: A Retrospective Approach, Urban Studies, 20, pp. 343-351.
20. Ostro, B., 1987, Air Pollution and Morbidity Revisited: A specification Test, Journal of Environmental Economics and Management, 14, pp. 87-98.
21. Ostro, B., 1990a, Associations Between Morbidity and alternative Measures of Particulate Matter, Risk Analysis, **10**, pp. 421-427.
22. Ostro, B., D. Robert and L.G. Chestnut, 1990b, Transferring Air Pollution Health Effects Across European Borders, paper presented at Congress of European Association of Environmental and Resource Economists, Venice (Italy).
23. Portney, P.R. and J. Mullahy, 1986, Urban Air Quality and Acute Respiratory Illness, Journal of Urban Economics, 23, pp. 21-38.
24. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Luchtkwaliteit, Jaarverslag 1987, 1988 en 1989, Bilthoven.
25. Zuidema, Th., 1992, A Determination of the Benefits of Environmental Goods. An Application to the Abatement of Air Pollution, Proceedings of the 9th World Clean Air Congress in Montreal in 1992, Vol. 5, Pittsburgh.