Air Pollution Deaths in Europe 2020: A Survey*

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Abstract

This paper discusses air pollution mortality in Europe by projecting future incomes and the associated air pollution until 2020. A gravity model for transboundary emissions is introduced to investigate the role of emission trade between countries. Important determinants of air pollution deaths, such as urbanization and technical progress in medicine are evaluated. The results show that in spite of considerable increase in incomes, air pollution and induced deaths will decrease in most countries.

Journal of Economic Literature: Q01, Q53, Q54, J11

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1 Introduction

How much will economic growth increase the number of air pollution deaths in the future? To answer this question several sub.questions arise. How to model transboundary emissions and their deposition into far distance sources? How big will economic growth be in the future? Does the number of exposed people increase through population growth and urbanization? Will the survival rates of them stay constant? This paper discusses air pollution mortality in Europe by projecting future incomes and the associated air pollution until 2020.

The first building block of this research is the pioneer work performed by the Clean Air for Europe (CAFE) and WHO. These works provide estimates for emissions of several air pollutants and the related premature deaths in Europe, showing that there is some 350 000 such deaths annually. In projecting the future deaths, we build on these pioneer works. This, however, poses considerable methodological limitations to our research, since the data is available only for one single year (year 2000), being thus very limited in number.

The second building block is the well-known Environmental Kuznets Curve (EKC) decomposition, suggesting that per capita pollution depends on three competing effects (technology, composition, and scale) such that the dominance between these effects dictates the respond of pollution to economic growth (Arrow et al. 1995). The EKC decomposition is an important tool in solving the missing data problem because it makes possible to derive country-specific conclusions from cross-sectional association by allowing us to concentrate on individual effects rather than on their potentially complex combination.

The third building block is the gravity model, known for economists from the theory of international trade, here applied to understand "trade" of emissions between countries. Given that deposits from far-distance sources is often as important as domestic emission, we provide here a model to think and quantify these deposits.

The paper is organized as follows: Section 2 introduces the gravity model and Section 3 works out future incomes, population, and emissions by applying the EKC decomposition. Section 4 collects these results to evaluate European air pollution deaths with country-specific results and Section 5 provides a sensitivity analysis. Section 6 discusses the findings and closes the paper. The appendix contains the data.

2 Transboundary Emissions.

Meteorology has applied several methods to evaluate transboundary air pollution. The so called receptor method calculates the upwind back-trajectories for the deposits observed in the field data to discover their sources (e.g., Niemi et al. 2009) while the dispersion method calculates the sectoral downwind trajectories to determine the destination of emissions emerging from a given source. Some methods are based on well-developed theory, such as the Gaussian plume model of aerosol dispersion, while some derive from statistical and simulation techniques (Moussiopoulos et al. 2004, Borge et al. 2007). A perfect $(m \times n)$ receptor-source matrix reports all m sources and n receptors of some pollutant. It is also possible to calculate the so called intake fraction, showing the share of deposit from other than domestic sources (Greco et al. 2007). For a critical analysis of these methods, see Scheringer 2009.

This paper proposes that the principal elements of transboundary pollution can be best understood by applying the concept of gravity, already familiar to economists from the theory of international trade (McCallum 1995, Helliwell 1998, Harrigan 2003). The original gravity equation

$$G_{1,2} = \frac{M_1 M_2}{{d_{1,2}}^2}$$

suggests that gravity between two subjects is dictated by their masses M_1 and

M_1 and by their squared distance $d_{1,2}$. This gravity equation has been utilized by the theory of international trade which claims that the bilateral trade between two countries depends on their incomes and distances. Analogously, we propose that the bilateral emission-trade obeys

$$D_{1,2} = \frac{E_1 E_2}{{d_{1,2}}^2}, \tag{1}$$

in which $D_{1,2}$ refers to net deposits (i.e., net import) from country 2 to country 1 and E refers to emissions.[1] Important are also the trade cost of trading, the counterpart of which are the wind directions since it is much "cheeper" to trade emissions downwind than upwind. As the scale factor, the geographical size of the economy is important.

Trade, however, is seldom bilateral. Emissions are imported and exported with third partners even from far-distance locations whereas some of the produced emissions are "consumed" within domestic borders. Therefore, "[t]he trick is to find a parsimonious way of summarizing the salient aspects..." of multilateral emission trade (Helliwell 1997). To that end, we make the simplifying assumption that EU_{25} is a closed emission-trading area, indicating that its net trades with other partners is zero.[2] Therefore, after subtracting the intraboundary deposits (IBD), the transboundary emissions (TBE) from EU_{25} are distributed to its own members according to their geographical location, wind position, and areal share. In what follows, instead of calculating all emission-trade flows, we follow the tradition of trade theory and propose a practical solution to evaluate the factors dictating the distribution of TBE in a form of indexes and produce a combined a combined index which shows how vulnerable a given country is to TBE.

