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Association between unemployment, income, education level, population size and air pollution in Czech cities: Evidence for environmental inequality? A pilot national scale analysis

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ABSTRACT

We analyzed differentials in exposure to SO_2, PM_{10} and NO_2 among Czech urban populations categorized according to education level, unemployment rate, population size and average annual salary. Altogether 39 cities were included in the analysis. The principal component analysis revealed two factors explaining 72.8% of the data variability. The first factor explaining 44.7% of the data variability included SO_2, PM_{10}, low education level and high unemployment, documenting that inhabitants with unfavorable socioeconomic status mainly reside in smaller cities with higher concentration levels of combustion-related air pollutants. The second factor explaining 28.1% of the data variability included NO_2, high salary, high education level and large population, suggesting that large cities with residents with higher socioeconomic status are exposed to higher levels of traffic-related air pollution. We conclude that, after more than a decade of free-market economy, the Czech Republic, a former Soviet satellite with a centrally planned economy, displays signs of a certain kind of environmental inequality, since environmental hazards are unevenly distributed among the Czech urban populations.

1. Introduction

In spite of the fact that the field of environmental justice suffers from many conceptual and methodological shortcomings (e.g. Schweitzer and Stephenson, 2007; Bowen, 2002; Buzzelli, 2007), research has documented that (sub)populations and/or minorities with low socio-economic status (SES) are disproportionately affected by environmental hazards (Asch and Seneca, 1978; Brown, 1995; Bullard et al., 2007; Diekmann and Meyer, 2010; Havard et al., 2009; Higginbotham et al., 2010; Jerrett, 2009; Laurian, 2008; Maantay, 2002; Mitchell and Dorling, 2003; O'Neill et al., 2003; Perlin et al., 1995; Pearce, et al., 2006).

For almost four decades, the debates about environmental justice were mostly limited to the territory of the USA (Asch and Seneca, 1978; Brown, 1995). Only recently has the issue of uneven distribution of environmental pollution among populations with different socioeconomic status entered into discussions in Europe and other continents (Walker, 2009). However, to date very little attention has been paid to this problem in the so-called transition post-communist countries of the former Soviet block (Wojtyniak et al., 2001).

The Czech Republic is one of the countries belonging to this political structure in the past. In 1948, after the Second World War, this central European country found itself in the sphere of the Soviet empire. Private property was seized by the socialist government (the private sector was practically non-existent in Czechoslovakia before 1989), the economy became centrally planned, employment of the employable part of the population was compulsory (the right to a job was adopted by parliament), the social welfare system was represented by universal paternalistic general social security, guaranteed pensions and a "free-of-charge" centralized health system. Even though there were some differences in individual incomes, salaries were more or less uniform (Machonin, 1970; Adam, 1993; Illner, 1998).

In 1989, as in other former Soviet satellite countries, the communist regime collapsed in the Czech Republic. The political and economic system returned to a standard free-market type and state ownership was drastically reduced by massive privatization. Changes in the structure of the national economy affected all sectors of the economy, led to regional and land-use changes, caused salary differentiation, and unemployment and society became socio-economically stratified (Illner, 1998; Basu et al., 2005).

In the light of these trends, we decided to perform a pilot study to determine whether there is a spatial correspondence between cities exhibiting low SES of the residents and poor air quality and to discuss the possible implications of this association for environmental justice.

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We hypothesized that, after more than a decade of the free-market system, regional changes in industry, agriculture and the service sectors may have already resulted in a noticeable disproportionate distribution of environmental pollution imposed on local populations.

Our research took advantage of the good statistical records of various social and economic variables, the high standard of air quality monitoring and good access to these data in the Czech Republic.

2. Data collection and analysis

A retrospective study covering the year of the 2001 Czech census was performed (CSO, 2003). Altogether, 39 Czech cities with populations of over 10,000 (10,401–1,161,938 inhabitants), for which air quality data for 2001 were available, were selected for the study (Table 1). The 2001 census results were used for the size of the population. The Czech censuses comply with the EUROSTAT guidelines (EUROSTAT, 1999; EC, 2001). The Czech Statistical Office database was employed for the selected socio-economic variables (average annual salary, educational level, and unemployment rate). The data on education level were available in two subsets: (i) the number of inhabitants with only elementary education and (ii) the number of inhabitants with completed university education. The education and unemployment variables were used in the analysis as percentages in relative figures.

