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Health Costs of Automobile Pollution

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Summary

The methodology developed by the ExternE ("External Costs of Energy") Project of the European Commission is used to estimate the health costs associated with air pollution due to tail pipe emissions from cars. The analysis begins with emissions data for several car types in the current fleet and for three driving sites: a trip in Paris, a trip from Paris to Lyon, and travel in the rural southwest of France. Atmospheric dispersion and chemistry is modeled, both at the local and the regional scale, including the formation of secondary pollutants (ozone as well as nitrate and sulfate aerosols). Health impacts are quantified using linear dose-response functions, based on a survey of the epidemiological literature. The economic valuation is based on the willingness-to-pay to avoid a harmful impact; of particular importance is the cost of a year of life lost (YOLL), here taken as 0.083 MEuro (derived from a "value of statistical life" of 3.1 MEuro). Except for post 1997 gasoline cars whose emissions are very low, the resulting damage costs per km are not much smaller than the price of fuel, and the number of YOLL is comparable to the number lost by traffic accidents.

Key words: air pollution, health impacts, damage costs, diesel cars, gasoline cars

1. Introduction

This paper presents a summary of the health damage costs due to air pollution from cars in France, as estimated by the ExternE Project ("External Costs of Energy") of the European Commission [ExternE 1995, ExternE 1998]. According to ExternE [1998] the vast majority (over 95%) of the total damage cost is due to health impacts, and among health costs the dominant item is reduced life expectancy. Chronic bronchitis is also important, and so are impacts for asthmatics. Cancers have also been quantified, but their contribution to the total cost is very small. ExternE has not identified allergy as an endpoint of automobile air pollution.

For environmental policy one needs to know which source of pollution causes how much damage. Therefore the ExternE methodology begins at the pollution source rather than at the measured ambient concentration of a pollutant. This involves an analysis of the impact pathway for each pollutant, from source to receptors (population, crops, buildings, etc.):

- specification of the technologies and emissions (e.g. kg/yr of NO_2 from tailpipe);
- calculation of increased pollutant concentration in all affected regions (e.g. µg/m^3 of O_3, using models of atmospheric dispersion and chemistry for O_3 due to NO_2);
- calculation of physical impacts (e.g. number of asthma attacks due to O_3 using dose-response functions);
- economic valuation of impacts (e.g. multiplication by cost of asthma attack).

The damage is summed over all affected receptors. For details of this analysis, the reader is referred to publications by the ExternE [1995, 1998[Project; shorter accounts can be found in Rabl, Spadaro & McGavran [1998] and Rabl & Spadaro [2000].

2. Key Assumptions

2.1. Dispersion modeling

For most air pollutants from combustion, atmospheric dispersion is significant over hundreds to thousands of km. Both local and regional effects are important. We have therefore used a combination of local and regional dispersion models to account for all significant damages. For modeling dispersion over the short range we have used two gaussian plume models: ISC [Wackter & Foster 1987] and ROADPOL [Vossiniotis et al 1996]. At the regional scale we have used two different models, the Harwell Trajectory model as implemented in the EcoSense software [Krewitt et al 1995] of ExternE, and the EMEP model of the Norwegian Meteorological Service [Simpson 1993], the official model for the analysis of transboundary pollution in Europe.

2.2. Health Impacts of Air Pollution

A consensus has been emerging among public health experts that air pollution, even at current ambient levels, aggravates respiratory and cardiovascular diseases and leads to premature mortality [e.g. Wilson & Spengler 1996, ERPURS 1997]. There is less certainty about specific causes, but most recent studies have identified fine particles as a prime culprit; ozone has also been implicated directly. The most important cost comes from mortality due to particles, calculated on the basis of Pope et al [1995]. Another important contribution comes from chronic bronchitis due to particles [Abbey et al 1995]. In addition there may be significant direct health impacts of SO_2, but for direct impacts of NO_x the evidence is less convincing.

In ExternE [1998] the working hypothesis has been to use the dose-response (DR) functions for particles and for O_3 as basis. Effects of NO_x and SO_2 are assumed to arise indirectly from the particulate nature of nitrate and sulfate aerosols, and they are calculated by applying the particle DR functions to these aerosol concentrations. With this assumption the impacts of NO_2 and SO_2 become very large, but this is uncertain because there is insufficient evidence for the health impacts of the individual components or characteristics (acidity, solubility, …) of particulate air pollution. In particular there is a lack of epidemiological studies of nitrate aerosols because until recently this pollutant has not been monitored by air pollution monitoring stations. All DR functions for health impacts of air pollution have been assumed linear at the population level, in view of the lack of evidence for thresholds at current ambient concentrations.

2.3. Monetary Valuation

The goal of the monetary valuation of damages is to account for all costs, market and non-market. For example, the valuation of an asthma attack should include not only the cost of the medical treatment but also the willingness to pay to avoid the suffering. If the willingness to pay for a non-market good has been determined correctly, it is like a price, consistent with prices paid for market goods. Economists have developed several tools for determining non-market costs; of these tools contingent valuation has enjoyed increasing popularity in recent years. The results are considered sufficiently reliable.

