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NOTA DI LAVORO 120.2006

SEPTEMBER 2006

SIEV – Sustainability Indicators and Environmental Valuation

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Air Pollution Costs in Ukraine

Summary

The paper presents estimation of the health losses from urban air pollution in Ukraine. The methodology developed by US EPA and adjusted in Russia for Eastern European transition countries was applied for health risk assessment. $PM_{2.5}$ was identified as the major source of human health risk, based on experience from the Russian studies. In the absence of reliable computed concentrations of PM2.5, the study was based on monitoring data of total suspended particle (TSP) emissions in Ukraine. Additional cases of mortality and morbidity were calculated based on reporting data on TSP concentration that was recalculated into PM2.5. Then the concentration–response function was applied to estimate individual risk. Next, individual risk was applied to the population exposed to the concentration reported for each city included in the analysis (we selected most polluted cities). For each city we considered individual data on baseline mortality and morbidity and population structure. In total, air pollution related mortality represents about 6 percent of total mortality in Ukraine. In Russia the corresponding indicator totals about 4 percent. The relative mortality risk attributed to air pollution calculated per 100 000 population in both countries is about 55-59 cases. Since applied method is sensitive to the primary data uncertainties we conducted sensitivity analysis applying Monte-Carlo method. Economic damage related to mortality risk was estimated at about 4 percent of GDP. There was no relevant WTP study in Ukraine therefore we applied the benefit-transfer method in order to estimate VSL, since mortality attributed to air pollution is major component of health losses (about 94 percent). In order to compare and aggregate mortality and morbidity risks we recalculated them in DALY. Then morbidity represents about 30 percent of total air pollution health load. Data on baseline morbidity is less reliable than data on baseline mortality; therefore the morbidity risk estimates are more uncertain than mortality estimates. It is likely that morbidity risk is underestimated. Regardless of uncertainties mentioned above and some problems with reported data we can conclude that the mortality risk attributed to air pollution is significant. Therefore, costs of air pollution in Ukraine are sizable and in the nearest future may offset the economic growth. Recovery of the Ukrainian economy based on restoration of polluting industries may lead to stagnation since mortality and morbidity risks not only puts burden on the economy, but also reduce labor force.

Keywords: Air Pollution, Ukraine, Environmental Damages

JEL Classification: Q53, I10, I18

This work was supported by US EPA Environmental Capacity Building in the Newly Independent States. #X4-83199301.

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1. Introduction

The health of the population of the Former Soviet Union suffered notably as a result of the transition to a market economy (See Brainerd, Cutler, 2005). The unprecedented decline in life expectancy, especially among men, was attributed largely to social collapse and the ensuing increase in alcohol consumption and a lack of personal care. The role of environmental factors in this decline is disputed. The precise contribution of environmental pollution to human health in the member states of the FSU was first studied for Russia. Regardless of the conservative approach applied in most of the studies, it was demonstrated that human health risk from air pollution is significant. These results were extrapolated nation-wide and were presented in Bobylev et al, 2002. The total annual mortality rate related to air pollution was about 46,000 or 2.1% of the total non-accidental mortality rate (Bobylev et al, 2002, p.16). Contrary to common belief, air pollution related mortality was an important component of overall mortality, being much more important than TB, transport accidents and suicides, for example. In total the monetary costs of such pollution was estimated at 2-5 percent of current GDP.

In this paper we wish to see if these results are special to the Russian Federation or if they apply to other FSU states. Moreover, we wish to estimate the importance of air pollution as a source of human and economic loss in Ukraine. The paper proceeds as follows. In Section II we discuss briefly the monitoring of air quality in Ukraine, and the data that are available for estimating health impacts. In Section III we discuss the epidemiological basis of the estimated health impacts and the resulting estimates of number of excess deaths and morbidity cases. In Section IV we present some values of the costs of these health and mortality and put them in a comparative context. Section V concludes the paper, with some observations on the policy implications of the results.

II. Measuring Air Quality in Ukraine

Based on a few pilot studies in Russia, it can be concluded that among the hundreds of pollutants controlled by Russian law, only a handful account for up to 90% of human health risk from air pollution (mainly PM10 or PM2.5[1]). Fossil fuel combustion is the main source of these pollutants.

Unfortunately, levels of PM10 or PM2.5 are not monitored on a reliable basis in either Russia or Ukraine. Hence any assessment of the impacts of the particles has to be based on what is reliably monitored, which is total suspended particles or TSP, and the link between TSP and PM10 or PM2.5.

In this context it is worth noting that huge amount of effort goes into monitoring a large number of pollutants (more than 35) in the FSU countries. The purpose of undertaking such extensive monitoring was to set emissions standards for individual emitters so that actual concentrations of

[1] PM10 is particulate matter less than 10 microns in diameter; similarly PM2.5 refers to matter less than 2.5 microns in diameter. Small particles, however, are also formed from chemical interactions of SO2 and other pollutants with ozone. Hence emissions of these pollutants are also important contributors to health impacts.

pollutants did not exceed certain health determined maximum allowable concentrations (MACs). In practice, however, the MACs were not substantiated by practical methods and techniques of air pollution control. It was impossible to attain the desired accuracy of analytical control, to use adequate instrumentation, numerical estimation methods, unit emissions, technological standards, emission control requirements. Neither was there was adequate financing or professional staffing. The improvements in these areas are very slow.

Since air pollution monitoring data in Ukraine only provides data on TSP pollution, conversion factors were used to estimate PM10 and PM2.5 levels. The factors were PM10 = 0.5TSP (US AID Environmental Management Project in 1997); PM2.5= 0.55PM10 (Central European study on air pollution and health, 1997). The last coefficient has a range of 0.4-0.8. We will use this range for the sensitivity analysis reported later. .