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[1] In trade theory Wei (1996) uses the linear weight 1/2 for distance whereas Helliwell (1997) estimates that the logarithm of distance gets weight -1.5. To our knowledge, no unequivocal rule says what for would be most suitable for distance in emission-trade, but we start with the squared formula.

[2] The most important of these partners are Russia, Belarus, and Turkey, all of which are heavy polluters, yet located in the downwind direction from EU_{25}.

Although the available mortality numbers refer to several pollutants, most deaths are caused by particulate matter (WHO 2004). Furthermore, as particulates are closely associated with other pollutants, they can be used as an *indicator* of outdoor air pollution (Cohen et al. 2004). Thus, we concentrate on particulate matter here.[3] The data comes from Amann et al. (2007), who report the $PM_{2.5}$ emissions for 25 European countries (EU_{25}) for the year 2000. Appendix A gives the list of countries together with mortality and emission data.

To calculate the transboundary emissions, we derive from the gravity theory where masses are thought as concentrated to gravity centers. Analogously, think country i as a circle with radius r and area $A_i = \pi {r_i}^2$ such that all emissions emerge from its center, extending to the distance of $\bar{r}$ from this center. To calculate the fraction which country i with radius r_i receives from its own emissions, note that even though ratios of areas obey $A_1/A_2 = {r_1}^2/{r_2}^2$, the fact that the squared distance matters in emissions implies that the fraction of emissions deposited within own boundaries is $r_i/\bar{r}$ and the fraction of transboundary emissions is $1 - r_i/\bar{r}$. Unfortunately, little has been said about the role of maximal distance $\bar{r}$ for air pollution emissions. Greco et al. (2007) found that the median distance in the United States for the intake fraction of 50% is 150 km in cases where the $PM_2.5$ emission originates from mobile sources, i.e., from cars, but some deposits are measured in a distance of 1800 km. Fixed sources such as heating plants with long pipes are also important sources, sending their emissions to more remote goals. Given the great uncertainty, we assume that the maximal (effective) extension of $PM_2.5$ emissions is $\bar{r} = 750$ km but in the end of this research, we provide a complete sensitivity analysis in terms of the ef-

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[3] Particulate matter, PM, is solid airborne particles of varying size, chemical composition, mainly generated by energy combustion (mobile or fixed site), often also from long-distance sources. Particulate matter is further classified according to its maximum diameter size, the main groups being $PM_{2.5}$ and PM_{10} with maximal diameters of 2.5 and 10 μm respectively.

fects of distance. Thus, following the rule $IBD_i = r_i/750$ we calculated the intraboundary and transboundary emissions for each country and derived $TBE_{EU25} = \sum TBE_i = 930.79$ kilotons, presenting 59% of the total emissions of $1579,79$ kilotons produced in EU_{25}. First three column on Table 1 show the country-specific numbers.

To evaluate the destination of the TBE, note that since distance is a principal determinant of emission trade, a country located close to heavily polluting areas is most prone TBE. To capture this, we construct an index of centrality.[4] Hence, the index of centrality becomes

$$Centrality_i = \sum_{j=1}^{25} \frac{E_j}{{d_{i,j}}^2}, \tag{2}$$

where $Ej = 0$ for $d_{i,j} > 750$ and for $j = i$. Thus, centrality decreases together with distance but increases with emissions from j. Following the tradition of the trade theory, we measure the distance between countries as the distance between their capital cities. Column four on Table 1 shows the centrality index for each country, indicating that the most Belgium is the most central country, while Neither Cyprus nor Greece have (close enough) neighbors in EU_{25}.

Countries located downwind from heavy polluters suffer most. To construct an downwind index, we utilize the the fact that the cardinal wind direction in Europe is from the south-west. Therefore, in the index for country i, country j receives the value $w_{i,j} = 0.5$ if its capital is in south-west from the capital of i, whereas $w_{i,j} = 0.2$ if its location is south-east or north-west. Capitals in the north-east receive the value 0.1.[5] Hence, the wind index is

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[4] For the role of centrality index in trade theory, see Harrigan 2003. Alternatively, one can use an index of remoteness, which is the inverse of (2).