It turns out that damage costs of air pollution are dominated by mortality. The key parameter is the so-called value of statistical life VSL (really the collective willingness to pay for reducing the risk of premature death). In ExternE [1998], a European-wide value of 3.1 MEuro ($3.6 million) was chosen for VSL, close to similar studies in the USA. Unlike previous studies which simply multiplied the number of premature deaths by VSL, ExternE [1998] bases the valuation on the years of life lost (YOLL). The value of a YOLL due to air pollution is taken as 0.083 MEuro.

3. Damage Cost per kg of Pollutant

The damage costs per kg of pollutant are listed in column 2 of Table 1. Particles emitted by cars are $PM_{2.5}$ (where PM_d designates particles with diameter less than d microns) and are especially harmful because they penetrate deep into the lungs.

Table 1. Health damage costs per kg of pollutant, and tailpipe emissions per km, both for trip from Paris to Lyon. For the primary pollutants ($PM_{2.5}$ and CO) the cost per kg is about 14 times higher for travel in Paris and about 7 times lower for rural travel in SW of France. “cat.” = catalytic converter. 1 Euro = 6.56 FF = $1.00 to 1.20.

Pollutant	Health damage cost Euro/kg	Emissions, g/km				
		Old cars (before 1997)			New cars (since 1997)	
		Gasoline, without cat.	Gasoline, with cat.	Diesel	Gasoline	Diesel
$PM_{2.5}$	160	0.03 [d]	0.01 [d]	0.15 [d]	0.002 [c]	<0.08 [a]
SO_2	10	0.03 [b]	0.03 [b]	0.03 [b]	0.03 [b]	0.03 [b]
NO_2	15.7	3.36 [d]	0.79 [d]	0.62 [d]	<0.13 [a]	<0.51 [a]
VOC	0.7	1.62 [d]	0.12 [d]	0.11 [d]	<0.38 [a]	<0.19 [a]
CO	0.02	13.18 [d]	1.29 [d]	0.56 [d]	<2.20 [a]	<1.00 [a]

[a] Emissions limits imposed by directive 94/12/CEE, March 23, 1994 for new vehicles as of 1/1/97. The limits are specified for CO, HC + NO_x, and fine particles. HC and NO_x emissions are calculated with a split factor equal to the HC/NO_x ratio in the emission factors of Joumard et al [1995], calculated for representative driving cycle.

[b] Calculated by multiplying fuel consumption by 0.05%, the admissible sulfur content as of 10/1/96.

[c] based on CONCAWE [1998]

[d] based on Joumard et al [1995], as interpreted by Spadaro et al [1998] for driving conditions of Paris-Lyon trip.

A very important issue is the variation of the damage with emission site: health impacts depend on the population distribution in the affected region. In this regard there is a difference between primary and secondary pollutants. Primary pollutants, for instance particles, cause damage in the form in which they are emitted. Some pollutants are transformed in the atmosphere to secondary pollutants and cause damage in the latter form. For example, SO_2 is transformed into sulfate aerosols and NO_x into nitrate aerosols; NO_x is also a precursor of ozone. SO_2 can be harmful both directly as a primary pollutant and as a precursor of sulfates (especially sulfuric acid).

Damage due to primary pollutants varies strongly with local conditions, especially when emitted at ground level. The damage of secondary pollutants, by contrast, is quite insensitive to the conditions in the vicinity of the source. This is because the chemical reactions take some time and the formation of nitrate and sulfate aerosol particles occurs over distances of tens to hundreds of km. The formation of ozone is somewhat faster and occurs over several km to tens of km. In this paper we make the approximation (good to about 30% for sites in France) that the damage of secondary pollutants does not vary with emission site.

It may appear surprising that the ExternE estimate for CO damage is so small. This may well be due to the difficulty of correctly identifying its effects in epidemiological studies.

4. Emissions and Damage Costs per km

Columns 3 to 7 of Table 1 shows the tailpipe emissions assumed in this study. For existing cars they are based on emissions measured by Joumard et al [1995], as interpreted by Spadaro et al [1998]. For new cars they are taken as the regulatory limits imposed in France for all new vehicles as of January 1, 1997 (with exceptions noted); the real emissions may turn out to be lower.

There are no regulations for particle emissions from gasoline cars, an item not considered significant in the past. However, in view of the high damage cost per kg of particles even small emissions can make an appreciable contribution to the total cost. They have been measured by CONCAWE [1998] for two gasoline cars of the kind being sold now with catalytic converter, and we base our $PM_{2.5}$ calculations on this report. The uncertainties of this item are high, not only because it is based solely on two cars but because the emissions are close to the detection limits of the instrumentation. We interpret the numbers in the CONCAWE report to imply a $PM_{2.5}$ emission of 2 mg/km for urban driving (with uncertainty range from 1 to 4 mg/km).