Table 1 presents the data on population in the 29 most polluted cities in Ukraine, together with estimated PM2.5 concentrations in these cities (based on TSP monitoring data) and estimated non-accidental mortality (based on total mortality for every city and mortality by causes for Ukraine, WHO, 2002). We estimated that about 5 percent of total mortality belongs to external causes (suiside, homicide, poisoning, traffic accidents, etc.). It should be note that, according to WHO recommendations the MAC value for annual average PM2.5 is 10 ug/m3. These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to fine particles in the ACS study (Pope et al., 2002). In Ukraine this was exceeded in all 29 cities listed below.

III. Air pollution and human health

A large number of epidemiological studies provide evidence that exposure to air pollution is associated with increased morbidity and mortality (WHO, 2004). The most affected are respiratory and cardiovascular systems. The mechanisms “may involve decrements in pulmonary function, effects on hart rate variability and inflammatory response”. Also, there is an evidence of carcinogenity of some components of urban air pollution. Both acute and chronic biological responses are affected by air pollution, since acute responses exacerbate the severity of chronic diseases.

Epidemiologic literature proposes to use Cox proportional hazards model for the long term health risk estimation. Basically, they have the following form:

$$y_C = -\left[y_B * (e^{-\beta * \Delta C} - 1)\right] * pop \qquad (1)$$

where:

y_C is incremental number of cases of negative health outcome (morbidity or mortality);
ΔC is the change in mean population-weighted annual concentration of criteria pollutant[2];
β is concentration-response coefficient;
y_B is baseline level of the health outcome;

[2] PM pollution could be used as an indicator of pollution mix.

pop is exposed population to which it is appropriate to apply β (the same as in the epi studies, where β was estimated).
For small changes in the annual mean criteria pollutant concentration, it is appropriate to use a linear relationship between incremental health outcome and change in annual mean criteria pollutant concentration:

$$y_C = \beta * \Delta C * y_B * pop \qquad (2)$$

Then, β is concentration-response coefficient that reflects change in health outcome per unit of pollution (slope of concentration-response function).
<u>Air pollution and mortality</u>
For $PM_{2.5}$ pollution, β values were developed for all cause mortality, cardiopulmonary mortality, and lung cancer mortality (Pope et al., 2002) Then β is the per cent change in health outcome per unit of pollution (i.e. the slope of concentration-response function). Estimates are given in Table 2 below.

It is appropriate to use β from epidemioloogical studies*,* when pollution in the focus area is in the range observed in the study used for the estimation. For example, WHO recommends to apply Pope coefficients for PM2.5 pollution in the range of 7.5-50 µg/m3 PM2.5. Beyond 50 µg/m3 the β value is set at zero.

Experts agree that based on the current status of worldwide research, the risk ratios, or concentration response coefficients from Pope et al (2002) are likely to be the best available evidence for the mortality effects of ambient particulate pollution (PM 2.5). This study provided a global estimate of the health effects of environmental risk factors including health risk from environmental pollution. It was the American Cancer Society study within the framework of Cancer Prevention II prospective study of risk factors for mortality, where 1.2 million Americans from 50 metropolitan areas 30 and older were involved. This study concentrated on long-term exposure to air pollution from fine particulates (PM2.5) that are the most harmful for human health and include sulfates and nitrates. Long-term pollution is more important than short-term, because it include the effects of long-term exposure that can not be captured by a short-term study. The participants were observed for about 16 years. The study controlled for age, sex, weight, height, smoking, alcohol use, occupational exposure, diet, education, marital status, etc. As a result the study came up with the list of concentration-response coefficients, which identify additional risk of non-accidental death, cardio-pulmonary and lung-cancer mortality.

If our goal is to assess total health risk caused by air pollution, one should take into account the difference between observed mortality and baseline mortality. From formula (1) above, y_B should be derived for the baseline situation if we would like to have y_B associated with the ΔC ambient concentration levels (of $PM_{2.5,}$ for example). If y is defined by the equation (2) (choosing a linear specification over the relevant range of C):

$$y_C = \beta * \Delta C * y_B \qquad (3)$$

The baseline y_B however, is not directly observed, and is given by:

$$y_B = y_0 - y_C \qquad (4)$$

where y_0 is the observed or recorded number of all cause non accidental or cardiopulmonary and lung cancer deaths. Substituting equation (4) in equation (3) provides the following solution for y_B:

$$y_C = \beta * (\Delta C) * y_0 / \{1 + \beta * (\Delta C)\} \qquad (5)$$

We have applied Pope's all cause non accidental mortality coefficient $\beta = 0.004$ per 1 µg/m3 of PM2.5. If PM2.5 concentration is above 50 µg/m3, the value was set at 50 µg/m3. Since the Pope estimates apply only to persons over the age of 30,this share had to be estimated. In Ukraine demographic data indicate that about 60% of population in Ukraine is older than 30 (http://www.census.gov/cgi-bin/ipc/idbagg).

Based on the data on non-accidental deaths in Ukraine presented in Table 1, we estimated that about 22,000 people annually die from air pollution related causes in the most polluted cities of Ukraine. That represents about 10% of total mortality in these cities.

The same analysis could be undertaken based on cardiovascular, respiratory and lung cancer mortality and the corresponding β coefficients from Table 2. Table 3 presents major death causes in Ukraine related to air pollution by region.