[5] When working with this first version of the paper, complete wind statistics is not available yet. In the final version, we will replace these assumed approximate values by their statistical counterparts.

$$Downwind_i = \sum_{j=1}^{25} w_{i,j}, \tag{3}$$

with $wi, j = 0$ for $d_{i,j} > 750$ and for $j = i$. Table 1 shows that the highest values arise in Germany and Poland.

In the trade of goods, the scale of the economy is said to matter (Harrigan 2003). In emissions, the scale is important because large countries capture the major fraction of tradable emissions. Hence, we also calculate an area index

$$Area_i = \frac{A_i}{\sum\limits_{j=1}^{25} A_j}. \tag{4}$$

Thus, the centrality, downwind, and area indexes together capture how vulnerable a country is to transboundary emissions. Given that EU_{25} is a closed emission-trading area, all TBE from EU_{25} falls to its member countries according to the rule

$$TBD_i = TBE_{EU25} \times \frac{Centrality_i \times Downwind_i \times Area_i}{\sum\limits_{i=1}^{25} Centrality_i \times Downwind_i \times Area_i}, \tag{5}$$

where TBD_i is the transboundary deposits in country i and $Centrality \times Downwind \times Area$ is the (unweighed) combined index implying that largest shares of TBE_{EU25} go to big, central, downwind countries. These shares are shown in column seven on Table 1. olumn eight reports the intraboundary deposition and the las column adds both types of deposits to total deposits D. To take an example, note that from the emissions of $E = 28.26$ kilotons, Finland delivers $TBE = 15.90$ kilotons and consumes domestically $IBD = 12.36$ kilotons. Given that its imports are $TBD = 58.59$ kilotons, its total deposits become $D = 70.95$ kilotonns, i.e., Finland is a net importer of air pollution.

Country aa	Emissions E	Radius r	TBE	Centrality	Down wind	Area	TBD	IBD	Deposits D
Austria	28.18	163.39	22.04	1.39	1.30	0.02	40.99	6.14	47.12
Belgium	32.86	98.58	28.54	2.07	1.30	0.01	22.27	4.32	26.59
Cyprus	2.18	54.26	2.02	0.00	0.00	0	0.00	0.16	0.16
Czech Rep.	42.69	158.44	33.67	1.61	2.50	0.02	86.18	9.02	95.20
Denmark	25.97	117.12	21.91	0.93	1.30	0.01	14.11	4.06	18.16
Estonia	21.69	119.98	18.22	0.47	1.00	0.01	5.77	3.47	9.24
Finland	28.26	328.08	15.90	0.38	1.70	0.08	58.59	12.36	70.95
France	328.23	453.26	129.86	0.52	0.50	0.16	45.15	198.37	243.52
Germany	159.86	337.11	88.01	0.89	2.90	0.09	250.50	71.85	322.35
Greece	47.32	204.93	34.39	0.00	0.00	0.03	0.00	12.93	12.93
Hungary	52.38	172.08	40.36	0.95	1.40	0.02	33.52	12.02	45.53
Ireland	14.16	149.57	11.34	0.24	0.20	0.02	0.90	2.82	3.72
Italy	150.27	309.65	88.23	0.10	0.40	0.07	3.27	62.04	65.31
Latvia	10.93	143.39	8.84	0.66	1.70	0.02	19.62	2.09	21.71
Lithuania	12.5	141.05	10.15	0.68	1.30	0.02	15.02	2.35	17.37
Luxemb.	2.73	0.91	2.73	1.98	1.50	0	0.00	0.00	0.01
Malta	0.59	10.03	0.58	0.22	0.20	0	0.00	0.01	0.01
Netherl.	26.78	114.97	22.67	1.65	2.10	0.01	39.01	4.11	43.12
Poland	202.7	315.48	117.43	0.66	2.60	0.08	144.65	85.27	229.91
Portugal	76.99	171.49	59.39	0.30	0.10	0.02	0.75	17.60	18.36
Slovak Rep.	14.5	124.69	12.09	1.54	1.50	0.01	30.64	2.41	33.05
Slovenia	12.08	80.33	10.79	0.91	1.40	0	7.02	1.29	8.32
Spain	151.14	400.85	70.36	0.15	0.50	0.12	10.47	80.78	91.25
Sweden	25.4	378.45	12.58	0.22	1.20	0.11	32.43	12.82	45.24
United Kgd.	109.4	279.16	68.68	1.17	0.90	0.06	69.96	40.72	110.68
Sum	1579.79		930.79				930.79	649.00	1579.79

Table 1: Calculating transboundary emissions TBE, intraboundary and transboundary deposits IBD and TBD, and total deposits D.

