Air Pollution and Migration – exploiting a natural experiment from the Czech Republic♣

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ABSTRACT

This paper examines causal effects of air pollution on migration flows by exploiting a natural experiment of rapid desulfurization of power plants in the region of Northern Bohemia in the Czech Republic in the years following the fall of communism in 1989. Our preliminary findings from a difference in differences estimator show a significant positive effect of sulfur dioxide concentrations on emigration. All the above results are validated in analyses using net immigration rates: we find negative effects of air pollution on net migration. The results are also supported by zero effects from placebo tests. Our preliminary results thus suggest that air pollution as measured by concentrations of sulphur dioxide (SO2) in the air pushes away people from the highly polluted areas. In the future, we would like to include analyses of heterogonous responses to air pollution by different characteristics of people, for instance by their educational attainment, by age and gender.

JEL Classification: Q53, J61, O15 **Keywords:** Air pollution, migration, natural experiment.

INTRODUCTION

Although the environmental migration receives growing attention in media, the research-based evidence is still relatively scarce. A majority of recent studies tend to confirm a significant impact of climate change on international migration (e.g., extreme weather events, environmental degradation, or crop failure). For instance, in Nigeria, the likelihood of migration is found to increase with greater temperature variability (Dillon et al., 2011). Heat stress is responsible for greater migration in

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Pakistan (Mueller et al., 2014). Drought increases men's labor migration in Ethiopia (Gray and Mueller, 2012). In Burkina Faso increased migration is a consequence of scarce precipitations (Henry et al., 2004). Rainfall scarcity and temperature anomalies are strong determinants of migration to urban areas and abroad in Sub-Saharan countries (Barrios et al., 2006; Marchiori et al., 2012). Increase in yearly temperature is positively correlated with bilateral migration flows worldwide, and the impact of climate variability is significant in particular for countries dependent on agriculture (Cai et al., 2016). However, not much is known about the role of environmental pollution.

Air pollution has been shown to have detrimental effects on a range of health outcomes and on infant and adult mortality (Chen et al, 2010, 2012, Currie and Neidell, 2005; Currie et al. 2009; Newell et al, 2018; Selevan et al. 2000; Sram et al, 2013; Tanaka, 2015; Schlenker and Reed Walker, 2016;). Air pollution impacts economic outcomes such as health expenditures, hours worked, labor productivity, housing market (Hanna and Oliva, 2015; Fu et al. 2017), and education outcomes such as reduction in test scores and increased school absences (Liu and Salvo, 2017). Thus, polluted environments can be seen as negative amenities, and one can posit that people would prefer to live and raise their children in environmentally clean areas. Yet, previous literature on the link between air pollution and migration is relatively scarce. Some recent studies focusing on the effects of air pollution on migration suggest that air pollution acts as a strong push migration factor. For instance, Chen et al (2017) looks at the effects of air pollution on migration in China using changes in the average strength of thermal inversions over five-year periods as a source of exogenous variation for medium-run air pollution levels. Their results show that air pollution is responsible for large changes in inflows and outflows of migration in China. Further, Xu and Silvester (2016) examined a relationship between air pollution (approximated by PM2.5) and international migration from low and middle-income countries to OECD countries. They showed that pollution is significant, although not dominant, factor as to why people migrate, especially in countries of Sub-Saharan Africa and Eastern Europe.

In this paper, we look at impacts of extreme pollution levels in areas in Northern Bohemia on emigration and net migration rates. In order to underpin the causal effects of pollution on migration we exploit a natural experiment that arose from the fact that in years between 1994-1998 Czech power plants had to comply to an obligation set by law to install desulfurization technologies. This lead to a rapid decrease in levels of sulphur dioxide (SO2) concentrations in the air in the affected areas. The results based on a difference-in-difference estimator show that the estimated effect of air pollution on emigration is positive and statistically significant. All the above results are validated in analyses using net immigration rates: we find negative effects of air pollution on net migration. The results are also supported by zero effects from placebo tests. In the next steps, in the future version of the paper, we will add analyses focusing on heterogonous responses to pollution by different characteristics of migrants, for instance we will investigate whether the migration responses to air pollution differ by their educational attainment, by different age categories and by gender.