Cardiopulmonary mortality is a major cause of death in Ukraine. We estimated that about 66% of total deaths are related to cardiopulmonary causes (weighted average). Lung cancer mortality would elevate this figure up to 68% of total deaths. In this case $\beta = 0.006$ per 1 µg/m3 of PM2.5 should be applied (see Table 2). This is a conservative estimate, since for lung-cancer mortality β is equal to 0.008. Taking this value we find that air pollution related mortality estimated based on cardiopulmonary and lung cancer mortality is totaling 27,000 annual deaths. **Hence the range of air pollution related deaths in Ukraine is estimated to be in the range of 22,000 to 27,000 annually.**

Air pollution related morbidity

Although available information on mortality is quite reliable, morbidity information is not. Therefore, we had to apply the method proposed by Ostro (1994) to estimate respiratory hospital admissions, emergency room visits, restricted activity days, lower respiratory illness in children and respiratory symptoms. For chronic bronchitis we applied the approach from Abbey et al (1995). Method from Ostro (1994) doesn't requite baseline morbidity. Thus it is applicable even with poor primary data about background morbidity indicators. Abbey's approach requires a baseline chronic bronchitis morbidity. Official data on chronic bronchitis were provided by the Ministry of Public Health of Ukraine. Both studies Ostro (1994) and Abbey (1995) link exposure to PM10 air pollution with additional morbidity end-points. For air pollution related cases of chronic bronchitis we applied the formula similar to (5), where yc is additional number of chronic bronchitis and y0 is observed number of cases for Euro B region. For other morbidity end-points we applied the following formula, as in Ostro (1994):

$Yc = \beta * C$,

Where C is observed PM10 concentration and β is concentration-response coefficient.

For chronic bronchitis we also obtained an estimation using Ostro (1994) method and compared it with Abbey (1995) results. The morbidity coefficients are presented in Table 4.

Thus, in order to estimate the cases of morbidity we used background bronchitis morbidity provided by the Ministry of Public Health, as given in Table 5. The data could be underestimated, since many cases are not reported. However, we use them in our analysis to get a conservative estimate of morbidity cost of air pollution in Ukraine. This yields an estimate of the number of cases of chronic bronchitis attributable to air pollution of 13,000. An alternative approach that could be taken is that recommended by Ostro 1994, who posits 61.2 cases per 100,000 of population per each 10 μg/m3 of PM10 pollution. On this basis the number of cases for the 30 urban areas listed below is about 90,000 cases per year. Hence the range is 13,000-90,000.

Negative morbidity end-points were estimated as shown in Table 6. In that table chronic bronchitis attributed to air pollution is estimated based on the Abbey et al (1995) approach using background data from Ministry of Health. It presents a lower bound estimate. Other health end-points are estimated using the Ostro (1994) method. They present upper bound estimation. However, as we see in the next section, these uncertainties related to the indicators estimated based on Ostro should not significantly influence aggregated human health damage.

Table 7 presents the distribution of estimated health effects across the selected cities as a percentage of total national cases. About 50% of all health effects are in Donetsk, Odesa, Krivy Rog, Zaporizhya, Makiyevka and Dnepropetrivsk, whereas only 34% of the population lives there. Kiyv, Kharkiv and Lviv are relatively clean cities. About 33% of urban population from the covered cities live there, but joint pollution share is only 17% (Figure 1). The remaining cities represent about 33% of population and 35% of air pollution related load.

IV. Estimated Burden of Health Impacts

The burden of health impacts is converted to monetary terms by valuing mortality and morbidity. Valuation is based on robust willingness to pay studies that quantify the value of human health risk reduction. These valuation studies have not been done either in Ukraine or in any other FSU country. Therefore the only method to apply for valuation is a benefit transfer approach. The physical estimates of mortality and morbidity can be converted in monetary values under certain assumptions. The estimated annual cost of urban air pollution health effects is presented in Table 8. Details of how these estimates were derived are given below[3].

[3] Studies on the valuation of health effects of outdoor air pollution outside the OECD countries are rare. Recent work along this lines, using some benefit transfer has been undertaken in China (Eliason and Lee, 2003), in Russia (Bobylev, 2002) and Peru (Larsen, 2005).

Estimating VSL

The main approaches to estimating mortality use the 'value of a statistical life (VSL)' – i.e. the value society attached to saving a life, when it is not known whose life will be saved. The problem is that there are no studies of VSL conducted in Ukraine. This implies that values have to be transferred from studies in other countries. The overwhelming majority of VSL studies have been conducted in countries with substantially higher income level than in Ukraine. VSL estimates from these countries must therefore be adjusted to Ukraine.

A common adjustment method is calibration of VSL in developed country in per capita terms.

$$VSL_U = VSL_D * (\frac{GDP_U / N_U}{GDP_D / N_D}),$$

Where VSL_U and VSL_D are VSL in Ukraine and in the developed country,
GDP_U / N_U is GDP per capita in Ukraine; GDP_D / N_D is GDP per capita in the developed country.

Although in the literature there is no consensus about reliability of this approach, this is the only tool available to assign economic value to environmental health losses. In the recent study published by Ready et al, 2004 the authors concluded that the benefit transfer method results in error less than 50 percent. However, the authors acknowledge some extremes: it may lead to overestimation as much as 230 percent or underestimation as much as 77 percent (p. 80). This study was conducted for European countries and the issue of PPP and market exchange rate was not as important as it is for lower income countries. In Ukraine the ratio between PPP and market exchange rate is as much as 4.8 in 2004. This makes benefit transfer a very shaky methodology. However, we apply it using market exchange rate for conversion. This is a lower bound of estimation of VSL.