3 Emissions and Economic growth.

3.1 The EKC-decomposition.

The Environmental Kuznets Curve hypothesis claims that pollution first increases but then decreases along with economic growth as the pollution-intensity of output initially grows but adoption and implementation of cleaner techniques and a more important role of services ultimately changes this trend. On the other hand, the scale effect triggered by increasing per capita output and population has the opposite effect on pollution. The net effect depends on the dominance between the pollution-decreasing technology-composition effect and the pollution-increasing scale effect. Testing this hypothesis is not the scope of this paper but the proposed decomposition is of use where missing data makes it impossible to evaluate the effects of economic growth on pollution at a country-specific level.

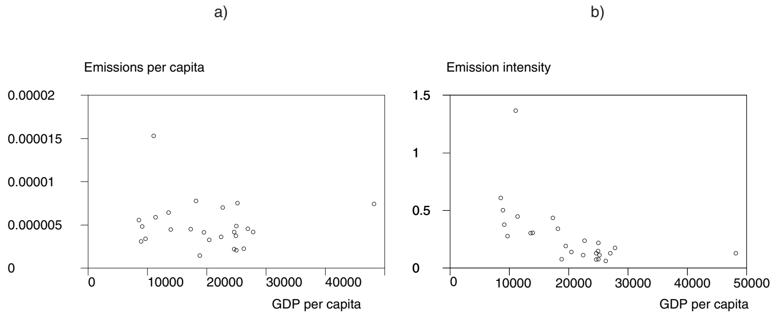

Figure 1: Emissions per capita and the emission intensity of output as a function of per capita GDP.

Usually, the EKC decomposition has been utilized by regressing per capita emissions against per capita incomes. This standard way is, however, inefficient for our purposes because if does not discriminate between two competing effects. As different countries can reach the switch-of-dominance point at different levels of incomes, the country-specific rule can not be revealed from cross-sectional correlation. Furthermore, this standard correlation may be weak, as has been shown in pane a of Figure 1, but if one concentrates on emission intensity of output, a clear correlation can be revealed, as is shown by panel b of Figure 1. Once this cross-sectional correlation is known, the roles of incomes and population can be calculated at country-specific level.

The theory presupposes that emissions intensity increases at low levels of income but because all members in EU_{25} are industrial countries, the observations seem to follow a log-linearly decreasing trend, so that we propose the formula $\phi = \alpha \cdot GDPpc^{\beta}$. By taking logs, we thus fit

$$\ln\ \phi_{i,2000} = \ln\ \alpha + \beta \cdot \ln\ GDPpc_{i,2000} + \varepsilon_i \tag{6}$$

by OLS, to derive the estimates $\alpha = 56298.77$ and $\beta = -1.27$. Formula (6) explains 55% of the cross-country variation in ϕ. Figure 2 illustrates the estimated function.

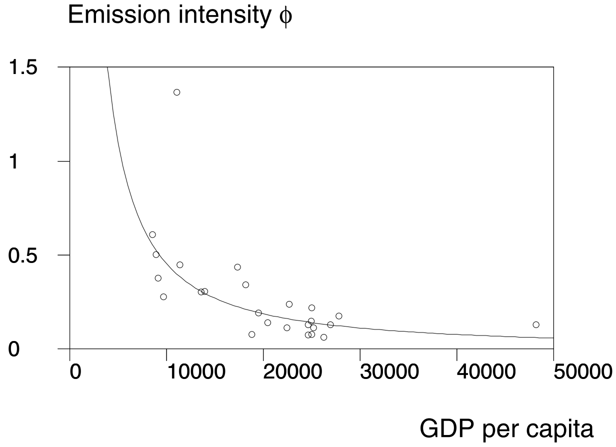

Figure 2: Emission intensity of output as a function of per capita GDP in 2000. 25 EU countries.