Experimental setup: History

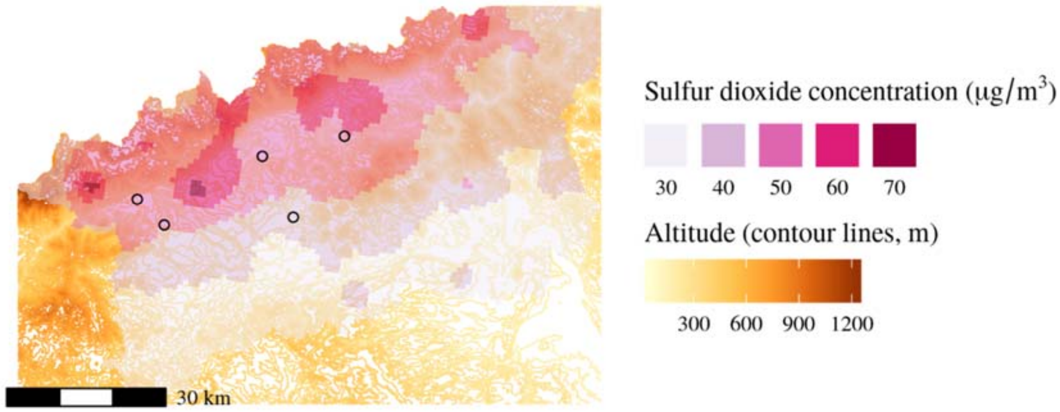
"As I walked down the street, I walked through some kind of cotton cloud, I could see just to my knees"[2] A local librarian describing situation during 1982 inversions.

The communist regime in Czechoslovakia (1948-1989), similarly to its Eastern European counterparts, pushed for a massive industrialization with energy-hungry heavy industry becoming a new center of the economy. The energy needs of industrialization were supposed to be fed by utilization of large lignite deposits in Northern Bohemia.[3] As the long distance transportation of lignite is not economically viable the new lignite-burning power plants (see Appendix Table A1), consuming about 2/3 of the coal production, were built in adjacency of surface open-pit mines. The rest of the lignite production was often used in heat-production plants and home heating stoves. Widespread burning of sulfur-rich lignite resulted in high emissions of sulfur dioxide – a typical pollutant emitted by lignite burning. Mountains surrounding the basin limited the dispersion of unfiltered emissions and therefore further scaled up the sulfur dioxide concentrations in the region (see Figure 1).

Figure 1: Sulfur dioxide concentration and altitude, region of Northern Bohemia, 1994

2 "*Když jsem šel po ulici, procházel jsem jakousi vatou, viděl jsem jen po kolena."* https://radiozurnal.rozhlas.cz/smog-v-80-letech-nevidel-jsem-ani-na-chodnik-popisuje-ustecky-archivar-6299282

3 We put Northern Bohemia equal to Ústí nad Labem county with the exclusion of Děčín district, which is geographically remote to the rest of the county (see Figure XXX).

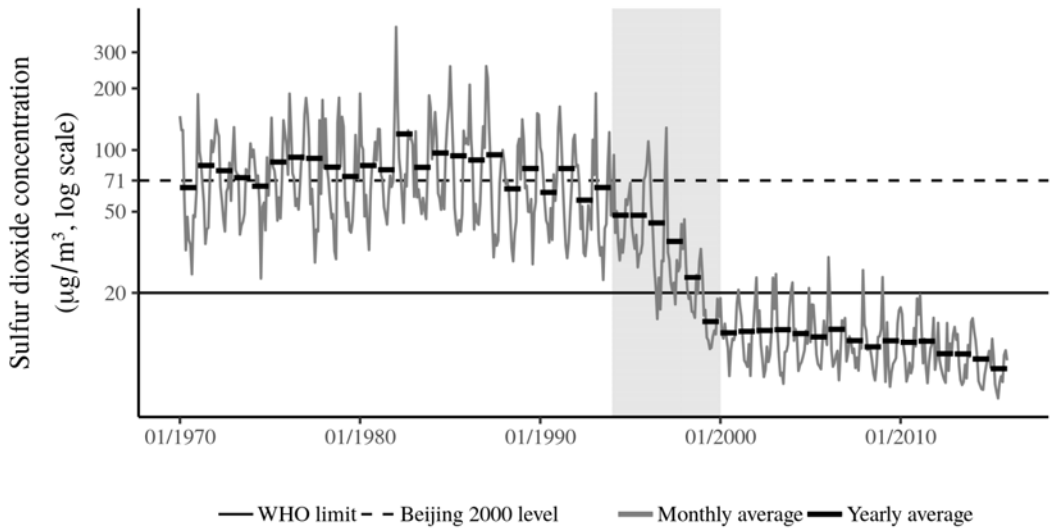


Source: Czech Hydrometeorological Institute

The Figure 2 shows the long-term development of sulfur dioxide concentrations in the worst polluted districts of Teplice, Most, and Chomutov from 1970 on (see Section 3 for details on data). The concentration levels were remarkably stable from the beginning of 1970s to early 1990s. The mean sulfur dioxide concentration reached 80μg/m^3 in 1970s and 89μg/m^3 in 1989s surpassing Beijing average level of 71 μg/m^3 in 2000 (UNEP 2007) and more than four times exceeding 20μg/m^3 – World Health Organization (WHO) guideline for 24-hours exposition (WHO 2006).[4] Winter peak sulfur dioxide concentrations were even higher. Pinto et al. (1998) compare the sulfur dioxide concentrations in 1993 Teplice (1600 μg/m^3) with the London smog episode from December 1952 where concentrations reached 1800 μg/m^3.