There is also a discrepancy in valuation of VSL in developed countries. Mrozek and Taylor (2002) provide a range for VSL of US $1.5-2.5 million in their meta-analysis of VSL. In Aldy and Viscusi the mean VSL estimation is about US $6 million. Again, we apply the lower estimation to be on a conservative side.

Resulting VSL for Ukraine from benefit transfer based on the range of VSL reported by Mrozek and Taylor (2002) (see table 8). However, if GDP would be estimated in PPP, then VSL in Ukraine would be about 434 thousand US $.

2. Valuing morbidity

A measure of the welfare cost of morbidity is often based on the willingness-to-pay (WTP) for avoiding or reducing the risk of illness. This measure is often found to be several times higher than the cost of medical treatment and the value of time losses (Cropper and Oates 1992), and reflect the value that individuals place on avoiding pain and discomfort. There are, however, no WTP studies from Ukraine. For this reason, the cost-of-illness (COI) approach (mainly medical cost and value of time losses) has been supplemented by a proxy for the cost of pain and discomfort in this report. We applied benefit transfer to estimate the suffering from chronic bronchitis in Ukraine in the same way, as we did for VSL. The value used for Russia in 2003 as 15,000 US $. Then corresponding value for Ukraine is 5,000 US $ per case of chronic bronchitis. We refrain from applying other than COI estimations for the rest of morbidity end-points due to the different structure of health system in the developed and FSU countries. The resulting costs of mortality and morbidity (based on a sum of the COI and the value of DALYS) are given in Table 9.

Further details of the morbidity costs are given in Table 10, which presents the cost of illness, the DALYs for different health impacts and the sum of the two. In most cases the cost of illness is substantially higher than DALY estimate. The main exception is chronic bronchitis, which often has a severe effect on people's life without necessarily causing substantial medical treatment cost or time losses.

Table 11 presents estimated annual cost of morbidity by type of cost. The value of time losses represents almost 57 percent of total cost, and the cost of pain and discomfort (proxied by DALYs valued at GDP per capita) represents somewhat less than one-third.

Table 12 provides the baseline data that were used to estimate the cost per case of illness. Some of these data require explanation. The value of time for adults is based on urban wages. Economists commonly apply a range of 30-50 percent of wage rates to reflect the value of time. The rate of 21 Grivnas per day is about 40 percent of average urban wages in average Kiev-Zaporizhya.

There is very little information about the frequency of doctor visits, emergency visits and hospitalization for CB patients in any country in the world. Estimations from (Larson, Egypt) have been applied to Ukraine. Estimated work days lost per year is based on frequency of estimated medical treatment plus an additional 7 days for each hospitalization and one extra day for each doctor and emergency visit. These days are added to reflect time needed for recovery from illness.

To estimate the cost of a new case of CB, the medical cost and value of time losses have been discounted over a 20-year duration of illness. An annual real increase of 2 percent in medical cost and value of time has been applied to reflect an average expected increase in annual labor productivity and real wages. The costs are discounted at 3 percent per year, a rate commonly applied by WHO for health effects.

<u>Sensitivity analysis</u>

There are certain uncertainties in the health risk analysis. Basically, they are presented in the report on pollution cost in Russia. We applied Monte-Carlo approach to analyze these uncertainties. The results are presented in Figure 2 below:

The figure shows that with a probability of 90% there are no less than 14,000 cases of air pollution related mortality in Ukraine (Crystall Ball 7, 10,000 trials).

Table 13 allows comparing different causes of death in Russia and Ukraine. It is easy to see that air pollution related mortality exceeds deaths from TB by a factor of 2. It exceeds deaths from traffic accidents and assaults 3 times. It is almost 2 more than suicide and poisoning. Figure 3 provides the same comparative figures of air pollution mortality with other causes. While the overall mortality rates and those for air pollution for the two countries are similar, there are major differences in the rates attributed to 'social' factors, such as external factors, such as traffic accidents, poisoning, suicide and assault, where the Russia rates are much higher.

V. Conclusions

This paper has shown that Ukraine has considerable health and mortality costs in human and monetary terms associated with air pollution. At a conservative estimate these costs amount to 27,000 excess deaths and 280,000 DALYs lost annually. In monetary terms, we estimate the costs at around 13 billion grivynas ($2.6 billion), or 4 percent of GDP. By any standards this is a significant cost. In Russia the corresponding indicator is about 5 percent of GDP. Studies in the EU of similar costs, but using much more detailed data and a more sophisticated modeling of the dispersion of air pollution and the creation of particles, comes up with air pollution costs from similar items in the range of 2 percent (Markandya and Tamborra, 2005). Thus by this measure the problem is more serious in Ukraine than in these countries. At the same time, the level of effort devoted to addressing it is much lower. Public and private sector spending on investment in air pollution control is very small (World Bank, 2003). Studies like these provide a useful guide to where efforts should be made to reduce air emissions (the focus needs to be on particulate pollution control in certain cities we have identified), and how the air pollution problem compares with other sources of morbidity and mortality (it is more serious, for example, than most social causes of death and more serious than TB). This is not something that is generally appreciated or acted upon.

The paper also demonstrates how the analysis can be done using limited and uncertain information. Therefore, estimates presented in the paper where complemented by sensitivity analysis. Limited data on air pollution is not enough to develop a detailed action plan for environmental costs burden alleviation, however, it is a good way to draw attention to environmental problems ignored in the former Soviet Union for years. Thus environmental degradation may soon become a significant barrier for economic growth and can not be ignored by policy makers.