For each of the cities involved, the 2001 annual averages of SO_2 (measured by UV fluorescence), PM_{10} (particulate matter of aerodynamic diameter below 10 μm measured by beta attenuation) and NO_2 (measured by chemiluminescence) concentration data were retrieved from the Czech Hydrometeorological Institute database. The annual average data are based on daily averages which are computed from 1 h integration time measurements. Only data from the National Automated Ambient Air Quality Monitoring System (AMS) were included in the analysis. The Czech AMS consists of more than 100 fixed site monitors (FSM) situated in most cities as well as in industrial and background locations. In the urban areas, the FSMs of the AMS are mostly located in residential areas defined as "urban background". According to World Health Organization (WHO, 2000), an urban background FSM should be distanced from sources and is therefore broadly representative of city-wide background conditions. In cities where more than one FSM was in operation, we used the arithmetic average of all of them, excluding the curb-site (hot spot) monitors. The locations of all FSMs in the national network (i.e. all included in the present study) meet the WHO standards (WHO, 2000) as well as the European Commission air quality monitoring guidelines set for community exposure assessment (EC, 2008). The network of FSMs in the Czech Republic is among the densest in Europe (Hunova, 2001).

Table 1
A list of cities included in the analysis.

Settlement	Population	No. of FSMs	Settlement	Population	No. of FSMs
Beroun	17481	1	Mlada Boleslav	43544	1
Bohumin	23116	1	Most	68028	1
Brno	370505	8	Olomouc	101624	2
Ceské Budejovice	95986	2	Opava	60731	1
Cesky Tesin	26184	1	Orlova	34488	1
Decin	52155	1	Ostrava	314102	4
Frydek–Mistek	60603	1	Pardubice	89725	2
Havirov	85271	1	Plzen	164703	8
Havlickuv Brod	24320	1	Praha	1161938	15
Hodonin	26575	1	Prachatice	11827	1
Hradec Kralové	95755	2	Prostejov	47678	1
Chomutov	50514	1	Prerov	47582	1
Jablonec nad Nisou	44991	1	Sokolov	24999	2
Jesenik	12517	1	Studenka	10401	1
Karvinna	64146	1	Svitavy	17538	1
Kladno	70328	2	Trinec	38530	2
Klatovy	22873	1	Ústi nad Labem	94544	3
Kolin	29817	1	Ústi nad Orlicí	15082	1
Krupka	13513	1	Zdar nad Sazavou	24028	1
Liberec	97677	1	–	–	

Settlement—name of the city; Population—number of inhabitants according to the 2001 census; no. of FSMs—number of fixed site monitors of the National Air Quality Monitoring network included in the analysis.

For the purpose of the present study, the average SO_2 and PM_{10} concentrations were considered to be surrogates for solid fuel combustion (Junninen et al., 2009), while the NO_2 concentration was taken as an indicator of automobile exhaust emissions (Grice et al., 2009).

In contrast to the majority of papers so far addressing the issue of environmental justice using linear regression models, we employed Principal Component Analysis (PCA). PCA is basically a data reduction technique which is intended to find linear combinations of the original variables that account for as much of the total variance in the measured data as possible. The linear combinations fulfilling this condition are called Principal Components (PCs) and are, by definition, not correlated with each other. The first PC explains most of the variance in the data (i.e. carries most of the information about the data), the second one will then carry the maximum residual information, and so on. PCA is a special case of factor analysis that transforms the original set of inter-correlated variables into a set of uncorrelated variables. The main results of PCA are factor loadings, which reflect how much a given variable contributes to that particular PC and how well that particular PC describes the variation of that particular variable. Generally, PCA is recommended as an exploratory tool to reveal unknown trends in the researched dataset.

3. Results

The annual (2001) concentrations of selected air pollutants were in the range 5.3–15.7 μg m^{-3}, 8.4–48.0 μg m^{-3} and 18.9–55.5 μg m^{-3} for SO_2, NO_2 and PM_{10}, respectively in the 39 cities included. According to the Czech air quality guidelines and identical guidelines of the European Union (EC, 2008), the annual limit for SO_2 was not exceeded during the period in question, while the annual limit for NO_2 was exceeded in only 1 city and that for PM_{10} in 13 (33%) of the cities included.

The principal component analysis revealed two factors explaining 72.8% of the data variability (Table 2). The first factor explaining 44.7% of the dataset variability included significant positive loadings of SO_2, PM_{10}, low education level, and high unemployment level, and a significant negative loading of high education level. It suggests that inhabitants with unfavorable socioeconomic status mainly reside in smaller cities (insignificant negative loading for the population size) with higher concentration levels of combustion-related air pollutants. The second factor explaining 28.1% of the dataset variability involved significant positive loadings of NO_2, high salary, high education level and large population size, suggesting that large cities with residents with higher socioeconomic status are potentially exposed to high levels of traffic-related air pollution.