Figure 2 : Time-series on SO_2 concentrations in districts of Teplice, Most, and Chomutov

4 WHO does not set an annual guideline because *"compliance with the 24-hour level will assure low annual average levels"* (WHO 2006).



Source: Czech Hydrometeorological Institute, WHO 2006, UNEP 2007

High concentrations of pollutants caused rapid deterioration of the environment. Long- as well as a short-time exposure to high concentrations of ambient air pollution is associated with health problems and increased mortality (for long-term effects see e.g. Lai et al. 2013 and Shang et al. 2013, and for short-term exposition effects see review in WHO 2013). In long-term epidemiological studies subjects face a mixture of gaseous and other pollutants. That was also the case in the North Bohemia coal basin, where the high concentrations of sulfur dioxide were accompanied by increased levels of other pollutants – especially by particulate matter and nitrogen oxides (Bridgman 2002).

Several papers studied the impact of air pollution on population of Northern Bohemia. For example Kotěšovec et al. (2001) analyze mortality data from period 1982-1998 and provide a descriptive evidence of lower life-expectancy in North Bohemian coal basin in comparison to cleaner regions of the Czech Republic (South Moravia and Prachatice). Dejmek et al. (1999) use data from Teplice (1994-1996) to show the association between particulate matter concentration and higher risk of intrauterine growth retardation. Selevan et al. (2002) use samples from young males living in Teplice to show negative impact of high air pollution periods on sperm quality.

The Czechoslovak communist government was aware of the environmental problems since the early 1960s (Glassheim 2006), however, it did not take any action to reduce the pollution. The reduction of pollution via decrease of energy production was not clearly option as planned production grew steadily through 1960s and 1970s (Glassheim 2006). The reduction of energy production could also upset miners and the communist government was not willing to take the risk (Vaněk and Štrougal). The technical means of desulfurization were also unreachable to the government as available Soviet desulfurization technology was not compatible with Czech power plants (XXX) and Western technology was too expensive for a country struggling with the permanent lack of convertible currency (XXX). In addition, there was an embargo on Western technology, the so called COCOM list, for countries of the former Eastern bloc during the times of Cold War, (XXX). Glassheim (2006) also hypothesize that government had only a little interest in pollution reduction as Northern Bohemia was treated by the central government as an experiment with a goal to produce as much energy as possible with minimum costs.

The pollution brought a considerable burden to locals. Nevertheless, they were willing to bear it – at least to some extent. Glassheim (2006) puts their attitude into the context of the post-World War II resettlement of the region. The population of Northern Bohemia was originally dominated by ethnic Germans (see Table XXX) who were forcibly expelled in the aftermath of the war. The emptied settlements were resettled by settlers mostly from inland regions of today's Czech Republic. The settlers become owners of formerly German properties. However, they had to establish new communities with all social contacts herein. Glassheim (2006) claims, that coal and coal miners, become, with the help of the communist government propaganda, pillars of the newly build regional identity. Such identity would increase a political sensitivity of taking any measures harmful to miners' well-being and it could also increase the tolerance of locals to pollution. On the other hand, Matějka (2008) and Petráček (XXX) hypothesize that people in resettled areas lacked mobility impeding social ties in their communities (see also e.g. Bräuninger and Tolciu 2011, David et al. 2010, or Bönisch and Schneider 2013). Guzi, Huber and Mikula (2019) show the persistent higher population churning in 1971-2015 and lower levels of civic participation in resettled settlements in the Czech Republic.

Figure 7 shows that Northern Bohemian settlements were experiencing negative net immigration rates throughout 1970s and 1980s. In order to attract and keep qualified labor force in the region the government introduced a series of measures: (a) The authorities did not inform the public on health risks or pollutant concentrations. Only by late 1980s a limited warning system was implemented (e.g. yellow flags or signs were mounted on public transport vehicles during inversions). (b) Government created a system of subsidies and benefits to keep people in the region. Those who worked there for 10 years were eligible for a monetary benefit of 2,000 Czechoslovak crowns (CZK) per year (5.7% of average annual wage as of 1985).[5] Locals used to call it a "burial benefit" *("pohřebné")*. Government also provided housing construction subsidies that could reach up to 50,000 CZK (142%

5 Historical data on wages in Czechoslovakia are available at https://www.czso.cz/csu/czso/casove-rady-zakladnich-ukazatelu-statistiky-prace (last accessed on February 7th 2019).

of average annual wage as of 1985). (c) Government limited mobility of highly-qualified workers from the region. (d) Government provided heavily subsidized or free trips to clean mountain areas to children during inversions.

Despite all benefits, the frustration of local population grew under the lid of authoritarian regime and boiled over in late 1989. A hundreds of locals attended a series of demonstrations, which took place in Teplice between 11th and 13th November 1989. They demanded an action in air pollution reduction under slogans *"Let us breathe!"* and *"We want clean air!"*. Sensitive anti-government or anti-communist political issues were not raised (very likely on purpose) during demonstrations. Under the pressure local authorities unprecedently agreed to organize a public meeting with experts on 20th November. Country level political development gained momentum in 7 days between demonstrations and promised public meeting. Major anti-government demonstration, which started the so called Velvet revolution and the rapid end of the communist regime took place in Prague on November 17th 1989. The meeting eventually took place with the attendance of about 6,000 citizens. Nevertheless, the search for the solution of the pollution problem was not about to stay in hands of Communist Party as the first non-communist government swore in on 10th December 1989.