The cross-sectional relationships for emission intensity $\phi = E/GDP$ implies

$$E = \phi \cdot GDP = \phi \cdot GDPpc \cdot L = 56298.77 \cdot GDPpc^{-0.27} \cdot L,$$

showing that the elasticity of emissions in terms of $GDPpc$ (population) is a negative (positive) constant. Hence, given (6) and (7), on can derive the country-specific emission function $E = \phi * GDP$

$$E_{i,t} = l_i \cdot 56298.77 \cdot GDPpc_{i,t}^{-0.27} \cdot L_{i,t}, \tag{7}$$

both backwards and forwards. The multiplicative country-specific fixed factor $l_i = \varepsilon_i / \phi_{i,2000}$ is derived from the residual error in (6). Equation (9) shows that, in spite of decreasing emission intensities, emissions themselves may increase or decrease, depending upon the growth rate of $GDPpc$ and population L.[6]

3.2 Income, Population, and Emissions

In this paper, we provide estimates for emissions for the year 2020. To that end, we project per capita GDPs for all countries by applying linear trends with country-specific breaks allowed in period 1973-1982 and in period 1990-1992. The former window refers to the oil crises and the latter to the collapse on the Soviet Union. Column 1 shows the projected per capita incomes for 2020, column 2 reports the years of breaks, and column 3 reports R^2 for each regression, the average R^2 being 95%. The projected average growth rate is 2.5%.

To give population in 2020, we utilize the projections provided by the United Nations (2007). These projections are available in low, medium, and high variants, of which the medium variant numbers are shown in column 4 of Table 2.

Figure 3 illustrates the results in Table 2 by showing its main numbers as an index, the base year of which is 2000. The average growth rate of 2.5% increases the incomes on the average of 70%. In general, this increase is rather unequivocal, but the projected economic growth for Ireland is exceptionally high ($6.2, \%$) implying that its income increases to more that three fold and

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[6] The analysis here is subject to several open question. The first of them is, to which extend the EKC approach is able to take the new innovations into account. Another is, what is the role of legislation and, finally, is EKC irreversible or not. These topics will be discussed in later versions of this paper.

Country	GDPpc	R^2	Growth %	POP (1000)	POP growth %	Emissions E	Deposits D
Austria	35969	1.00	1.43	8575.29	0.29	27.60	43.82
Belgium	34249	1.00	1.64	10684.12	0.18	31.15	24.63
Cyprus	38546	0.99	3.17	975.21	1.26	2.36	0.17
Czech Re.	18041	0.70	1.41	10042.94	-0.11	38.67	87.66
Denmark	36473	0.99	1.35	5543.82	0.19	25.04	16.92
Estonia	19161	0.53	2.74	1277.64	-0.57	16.67	7.99
Finland	29744	0.99	1.34	5433.57	0.24	27.56	66.10
France	33673	1.00	1.48	64824.74	0.45	331.04	241.71
Germany	31097	1.00	1.08	81160.69	-0.07	148.54	297.83
Greece	23041	0.99	2.5	11274.29	0.13	42.41	11.59
Hungary	21036	0.98	3.07	9620.66	-0.3	41.66	40.48
Ireland	86217	0.99	6.2	5055.46	1.43	13.42	3.51
Italy	28575	1.00	1.2	58600.98	0.08	142.90	62.01
Latvia	22170	0.96	4.51	2133.68	-0.6	7.58	19.55
Lithuania	22383	0.93	4.47	3187.83	-0.64	8.62	15.47
Luxemb.	87983	1.00	3.01	538.28	1.06	2.86	0.01
Malta	28827	1.00	2.12	426.48	0.43	0.57	0.01
Netherl.	36460	0.99	1.63	16760.03	0.26	25.82	39.94
Poland	17348	0.96	3.5	37079.18	-0.21	160.58	200.97
Portugal	26911	0.99	2.2	10790.29	0.27	72.03	17.16
Slovak Re.	17921	0.94	3.07	5365.85	-0.03	12.18	30.29
Slovenia	32081	0.88	2.83	1972.28	0.11	10.59	7.61
Spain	29745	1.00	2.1	46445.21	0.66	153.69	91.80
Sweden	35434	1.00	1.7	9652.45	0.42	25.17	42.61
United Kgd	40002	1.00	2.42	64033.23	0.44	104.62	103.47
Sum/Aver.	33323	0.95	2.49	471454.2	0.21	1473.32	1473.32

Table 2: Income, population, emissions, and depositions in 2020.

Ireland jumps ahead in its emissionintensity-income curve. On the other hand, Ireland will face the highest population growth, staggering the decrease of its emissions.

The growth differential between the old and new EU members is considerable as the income in the former group increases to index number 159, whereas the index number in the latter group is 1993. On the other hand, the projected population growth in new members is so low, that population decreases (index 94), whereas the demographic increase in the old old members still continues (index 110). Given that economic growth decreases but demographic growth increases pollution, the new members are able to diminish their emissions faster than old members.