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Table 1. Fine particulates concentration, population and non-accidental mortality in major metropolitan areas of Ukraine (2001) (Annual Averages)

City	PM2.5 µg/m3 (Annual Average)	Population, '000	Non-accidental mortality rate per 1000
Lugansk	33	459	16.34
Alchevsk	66	118	16.34
Kerch	33	157	14.25
Yalta	66	81	14.25
Dnipropetrivsk	66	1072	15.485
Dniprodzerzhinsk	33	253	15.485
Krivy Rig	66	704	15.485
Donesk	99	1009	13.87
Enakiyeve	99	101	18.335
Gorlivka	99	287	17.765
Dzerzhinsk	99	86	17.86
Kramatorsk	33	179	16.055
Mariupol	66	488	14.06
Makiyivka	132	384	17.195
Slovyansk	33	124	15.295
Ivano-Frankivsk	66	219	8.265
Kirovograd	66	252	17.1
Svitlovodsk	99	50	17.1
Kremenchug	66	232	15.58
Lviv	66	733	11.4
Odesa	66	1021	15.01
Sumi	66	289	17.1
Vinnitsa	99	358	15.865
Kiyv	33	2622	10.07
Mikolayiv	33	512	15.295
Zhitomir	33	282	16.245
Zaporizhya	66	808	13.965
Rivne	33	249	6.935
Uzhgorod	33	117	9.025
Kharkiv	30	1470	15.00
Total		11278	

Source: State Committee for Statistics, Ukraine

Note: PM2.5 concentrations are recalculated from TSP concentrations base on the formula presented above.

Table 2. Mortality risk associated with a 1 ug/m^3 change in PM 2.5

Cause of Mortality	β
All-cause non accidental	0.004
Cardiopulmonary	0.006
Lung cancer	0.008

Source: adapted from Pope et al, 2002

Table 3. Death rates in Ukraine by major causes of death in 2002, by region

Region (oblast)	Mortality	Cardio	Pulmonary	Lung cancer	Population,
	per 100 000 population				*thousand*
Cherkaskaya	1,763.1	1,183.2	97.1	32.4	1,398.3
Chernigovskaya	1,995.5	1,299.4	95.9	42.6	919.0
Chernovetskaya	1,314.2	868.5	68.0	33.3	1,236.1
Crimea	1,474.7	935.4	51.7	35.0	2,024.0
Dnipropetrovskaya	1,626.5	1,011.9	67.2	37.4	3,561.2
Donetskaya	1,712.3	1,038.7	60.0	42.5	4,825.6
Ivano-Frankivskaya	1,272.3	760.8	83.7	28.4	1,406.1
Kharkovskaya	1,602.2	1,042.7	38.9	28.1	2,895.8
Khersonskaya	1,582.7	877.2	26.7	43.6	1,172.7
Khmelnitskaya	1,622.2	939.3	97.2	40.7	1,426.6
Kirovogradskaya	1,796.4	969.6	86.3	44.2	1,125.7
Kievskaya	1,666.6	1,162.2	42.8	38.0	1,821.1
Luganskaya	1,721.5	1,064.4	85.6	39.8	2,540.2
Lvivskaya	1,295.2	817.4	83.8	25.3	2,606.0
Mikolayivskaya	1,605.4	721.6	56.1	39.8	1,262.9
Odeskaya	1,583.9	951.9	50.5	29.9	2,455.7
Poltavskaya	1,805.0	1,140.4	74.7	39.9	1,621.2
Rovenskaya	1,328.7	842.3	40.1	27.3	1,171.4
Sumskaya	1,800.1	1,141.3	108.2	33.0	1,296.8
Ternopolskaya	1,436.7	945.9	97.4	38.9	1,138.5
Vinnitskaya	1,667.3	1,156.4	65.8	33.6	1,763.9
Volinska	1,405.0	833.1	134.2	22.0	1,057.2
Zakarpatskaya	1,192.2	643.6	50.3	25.2	1,254.6
Zaporizhskaya	1,612.1	829.7	48.4	43.9	1,926.8
Zhitomirskaya	1,714.6	1,146.8	81.3	32.3	1,389.3
Kiev	1,056.6	649.2	26.4	23.7	2,567.0
Sevastopol	1,370.3	798.1	44.9	43.0	377.2

Source: Shalimov S.O. Chief ed. 2004. Bulletin of the National cancer-register of Ukraine. Institute of Oncology of Ukraine. No 5. Kiev.
Pidaev A. Chief ed. 2004. Health indexes and health related expenditures in Ukraine in 2002-2003. Ministry of Public Health of Ukraine. Center of Health Statistics. Kiev

Table 4: Urban Air Pollution Dose-Response Coefficients for Morbidity estimation

Annual Morbidity Effect	Dose-response coefficient	Per 1 ug/m^3 annual average ambient concentration of:
Chronic bronchitis (% change in annual incidence)	0.9%*	PM 10
Chronic bronchitis (per 100,000 population)	6.12**	PM 10
Respiratory hospital admissions (per 100,000 population)	1.2**	PM 10
Emergency room visits (per 100,000 population)	24**	PM 10
Restricted activity days (per 100,000 adults)	5,750**	PM 10
Lower respiratory illness in children (per 100,000 children)	169**	PM 10
Respiratory symptoms (per 100,000 adults)	18,300**	PM 10

Source: **Ostro (1994) and *Abbey et al (1995)

Table 5. Background bronchitis morbidity for adult population in metropolitan areas of Ukraine