After the fall of communism in late 1989, the political and economical transformation of the Czechoslovakia started. Law No. 309 passed in 1991 addressed the need for a substantial change in environmental policies. The law set an obligation for government to provide full and up-to-date information on air quality and emission sources to general public and constituted a framework for emissions and immissions regulation. It also effectively set an obligation to install desulfurization technologies before December 31st 1998 – i.e. within 7 years.[6] The strict deadline forced the existing power plants to swiftly introduce the desulfurization technologies. By early 1999 all power plants in the region were desulfurized (see Appendix Table 1).

Figure 3 shows a rapid decline in sulfur dioxide concentrations during the desulfurization period. The mean concentrations in the most heavily polluted districts dropped below the WHO guideline of $12 \mu g/m^3$ in the period of 2000-2015. The concentrations level reached after desulfurization remained stable throughout the 2000s followed by mild decline in the 2010s.

Figure 3 shows spatial distribution of sulfur dioxide concentrations in Northern Bohemia at the beginning of desulfurization programs in 1994 (older data are not available) and after their completion

6 The law set an obligation for all emission sources to meet emission limits designed for newly build emission sources equipped with modern up-to-date technology by December 31st 1998.

in 2000. Despite the fact that sulfur dioxide concentrations were already declining in 1994 (see Figure 2), the WHO guideline of 20 μg/m^3 was not met in any settlement in 1994. However, there was a substantial variation in the pollution load. The average sulfur dioxide concentrations in settlements ranged from 30 to 70 μg/m^3 with 68% of regions' population (as of 1991) living in settlements with sulfur dioxide concentration above or equal to 50 μg/m^3 – an interim guideline suggested by WHO (2006) for developing countries (Interim target 2). Reduction of concentrations below this limit would *"lead to significant health improvements"* (WHO 2006).

By 2000 the average concentrations in the region dropped below 20 μg/m^3 and so it did in individual settlements. CHMI projections from the dispersion model show that all settlements benefited from this substantial decrease in sulfur dioxide immissions with all of them having average concentrations below the WHO 20 μg/m^3 guideline.

Figure 3: Number of residents of Northern Bohemia by exposition to sulfur dioxide concentrations