Table 2
Results of the principal component analysis*

	Component 1	Component 2
POPUL	−.175	**.886**
REL-EL	**.869**	−.310
REL-UNI	**−.679**	**.604**
REL-UNE	**.894**	−.104
Salary	−.004	**.888**
SO_2	**.785**	−.065
NO_2	.103	**.667**
PM_{10}	**.750**	.309

*The Varimax rotated component matrix with Kaiser normalization was evaluated. Only those factors with Eigenvalues greater than 1 and factor loadings for each variable above .5 (in bold) were considered significant.POPUL—population size; REL-EL—relative number (%) citizens with elementary education; REL-UNI—relative number (%) citizens with university education; REL-UNE—relative number (%) of unemployed citizens. Salary—average per capita income for the particular city. Significant loads (over .5/−.5) in bold.

4. Discussion

Environmental (in)justice or (in)equality is broadly defined as the unequal exposure of socially or economically deprived individuals and/or groups to pollution and its associated effects on their health or their environment, as well as the disproportionate environmental protection provided through laws, regulations and enforcement (e.g. Asch and Seneca, 1978; Perlin et al., 1995; Maantay, 2002).

Numerous studies have found associations between low SES, poor health and degraded environment. Within the environmental injustice concept, air pollution has probably received the most attention. Already in the late 1970s, Asch and Seneca (1978) found that both the inter-city and intra-city analysis revealed inverse relationships between SES of a given community and local air pollution levels in the USA. Lately, O'Neill et al. (2003), who summarized the results of more methodologically advanced studies, pointed out that low educational attainment of a community also seems to be a consistent indicator of its vulnerability to air pollution. The results obtained in the present study partly correspond to these findings, documenting that low educational attainment and high unemployment rate are inversely associated with increasing SO_2 and PM_{10} but not with NO_2 concentrations.

Inconsistent results were obtained from studies performed in Europe, where similar associations between low SES and poor air quality were documented for British regions by Mitchell and Dorling (2003) and for French regions by Laurian (2008) but Diekmann and Meyer (2010) found low correlation between income and environmental pollution in Switzerland, arguing that environmental injustice may be more accentuated in countries with a higher degree of socioeconomic segregation than in the Swiss population.

Considering the sources of poor air quality, the vast majority of recent research found that the major adverse effects originate in industrial or traffic-related air pollution (Perlin et al., 1995; Bae, 1997; Linn et al., 2000; Norris et al., 2000; Tolbert et al., 2000; Korenstein and Piazza, 2002; Jerrett, 2009; Havard et al., 2009). This was not the case in our study. We showed that, in smaller cities, the population with lower education levels and higher unemployment is exposed to higher concentrations of emissions from the combustion of solid fuels in households. These findings are in good agreement with our previous results (Branis and Domasova, 2003) and with studies performed in New Zealand, where Pearce et al. (2006) found that particulate pollution levels originating from domestic heating tended to be higher in more socially deprived and low-income neighborhoods.

Surprisingly, and contrary to expectations, our results revealed that urban communities with more favorable SES are potentially exposed to higher levels of NO_2—a pollutant characteristic for car exhaust pollution (Grice et al., 2009). Similar findings were described by Cesaroni et al. (2010) in Italy, Gouveia and Fletcher (2000) in Brazil, and Jerrett. et al. (1997) in Canada. According to their results, people with higher education and higher SES live in areas with dense traffic and are hence exposed to higher air pollution levels having their origin in car exhaust fumes.

Similarly as other studies into the relationship between air pollution and human health, the present pilot study findings also pose several questions. One of the most important is related to the number of FSMs from which the data are used to describe the concentrations of pollutants to which the selected population is exposed. The lower the number of the FSMs per unit of population or per areal unit, the lower the quality of the exposure estimate. In their assessment of particulate matter, daily mortality and hospital admission in the West Midlands conurbation (United Kingdom) Anderson et al., (2001) used five SO_2, three PM_{10}, and four NO_2 FSMs for 2.5 million people. In Helsinki with a population of about 570,000 inhabitants Kettunen et al., (2007), Halonen et al. (2009), and Penttinen et al. (2001) all used 1 or 2 FSMs to assess the effect of air pollution on stroke mortality, cardiorespiratory hospital admission or asthma. In the present study, the population coverage ranged from 1 FSM per 10,000 inhabitants (the smallest town) to 15 monitors (Prague) per 1.2 million inhabitants. Compared with the studies cited above, our population coverage by fixed site monitors may be considered quite adequate.