	PM10 concentration	CB background incidence
Lugansk	60	522
Alchevsk	180	134
Kerch	60	151
Yalta	120	78
Dnipropetrivsk	120	2228
Dniprodzerzhinsk	60	526
Krivy Rig	120	1463
Donesk	180	2081
Enakiyeve	180	208
Gorlivka	180	592
Dzerzhinsk	180	177
Kramatorsk	60	369
Mariupol	120	1007
Makiyivka	240	792
Slovyansk	60	256
Ivano-Frankivsk	120	776
Kirovograd	120	434
Svitlovodsk	180	86
Kremenchug	120	264
Lviv	120	1041
Odesa	120	2800
Sumi	120	473
Vinnitsa	180	1220
Kiyv	60	7513
Mikolayiv	60	847
Zhitomir	60	251
Zaporizhya	120	677
Rivne	60	368
Uzhgorod	60	251
Kharkiv	50	2819
Total		30,404

Source: Pidaev A. Chief ed. 2004. Health indexes and health related expenditures in Ukraine in 2002-2003. Ministry of Public Health of Ukraine. Center of Health Statistics. Kiev.

Table 6. Total number of morbidity cases due to air pollution in Ukraine

	Chronic bronchitis	Hospital admissions	Emergency room visits	Restricted activity days	Lower respiratory illness in children	Respiratory symptoms
Lugansk	178	330	6,483	1,543,588	23,787	4,912,637
Alchevsk	80	108	2,119	429,525	2,586	1,367,010
Kerch	51	113	2,217	449,570	2,706	1,430,804
Yalta	39	117	2,288	463,887	2,793	1,476,371
Dnipropetrivsk	1,104	1,544	30,282	6,139,344	36,958	19,539,130
Dniprodzerzhinsk	176	182	3,573	724,466	4,361	2,305,690
Krivy Rig	725	1,014	19,887	4,031,808	24,271	12,831,667
Donesk	1,235	2,179	42,753	8,667,815	52,179	27,586,262
Enakiyeve	124	218	4,280	867,641	5,223	2,761,360
Gorlivka	351	620	12,161	2,465,474	14,842	7,846,637
Dzerzhinsk	105	186	3,644	738,783	4,447	2,351,257
Kramatorsk	124	129	2,528	512,567	3,086	1,631,299
Mariupol	502	703	13,785	2,794,776	16,824	8,894,678
Makiyivka	520	1,106	21,694	4,398,336	26,478	13,998,182
Slovyansk	86	89	1,751	355,074	2,138	1,130,062
Ivano-Frankivsk	383	315	6,186	1,254,213	7,550	3,991,669
Kirovograd	215	363	7,118	1,443,204	8,688	4,593,154
Svitlovodsk	51	108	2,119	429,525	2,586	1,367,010
Kremenchug	133	334	6,554	1,328,664	7,998	4,228,618
Lviv	526	1,056	20,706	4,197,891	25,271	13,360,244
Odesa	1,382	1,470	28,841	5,847,267	35,200	18,609,563
Sumi	237	416	8,164	1,655,103	9,964	5,267,545
Vinnitsa	707	773	15,169	3,075,399	18,514	9,787,792
Kiyv	2,506	1,888	37,033	7,508,097	45,198	23,895,335
Mikolayiv	288	369	7,231	1,466,112	8,826	4,666,061
Zhitomir	85	203	3,983	807,507	4,861	2,569,979
Zaporizhya	345	1,164	22,824	4,627,416	27,857	14,727,254
Rivne	125	179	3,517	713,012	4,292	2,269,237
Uzhgorod	85	84	1,653	335,030	2,017	1,066,268
Kharkiv	847	883	17,314	3,510,174	21,131	11,171,510
Total	13,316	18,243	357,857	72,781,264	452,631	231,634,283

Summary Statistics on Morbidity		
Health categories	**Total cases**	**Total DALYS**
Premature mortality	27,028	202,709
Chronic bronchitis	13,316	33,291
Hospital admissions	18,243	292
Emergency room visits/Outpatient hospital visits	357,857	1,610
Restricted activity days	73 million	21,834
Lower respiratory illness in children	452,631	2,942
Respiratory symptoms	232 million	17,373
TOTAL		280,051

Source:

Table 7: Estimated Health Impact by City

	Percent of Total Exposed Population*	Percent of Total Cases**
Lugansk	3.1%	1.7%
Alchevsk	0.3%	0.6%
Kerch	1.1%	0.7%
Yalta	0.6%	0.7%
Dnipropetrivsk	7.3%	9.5%
Dniprodzerzhinsk	1.7%	1.1%
Krivy Rig	4.8%	6.2%
Donesk	6.9%	10.9%
Enakiyeve	0.7%	1.4%
Gorlivka	2.0%	4.0%
Dzerzhinsk	0.6%	1.2%
Kramatorsk	1.2%	0.8%
Mariupol	3.3%	3.9%
Makiyivka	2.6%	6.2%
Slovyansk	0.8%	0.6%
Ivano-Frankivsk	1.5%	1.0%
Kirovograd	1.7%	2.5%
Svitlovodsk	0.3%	0.7%
Kremenchug	1.6%	2.1%
Lviv	5.0%	4.8%
Odesa	7.0%	8.8%
Sumi	2.0%	2.8%
Vinnitsa	2.4%	4.4%
Kiyv	17.9%	7.7%
Mikolayiv	3.5%	2.3%
Zhitomir	1.9%	1.3%
Zaporizhya	5.5%	6.4%
Rivne	1.7%	0.5%
Uzhgorod	0.8%	0.3%
Kharkiv	10.0%	4.9%

*Exposed population is reported in Table 2. **Total cases are reported in Table 9.