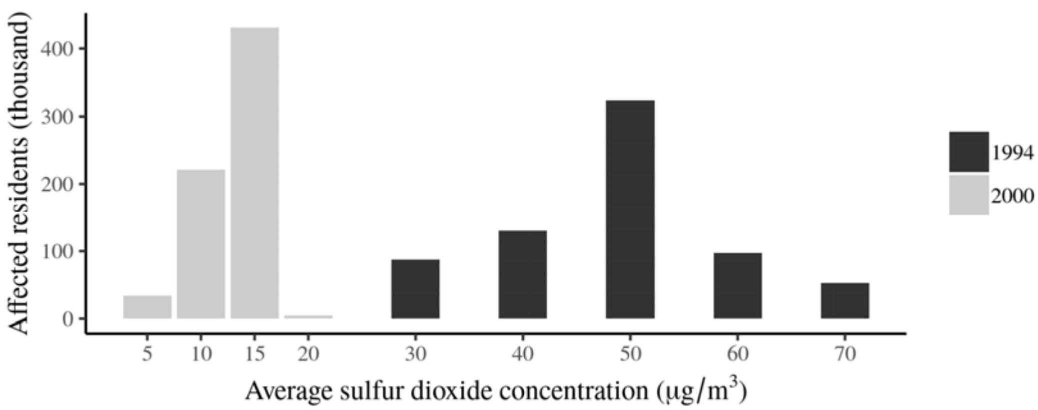
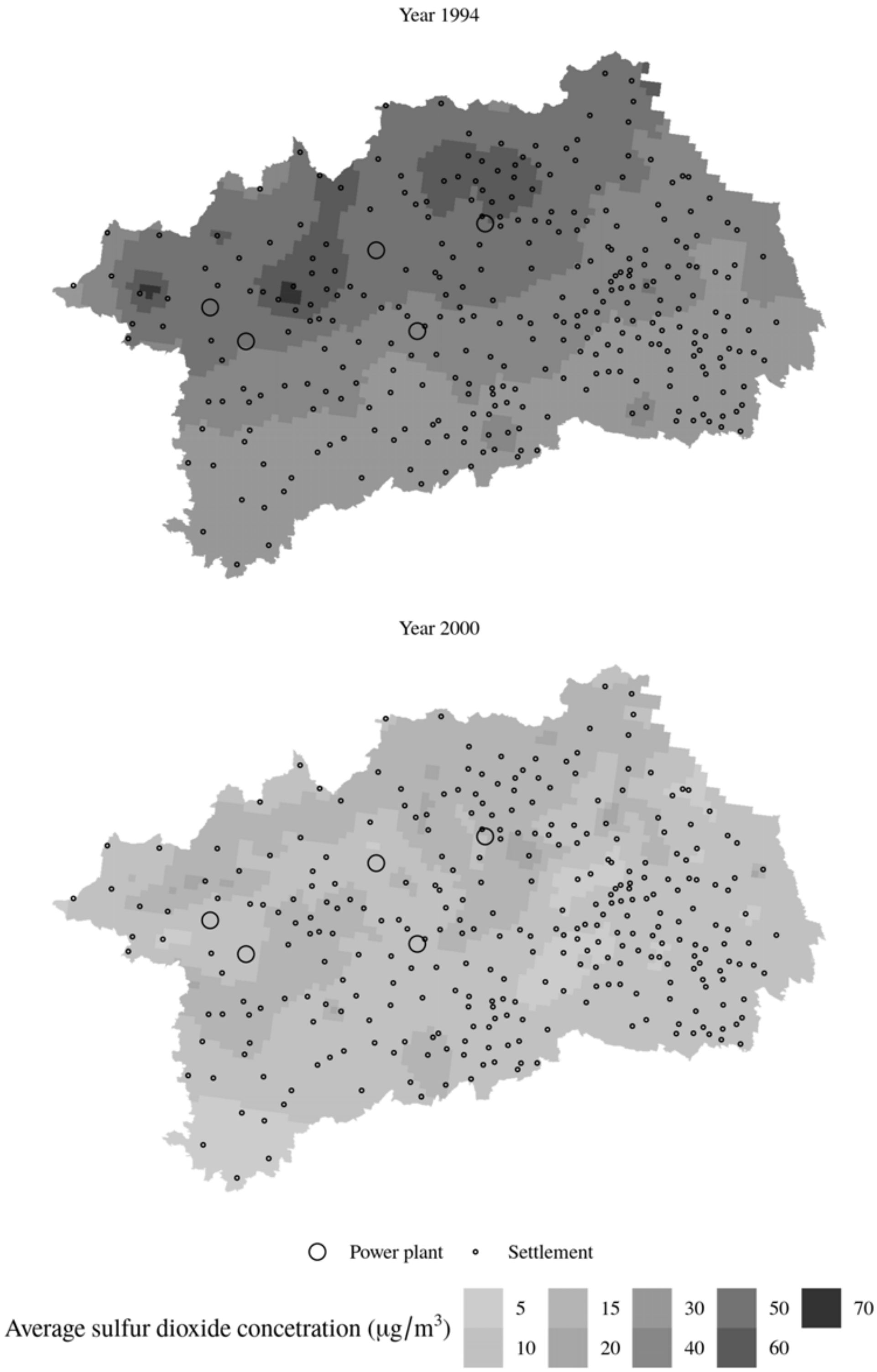


Figure 4: Spatial distribution of sulfur dioxide concentrations in Northern Bohemia, year 1995 and 2000.



Data

For our empirical analyses, we combine data on population and residential migration, and data on sulfur dioxide immissions. The migration rates are calculated from the annual settlement-level data on residential migration compiled by the Czech Statistical Office (CSO) from the administrative records on permanent residence changes in period from 1971 forward.[7] People in the Czech Republic were and are legally obliged to register their permanent residency. Moreover, they are motivated to keep their registration up to date as the preferential access to some public services (such as kindergartens, elementary schools or health care) is granted on its basis. The dataset is an unbalanced panel (due to records loses prior to digitization) and contains number of people who moved in and out from a settlement and population size as of January 1st. Therefore it allows us to calculate annual gross emigration and immigration, and net immigration rates defined as a number of movers per resident. We exclude outliers from the sample by removing top 1% of gross emigration and immigration rates. These outliers might be a consequence of unobserved events such as depopulation of a settlement due to mines expansion.

The publicly available dataset on residential migration does not contain any characteristics of movers. These are available in detailed place-to-place residential migration dataset compiled by CSO from the same administrative sources. The dataset contains date of moving, settlement of origin and destination, age, gender, education (only for 1993-2004), and marital status of all movers. However, these data are available only for period from 1993 forward.

The primary source of information on population characteristic are decennial population censuses. The CSO compiles *"Historický atlas obcí"*[8] a database of historical census records on population size and number of houses, which reaches back to 1869. More detailed settlement-level data on education and population structure are available only from 1980, 1991, 2001, and 2011 censuses because records from previous modern-day censuses were lost to a flood in 2002.

The concentrations of sulfur dioxide and other pollutants are measured by a network of measuring stations run by Czech Hydrometeorological Institute (CHMI). Daily mean concentrations from individual measuring stations are available from CHMI yearbooks for period from 1997 forward.[9]

7 Data are available at https://www.czso.cz/csu/czso/databaze-demografickych-udaju-za-obce-cr (last accessed on February 6th 2019).