This point illustrates the difficulty of obtaining representative data about the current vehicle fleet. There is continual evolution in technologies, tastes and driving patterns, and reliable data about the current situation are hard to get. The evolution has been particularly rapid with regard to emissions. The problems of estimating the emissions come on top of the great variability of the damages with emission site, making it doubly difficult to extract typical results suitable for policy applications.

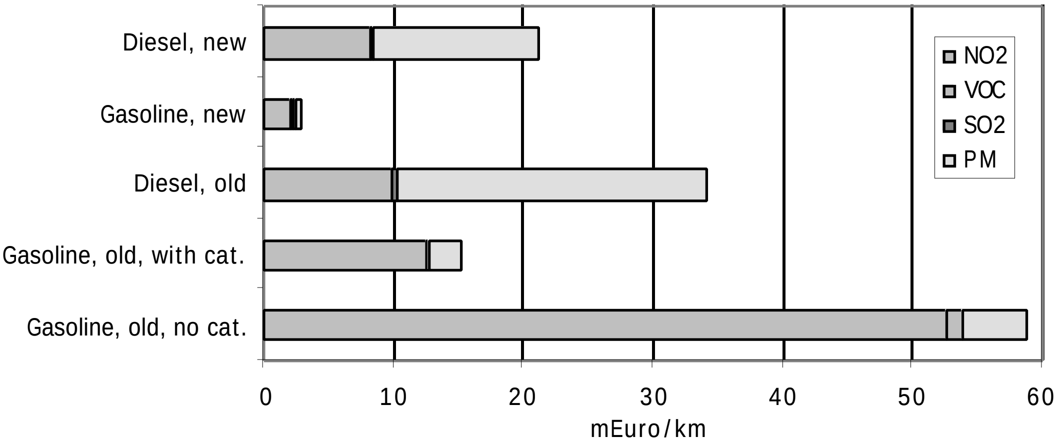
The damage costs in milli Euro per km are shown in Fig.1. The contribution of CO, according to the assumptions of ExternE, is so small that we do not even show it in the figure.

We emphasize that the uncertainties are very large. By considering the uncertainty distributions for each element of the impact pathway analysis, Rabl and Spadaro [1999] have estimated that the damage costs could be a factor of 4 larger or smaller. The main uncertainties arise from the epidemiology and from the value of a YOLL.

5. Conclusion

It is instructive to put the numbers in perspective. A natural comparison for the damage cost is the cost of fuel. Taking simple round numbers, a gasoline price in France of about 0.9 Euro/l (of which some 80% is tax) and a consumption of 8 l per 100 km, one finds a fuel cost of 72 mEuro/km. While the variability with car type and emission site makes a precise comparison difficult, the numbers in Fig.1 are somewhat but not much smaller than the fuel cost, with the exception of new (post 1997) gasoline cars whose damage cost is only 3 mEuro/km.

Fig.1. Health cost due to emissions from tail pipe, for diesel and gasoline cars driven from Paris to Lyon. The numbers for new cars are upper limits because they correspond to emissions equal to 1997 regulations. While costs of SO_2, NO_2 and VOC do not vary much with emission site, the damage due to particle and CO emissions would be about 14 times larger in Paris, and about 7 times smaller in the rural SW of France. The uncertainty is large, about a factor of 4 in either direction.



Another comparison is with the years of life lost (YOLL) due to traffic accidents; this comparison is especially interesting because it avoids the uncertainties and controversies surrounding the value of a YOLL. The YOLL due to air pollution can be extracted from the damage costs by noting that approximately 85% of the total health damage is due to mortality which has been evaluated at 83000 Euro/YOLL. The results are shown in Table 2. To estimate the YOLL due to traffic accidents, about 8000 per year in France, we assume a loss of 45 YOLL per accident on average. Allocating this to the average distance driven (7800 km/yr per person times 56 million persons) one finds approximately 0.8 YOLL per million km. This is of the same order of magnitude as the numbers in Table 2, only new (post 1997) gasoline cars being much lower.

Table 2. Years Of Life Lost (YOLL) per million km due to air pollution emitted by cars. For comparison traffic accidents cause 0.8 YOLL per million km.

Type of car Site of travel	Gasoline, old, without cat.	Gasoline, old, with cat.	Diesel, old	Gasoline, new	Diesel, new
Paris	0.80	0.58	5.02	0.07	1.89
Paris-Lyon	0.61	0.16	0.35	0.03	0.22

It is ironic that the diesel, which had been encouraged on the grounds of higher energy efficiency and lower emissions, would now look so poor in terms of health damage, especially when driven in large cities. Indeed, except for particle emissions the diesel is relatively clean, especially compared to gasoline cars without catalyst (required in France only since 1993). Fortunately the particle trap for diesel cars is close to being marketed and it can reduce any remaining particle emissions by about 90%.

To sum up, using the assumptions of the ExternE Project [1998], we have found that the health cost of air pollution from cars is large - large enough to merit the attention it has received. However, there has been impressive progress on the part of the automotive industry, and the latest generation of gasoline cars entail much lower damages. It may be wise to carry out cost-benefit analyses before deciding how much further the emissions should be reduced.

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