Table 8. Estimated Value of Statistical Life in Ukraine

Average VSL in high-income countries (million US $)	2
Average GDP/capita in high-income countries (US $)	30 000
GDP per capita in Ukraine (US $ in 2004)	1360
Estimated VSL in Ukraine (thousand US $)**	90,5
Estimated VSL in Ukraine (thousand Grivnas)**	452

* weighted average GDP per capita, based on the sample in Mrozek and Taylor (2002). ** Using an exchange rate of 5 Grivnas per US $ in 2004.

Table 9: Estimated Annual Cost of Health Impacts (Billion Grivnas)

Health categories	**Total Annual Cost**	**Percent of Total Cost**
Mortality	12.3	94.2%
Morbidity:		
Chronic bronchitis	0.13	1.0%
Hospital admissions	0.05	0.4%
Emergency room visits/Outpatient hospital visits	0.13	1.0%
Restricted activity days (adults)	0.38	2.9%
Lower respiratory illness in children	0.06	0.4%
Respiratory symptoms (adults)	0.00	0.0%
Total cost of Morbidity	0.75	5.8%
TOTAL COST (Mortality and Morbidity)	13.05	100 %

Table 10: Estimated Unit Cost by Health End-Point (Grivnas)

Health categories	COI per case (1)	WTP per case (2)	Total Cost per case (3)=(1)+(2)
Chronic bronchitis	5,953	5,000	10,953
Hospital admissions	2,969	0	2,969
Emergency room visits/Outpatient hospital visits	403	0	403
Restricted activity days (adults)	149	0	149
Lower respiratory illness in children	11	0	11
Respiratory symptoms (adults)	0.0	0	0.0

Table 11: Estimated Annual Cost of Morbidity

	Annual Cost (Billion Grivnas)
Cost of medical treatments (doctors, hospitals, clinics)	0.261 (23%)
Cost of time lost to illness	0.424(40%)
DALYs (valued at GDP per capita)	0.398(37%)
TOTAL	1.089

Table 12: Baseline Data for Cost Estimation

	Baseline	**Source:**
Cost Data for All Health End-Points:		
Cost of hospitalization (Grivnas per day)	424	Provided by the Health Risk center in Ukraine
Cost of emergency visit (Grivnas) - urban	318	
Cost of doctor visit (Grivnas) (mainly private doctors) – urban	106	
Value of time lost to illness (Grivnas per day)	21	Based on urban wages in Kiev-Zaporizhya

Table 13. Weight of different mortality causes in Russia and Ukraine
Actual numbers (and rates per 100,000 of population)

	Russia	**Ukraine**
All causes death	2,225,332 *(1540)*	758,082 *(1539)*
Air pollution*	85,000 *(59)*	27,000 *(55)*
TB total	29,800 (*21)*	11,000 (*22)*
External all causes	312,000 *(216)*	41,000 *(83)*
Transport accidents	39,500 (*27)*	7,000 *(14)*
Poisoning	59,500 *(41)*	14,000 *(28)*
Suicide	57,000 *(39)*	14,500 *(29)*
Assault	41,000 *(28)*	6,400 *(13)*
Total population thousand	144,500	49,246
* Our estimation based on primary data and concentration of TSP in the most polluted cities		

Source: 2000 WHO; authors estimation

Figure 1. The share of exposed population and health end-points in the most and least polluted cities in Ukraine (for cities with the pollution load more 5%)