8 The database is available at https://www.czso.cz/csu/czso/historicky-lexikon-obci-1869-az-2015 (last accessed on February 6th 2019).

9 Yearbooks are available at http://portal.chmi.cz/files/portal/docs/uoco/isko/tab_roc/tab_roc_CZ.html (last accessed on February 6th 2019).

We have supplemented this data with monthly means of sulfur dioxide concentrations from selected stations located in worst polluted districts (Most, Teplice and Chomutov) for the period 1970-1996.[10] This set of raw data allows us to observe the long-term development of overall sulfur dioxide concentrations in the area. For the spatial distribution of sulfur dioxide we use predictions from CHMI dispersion model. We have purchased predictions of spatial distribution of mean sulfur dioxide concentrations for 1994 (oldest prediction available) and 2000. The concentrations at settlements are defined as predicted sulfur dioxide concentrations at settlement reference points. These reference points, defined by CSO, are placed in social center points of settlements (e.g. in front of church or town hall).

Map collection ArcČR 500 v3.3 created by ARCDATA PRAHA is used in all geospatial visualizations.[11]

Descriptive Evidence

Figures 5 to 7 show development in gross emigration, gross immigration and net immigration rates, respectively, to settlements in Northern Bohemia according 1994 sulfur dioxide levels of concentration for years 1971-2015. As can be seen from Figure 5, the emigration rate from the settlements of Northern Bohemia is relatively large prior the desulfurization period in particular from the settlements with heavy pollution, i.e. with sulfur dioxide concentration above or equal to 50 $\mu g/m^3$ (an interim limit suggested by WHO for developing countries (WHO, 2006), see Figure 5. MORE TO BE ADDED

10 These additional data were purchased from CHMI. Frequent changes in measuring network (in locations, number of stations, and technology used) do not allow us to construct consistent long-term time series for individual measuring stations.

11 Map collection is available at https://www.arcdata.cz/produkty/geograficka-data/arccr-500

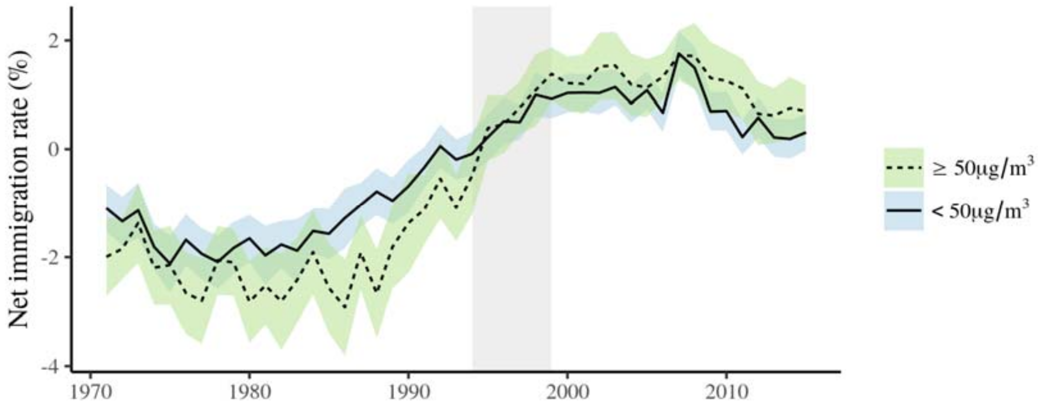


Figure 5: Gross emigration rate (mean and 95% confidence interval) from settlements in Northern Bohemia by 1994 sulfur dioxide concentration, years 1971-2015

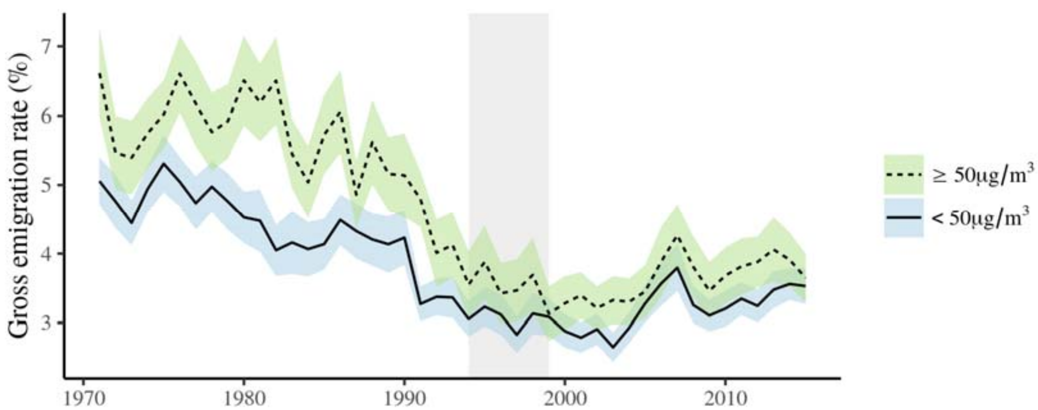


Figure 6: Gross immigration rate (mean and 95% confidence interval) to settlements in Northern Bohemia by 1994 sulfur dioxide concentration, years 1971-2015