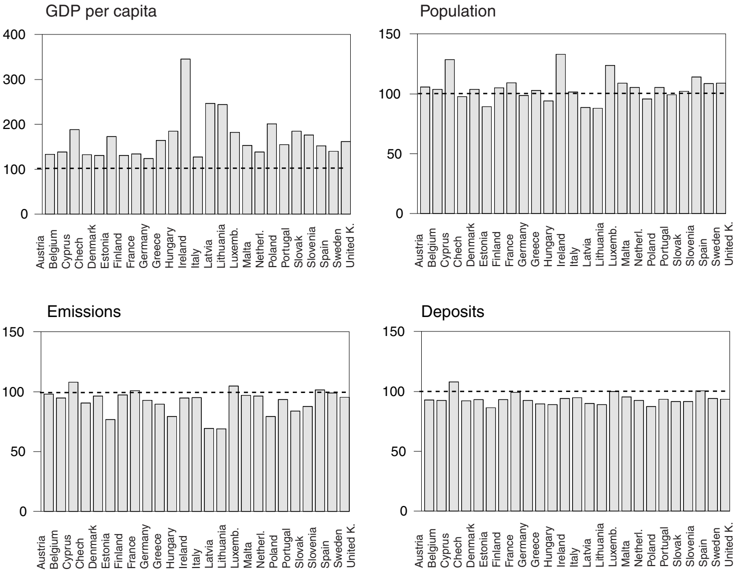

Figure 3: A comparison between years 2000 and 2020. Year 2000=100.

4 Deaths

Air pollution causes several unwanted health consequences from harmless aye irritation to death (Samet et al. 2000, Brunekreef and Holgate 2002, Pope et al. 2002). In this paper, we concentrate on deaths. *CAFE*, the Clean

Air for Europe program and WHO have recently provided summary estimates of mortality caused by short-term exposure in Europe by collecting 629 time-series and 160 individual or panel studies that regress daily mortality against daily changes in outdoor air pollution (WHO 2004). These summary estimates show that there is a significant response in mortality to particulate matter, PM, and ozone. Pope et al. (2002) have analyzed the effects of long-term PM exposures in the United States in a study in which questionnaires monitored individuals from 1982 onwards, making control for other risk sources possible. Their estimates were applied to the European data to derive the effects of long-term exposure; the short-term and long-term exposures together induced more than 300 000 premature deaths in 2000 in Europe (WHO 2004).[7]

Let

$$M = \eta D, \tag{8}$$

where M refers to air pollution deaths and D to total deposits, either from intraboundary or transboundary sources. The parameter $\eta = M/D$ controls for social factors such as population, urbanization, and medical care, but also some geographical factors (latitude) and weather conditions, which vary from country to country. An example is that warm climate may increase the probability of skin cancer from air pollution due to less protective clothing. Many of these factors keep constant but some change and we concentrate on them. The driving forces to change in η are population growth and the growth rate of urbanization, both of which increase the number of exposed people. On the other hand, persistent technical progress in medicine tends to improve the survival rates of the exposed people.

Of these factors, population growth has been discussed earlier (column

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[7] For methodological issues in epidemiological studies, see Chay et al. (2003). For studies on infant mortality, see Chay and Greenstone (2003) and Currie and Neidell (2005). For techniques for deriving country-level mortality estimates, see Ostro (2004).

5 Table 2). To evaluate the growth of urbanization, we regress the rate of urbanization against $1/time$; no breaks in this non-linear trend is allowed. Column 4 on Table 3 shows the country-specific estimates for the implied average annual growth of urbanization together with the values of R^2. To evaluate the increase in survival, note that most air pollution deaths come through cardiovascular and pulmonary diseases in the old age. The data from the United Nations (2007) shows that the life-expectancy in the age group 65+ has increased on the average by 0.80% annually (column 3, Table 3), and we take this number as the measure of increased survival.

To collect, given that average annual population growth (0.21%) and urbanization (0.23%) increases the number of exposed people less than what their survival rate increases (0.80%), the mortality factor η will decrease (column 4 of Table 3). Given that there also is a slight decrease in deposits D (D_{2020} in Table 2), the number of deaths, counted by the rule $M_{2020} = \eta_{2020} D_{2020}$ will decrease. This is shown in Column 7 on Table 3. However, great variation exists between countries. To illustrate this, we constitute again an index shown in Figure 4. This index indicates that even if mortality decreases in most European countries, some countries seem to suffer from increase. Since such an unequal development is unlikely, and mainly seems to be due to uncertainties in transboundary emissions, we perform a sensitivity analysis to see, how the elements discussed above change the now-derived results.