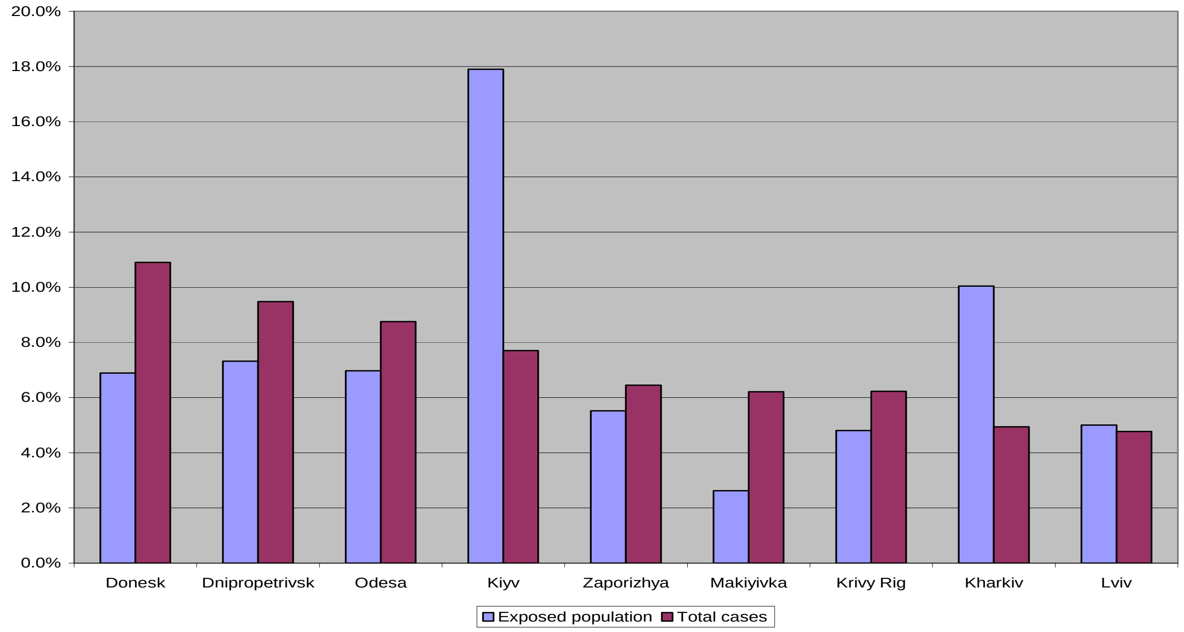
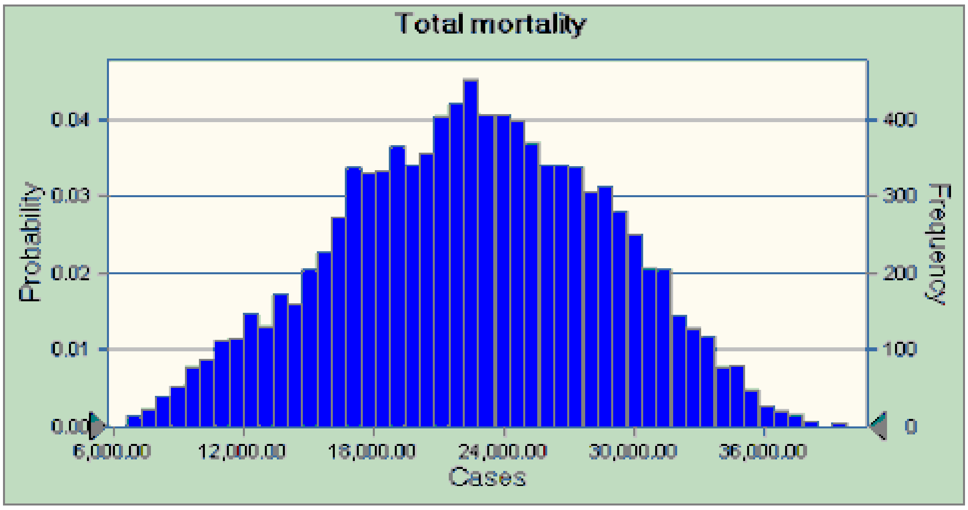
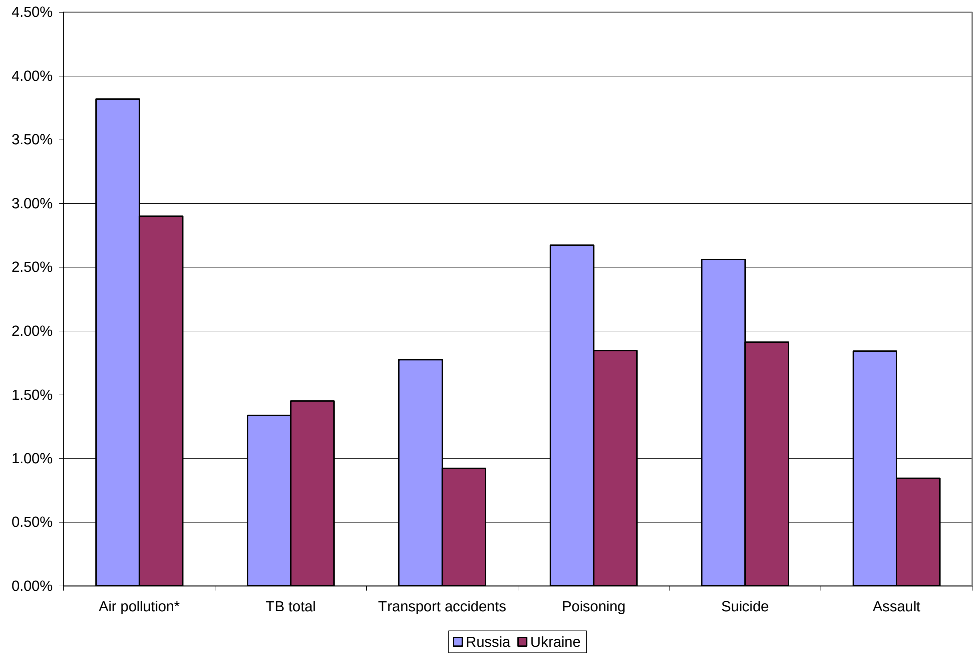


Figure 2: Sensitivity Range for Mortality Costs



	Forecast values
Trials	10,000
Mean	22,530.38
Median	22,627.51
Standard Deviation	6,171.81
Variance	38,091,180.30
Minimum	6,608.78
Maximum	43,849.00
Mean Std. Error	61.72

Figure 3: Share of different mortality causes in total mortality of Russia and Ukraine.



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(lxxviii) This paper was presented at the Second International Conference on "Tourism and Sustainable Economic Development - Macro and Micro Economic Issues" jointly organised by CRENoS (Università di Cagliari and Sassari, Italy) and Fondazione Eni Enrico Mattei, Italy, and supported by the World Bank, Chia, Italy, 16-17 September 2005.

(lxxix) This paper was presented at the International Workshop on "Economic Theory and Experimental Economics" jointly organised by SET (Center for advanced Studies in Economic Theory, University of Milano-Bicocca) and Fondazione Eni Enrico Mattei, Italy, Milan, 20-23 November 2005. The Workshop was co-sponsored by CISEPS (Center for Interdisciplinary Studies in Economics and Social Sciences, University of Milan-Bicocca).

(lxxx) This paper was presented at the First EURODIV Conference “Understanding diversity: Mapping and measuring”, held in Milan on 26-27 January 2006 and supported by the Marie Curie Series of Conferences “Cultural Diversity in Europe: a Series of Conferences.

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