The question may also be posed of how well a particular fixed-site monitor reflects the exposure of individuals, communities or large populations moving or residing at different distances from the monitoring site. The relationship between personal versus fixed-site air quality monitoring has been extensively studied in the past. A majority of publications dealing with this topic indicated that FSM measurements are suitable for population exposure assessment. Reasonable or strong FSM –personal/community correlations have been recorded for both adults and children by Janssen et al. (1999), and Janssen et al. (2000), for adults by Lachenmyer and Hidy (2000), Boudet et al. (2001), and Kim et al. (2006) and also in a long-term exposure study that we recently performed (Branis and Kolomaznikova, 2010). In a comprehensive EXPOLIS Europe-wide study, the authors concluded that, for regional air pollution, fixed-site monitoring data are valid exposure surrogates (Oglesby et al., 2000). It is obvious that using surrogates to estimate actual human exposures can be highly inaccurate and can introduce a great deal of uncertainty. However, environmental justice studies assessing actual human exposure to air pollutants by means of personal monitoring are scarce and are usually based on few or lower tens of individuals in 1 city (Perlin et al., 1995; Sexton et al., 2000; Payne-Sturges et al., 2004; Sahsuvaroglu et al., 2009).

Another question is related to the use of annual data for description of potential exposure. Annual air quality data were used in a similar study by Asch and Seneca (1978), who studied the distribution of air pollution and SES in 282 US cities. Annual data were also recently employed in environmental justice research by Brochu et al. (2011) and Richardson et al. (2011). We do not assume that city-level differences in annual concentrations of pollutants are directly associated with differences in exposure. Personal exposure measurements would be required to test the hypothesis that inhabitants in cities with higher annual average concentrations of pollutants experience correspondingly higher exposures. Bearing in mind this uncertainty, we used (similarly to other authors) annual airborne pollutant concentrations aggregated at the city level to ascertain national differences in air pollution in relation to education, unemployment rate, population size and salary. The main aim of the present pilot study is to form a picture of how Czech urban areas may vary according to these characteristics and to identify potentially critical issues for further study.

Finally, we mentioned that the annual limit for SO_2 was not exceeded during the period of our study, the annual limit for NO_2 was exceeded in only 1 city and that for PM_{10} in 13 (33%) of the cities included. This fact may suggest that air pollution below permitted limits may have had no or negligible effect on the health status of the urban population of concern. However, it was repeatedly documented in epidemiological and meta-analysis studies that the association between particulate and gaseous pollutants and health outcomes appears linear down to the lowest levels of pollutants observed (the effect of air pollution on human health has no discernible threshold effect; Spix et al., 1993; Schwartz and Zanobetti, 2000). Thus adverse health effects may also be expected as a result of exposure to low concentrations of pollutants included in our analysis.

It has been repeatedly documented in the scientific literature that exposure to air pollution can irritate the eyes, nose and throat, may lower resistance to respiratory infections, aggravates the symptoms of or worsens lung diseases (asthma, bronchitis, and chronic obstruction pulmonary disease) and can cause premature death in individuals with cardiopulmonary diseases (Stieb et al., 2002; Pope et al., 2004). A number of papers also showed that poor air quality combined with low socioeconomic status and/or educational attainment significantly contribute to health problems in affected individuals or communities (for a review see O′Neill et al., 2003). The higher the exposure, the more severe are the adverse health effects. No data on environmental inequity have so far been gathered in the Czech Republic; however, epidemiological research has shown that exposure to air pollution has adverse health effects in many Czech regions (Bobak and Leon, 1992; Sram et al., 1996; Katsouyanni et al., 1997; Peters et al., 2000; Jelinkova and Branis, 2001; Branis et al., 2011). New studies combining epidemiological, socio-economic and air pollution variables will be needed to reveal whether or not low SES significantly contributes to health problems in socially deprived groups of people also in the Czech Republic (and in other countries in transition).

5. Conclusions

In conclusion, our pilot study showed that, in 2001, after more than a decade of transition and socio-economic changes, the communities living in Czech urban areas exhibited certain and, it should be pointed out, unusual patterns of social stratification. While people residing in regions with lower education and higher unemployment rates are more likely to be exposed to solid fuel combustion pollutants (PM_{10} and SO_2), which are characteristic for residential heating (Branis and Domasova, 2003), the populations of larger cities are more likely to be affected by pollution from dense traffic. However, further research is needed to analyze (potential) exposure to air pollutants in populations with low SES and to evaluate its health impact. One year (2001) selected for the analysis represents only a snap-shot in time and can therefore not be considered sufficient. After the new (2011) census results become available, it will be possible to extend this study and to obtain a deeper insight into this interesting issue.

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