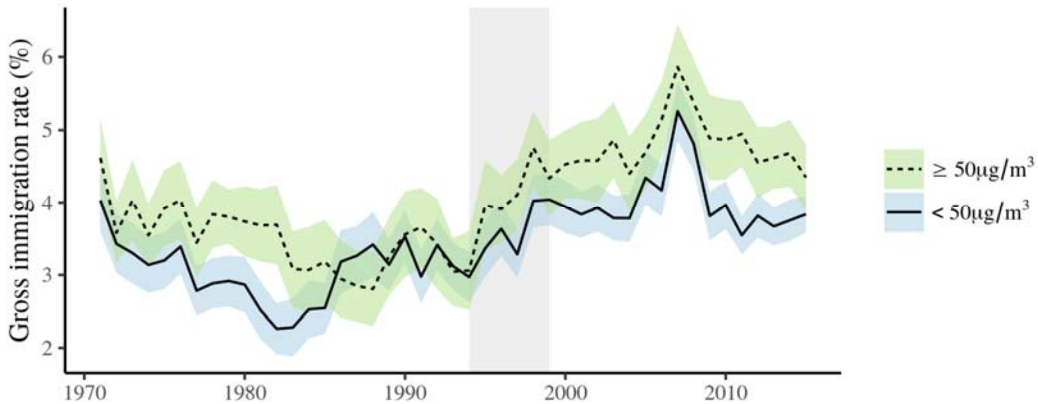
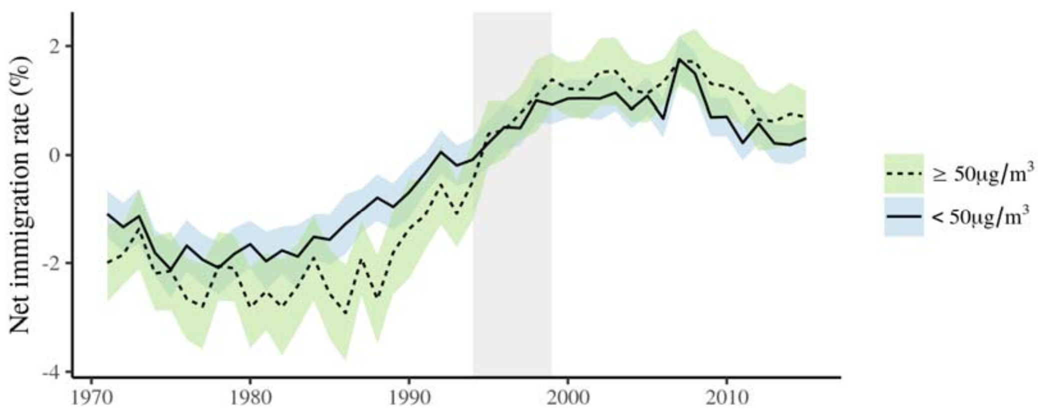


Figure 7: Net immigration rate (mean and 95% confidence interval) to settlements in Northern Bohemia by 1994 sulfur dioxide concentration, years 1971-2015



Estimation and results

To estimate the effect of air pollution on residential migration we estimate following regression:

$$y_{it} = \beta_1 SO_{i,1994} \times P_1 + \beta_2 SO_{i,1994} \times P_2 + \beta_3 SO_{i,2000} \times P_3 + \theta_t + \theta_i + \epsilon_{it} \qquad (1)$$

where y_it is outcome – i.e. gross emigration, immigration or net immigration rate – in the settlement i and year t. The variables of interest are interactions between the sulfur dioxide concentrations (SO) and period (P). As sulfur dioxide concentrations were remarkably stable in the period before and after desulfurization (see Figure XXX) we use 1994 concentrations throughout pre-desulfurization period and 2000 concentrations throughout post-desulfurization period. In the baseline specification (1) we use three periods. First period, P_1 covers years of communist regime in the Czech Republic (1971-

1989) which introduced series of benefits and restrictions on people living in Northern Bohemia. The second period P_2 is defined as time between the fall of communist regime and start of desulfurization (1990-1993). In this period restrictions imposed by the communist regime were lifted and the new law granting the desulfurization was introduced in 1991. However, the pollution levels were still high in this period. The last period P_3 covers all observations after the completion of the desulfurization (2000-2015). The pollution levels were low (below the WHO guidelines) throughout the region and period. The period of desulfurization (1994-1999) is excluded from the sample.

The baseline specification (1) also contains full set of settlement fixed effects θ_i including the constant, which controls for all time-invariant differences (such as geographical location, natural amenities or heritage of post-World war II resettlement) and ensures that we estimate the effect of sulfur dioxide concentrations within a settlement. We also include year fixed effects , which controls for events affecting all settlements in the region alike – such as turbulent macroeconomic development of the Czech Republic during the economic transition in 1990s.