5 Sensitivity Analysis

5.1 The Role of Emission Intensity

The theory presupposes that for low levels of income emissions intensity of output increases, making the emission function hump-shaped. For such a function, several formulas are available but the choice between the candidates is difficult since the data does not support the hump. In this paper, we

Country	M 2000	η 2000	POP growth %	Growth urb %	Dlifex 65+ %	Change in η	M 2020
Austria	5508	388.39	0.29	0.01	0.95	0.88	4287
Belgium	12904	1524.36	0.18	0.01	0.32	0.97	12649
Cyprus	231	112.8	1.26	0.41	0.76	1.2	300
Czech Re.	9086	480.43	-0.11	0.28	0.4	0.96	12735
Denmark	3274	205.22	0.19	0.13	0.8	0.91	2189
Estonia	631	20.25	-0.57	0.26	0.83	0.8	220
Finland	1272	4.93	0.24	0.5	0.8	0.99	764
France	42202	173.01	0.45	0.12	0.65	0.98	34417
Germany	75150	583.65	-0.07	0.02	0.95	0.82	85606
Greece	7242	329.37	0.13	0.28	0.12	1.06	6888
Hungary	12895	658.54	-0.3	0.2	0.82	0.83	9401
Ireland	1174	52.18	1.43	0.11	1.29	1.05	554
Italy	50766	771.77	0.08	0.11	0.92	0.86	38667
Latvia	1334	38.41	-0.6	0.29	0.89	0.79	651
Lithuania	2197	76.99	-0.64	0.45	0.64	0.85	921
Luxemb.	321	112300.77	1.06	0.06	0.62	1.11	387
Malta	193	6926.09	0.43	0.15	1.02	0.92	79
Netherl.	15573	1291.51	0.26	0.72	0.61	1.08	22604
Poland	32944	228.08	-0.21	0.16	1.18	0.78	26100
Portugal	5053	169.36	0.27	-0.12	0.93	0.85	3279
Slovak Re.	4265	541.73	-0.03	0.43	0.7	0.94	3740
Slovenia	1582	569.94	0.11	0.51	1.25	0.88	1402
Spain	19976	148.58	0.66	0.23	1.04	0.97	18283
Sweden	3284	12.96	0.42	0.12	0.43	1.02	1887
United Kgd	39543	491.3	0.44	0.26	0.86	0.97	31261
Sum/Aver	348599		0.21	0.23	0.79	0.94	319270

Table 3: Mortality in 2020.

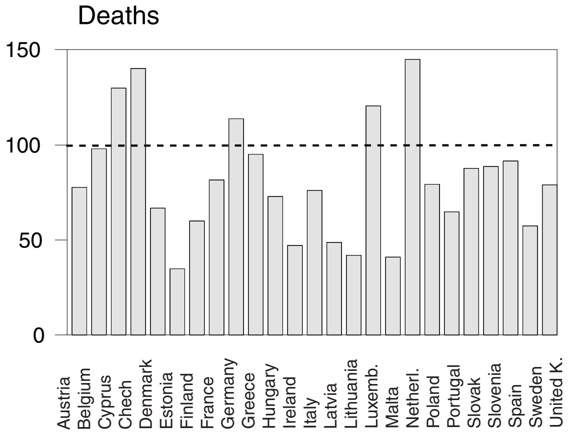

Figure 4: Mortality index in 2020.

propose the formula $\phi = \gamma \cdot Exp(\delta \cdot GDPpc^{0.3}) \cdot GDPpc$, the exponent 0.3 being chosen to locate the peak of the hump left of the observations, indicating that all countries of the sample have by-passed it. Thus, by taking logs we estimate

$$\ln\left(\phi_{i,2000}/GDPpc_{i,2000}\right) = \ln\ \gamma + \delta \cdot\ {GDPpc_{i,2000}}^{0.3} + \varepsilon_i \tag{9}$$

to derive the estimates $\gamma = 0.022$ and $\delta = -0.395$. Formula (9) explains 78% of the cross-country variation in ϕ. Pane a in Figure 5 illustrates the estimated function. One can now calculate $E = 0.022 \cdot Exp[-0.395 \cdot GDPpc^{0.3}] \cdot GDPpc^2 \cdot L$, suggesting that

$$E_{i,t} = k_i \cdot 0.022 \cdot Exp[-0.395 \cdot {GDPpc_{i,t}}^{0.3}] \cdot {GDPpc_{i,t}}^2 \cdot L_{i,t},$$

where $k_i = \varepsilon_i/\phi_{i,2000}$ is derived from the residual error in (9). Repeating the steps to calculate transboundary emissions and depositions, on can evaluate the associated deaths, shown in panel b of Figure 5. In this version, the projected total annual in 2020 is only slightly smaller (282 232) than in the basic model, but the difference is that the decrease in deaths is much more evenly distributed among countries because of the better fit of the humped curve. Therefore, one of the future challenges is to find the better humshaped formula to describe the emission intensity as accurately as possible.

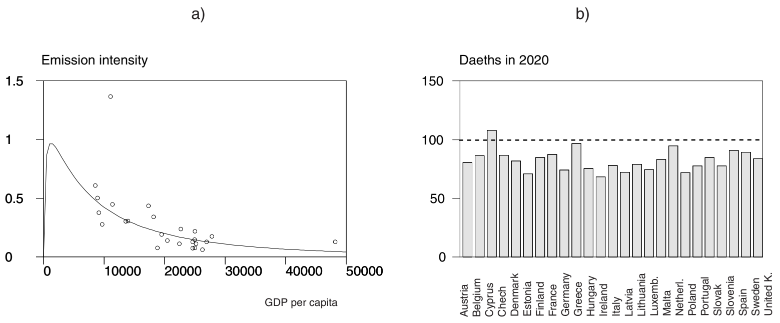

Figure 5: Hump-shaped emission intensity and the associated deaths in 2020.

6 Conclusions

This paper evaluates much will economic growth increase the number of air pollution deaths in the future. By building on the pioneer work performed by the Clean Air for Europe (CAFE) and WHO, we estimate air pollution deaths in 25 EU countries in 2020. The results of this working paper show that air pollution deaths are likely to decrease in the future.

However, given the limited availability of the date, the main interest in this working paper is methodological. We apply the Environmental Kuznets Curve (EKC) decomposition, suggesting that per capita pollution depends on three competing effects (technology, composition, and scale) such that the dominance between these effects dictates the respond of pollution to economic growth, to solve the missing data problem because it makes possible to derive country-specific conclusions from cross-sectional association by allowing us to concentrate on individual effects rather than on their combinations.

Transboundary emissions and deposits are evaluated by the gravity model to understand "trade" of emissions between countries. This approach seems to consist the important elements of transboundary emissions, but the main shortcoming is that, due to missing data, we an only calculate some results without any appropriate estimates and tests about their reliability. Hence, the main challenge in the future is to find data making such testing possible.

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A Appendix: Countries and Variables

Country	Isocode	$PM_{2.5}$	Death rate	Deaths
Austria	AUT	28.18	0.00068	5508
Belgium	BEL	32.86	0.00125	12904
Denmark	DNK	25.97	0.00061	3274
Finland	FIN	28.26	0.00025	1272
France	FRA	328.23	0.00071	42202
Greece	GRC	47.32	0.00066	7242
Hungary	HUN	52.38	0.00126	12895
Ireland	IRL	14.16	0.00031	1174
Italy	ITA	150.27	0.00088	50766
Netherlands	NLD	26.78	0.00098	15573
Portugal	PRT	76.99	0.00049	5053
Spain	ESP	151.14	0.00049	19976
Sweden	SWE	25.40	0.00037	3284
United Kingdom	GBR	109.40	0.00068	39543
Cyprus	CYP	2.18	0.00030	231
Czech Rep.	CZE	42.69	0.00088	9086
Estonia	EST	21.69	0.00044	631
Germany	GER	159.86	0.00091	75150
Latvia	LVA	10.93	0.00055	1334
Lithuania	LTU	12.50	0.00061	2197
Luxembourg	LUX	2.73	0.00074	321
Malta	MLT	0.59	0.00049	193
Poland	POL	202.70	0.00085	32944
Slovak Rep.	SVK	14.50	0.00079	4265
Slovenia	SVN	12.08	0.00082	1582
EU_{25} (Total / Average)		1579.79	0.00068	348600

All numbers refer to year 2000. $PM_{2.5}$ emissions in kilotons (Amann et al. 2007), deaths refer to premature air pollution induced deaths (WHO 2004). In addition, annual series from 1950 (from 1970 for Hungary) for GDPpc, (Heston et al. 2006) and urbanization (World Bank 2009). Population projections and and life expectancies from the United Nations (2007).