Table 1: Baseline regression results – specification (1)

	Dependent variable		
	Gross immigration rate (%)	Gross emigration rate (%)	Net immigration rate (%)
	(1)	(2)	(3)
SO2 level in 1994 * (year in 1971-1989)	-0.004	0.035***	-0.039*
	(0.013)	(0.010)	(0.018)
SO2 level in 1994 * (year in 1990-1993)	-0.012	0.017*	-0.029
	(0.014)	(0.009)	(0.016)
SO2 level in 2000 * (year in 2000-2015)	-0.011	-0.024	0.013
	(0.043)	(0.026)	(0.052)
Settlement fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	10345	10345	10345
Adjusted R2	0.208	0.393	0.255

Standard errors clustered by settlement are reported in parentheses: *p < 0.05, **p < 0.01, ***p < 0.001.

Estimates in Table 1 show (using the five-percent threshold for statistical significance) a significant effect of sulfur dioxide concentrations on net immigration rates with marginal effect of -0.039%. This effect is substantial as it implies that decrease in sulfur dioxide concentrations by 10 μg/m^3 (i.e. approximately by one standard deviation of 1994 sulfur dioxide concentrations) would decrease the rate of depopulation of the region by 3.9 p.p. and potentially stop the migration-driven depopulation of the region. The effect on the net immigration rates is obviously driven by emigration as the effect on gross immigration rates is zero and effect on gross emigration rate is substantial (0.035%) and highly significant.

The effect of sulfur dioxide concentrations in transitory period of 1990-1993 on net immigration and gross emigration is insignificant. The effect on gross emigration rate remains significant albeit it is half in size with respect to its pre-1990 value. In the post-desulfurization period (2000-2015) is the effect of sulfur dioxide concentration statistically insignificant.

These results suggest that higher pollution loads in pre-1990 period did not decrease the attractivity of settlements for immigrants, but made staying in settlement less desirable, i.e. acted as a strong push factor. Such effect could be an outcome of government policies in pre-1990 era, which could succeed in attracting immigrants to the region but failed to compensate disutility from the pollution. This a likely cause as policies on attracting immigrants were quite generous (e.g. subsidy on house construction equal to 142% of average annual income, allegedly up to 1/3 of construction costs) in comparison to measures aimed to keep people in the region which were based on information and mobility restrictions. Residents were eligible for financial benefits (5.7% of average annual wage) after 10 years of living in the region. Moreover, the behavior of the autocratic government gave no prospects to residents for future environment improvement.

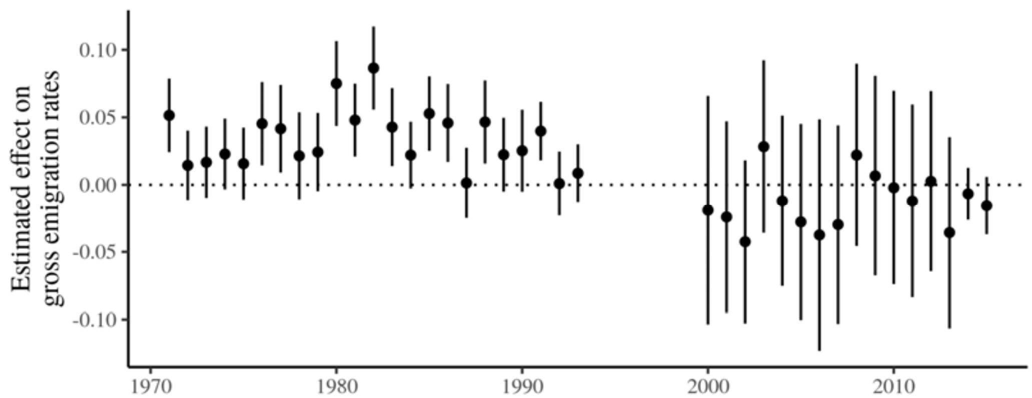
As we are unable to ascertain the impact of pro-immigration and anti-emigration government policies we interpret our estimates as lower bound of true treatment effect.

In the second period 1990-1993 the sulfur dioxide concentrations were still high, nevertheless the democratic government took decisive steps towards pollution reduction when the legislative framework for environmental regulation was established in 1991. The information on pollution were also made available to the public. The expectation of future environment improvement could increase the attractivity of then-highly polluted settlement relatively to less polluted settlement. The pooled estimates for gross emigration rate provide some evidence to such development as the estimated effect of sulfur dioxide decreased by ½ with respect to pre-1990 period. Year-by-year estimates presented in the Figure 8 provide additional evidence as the face value of effects of sulfur dioxide on gross emigration rate drop to zero in 1992 – a year after introduction of new legislative, which set an obligation to desulfurize within 7 years. On the other hand our estimates on gross immigration rate –

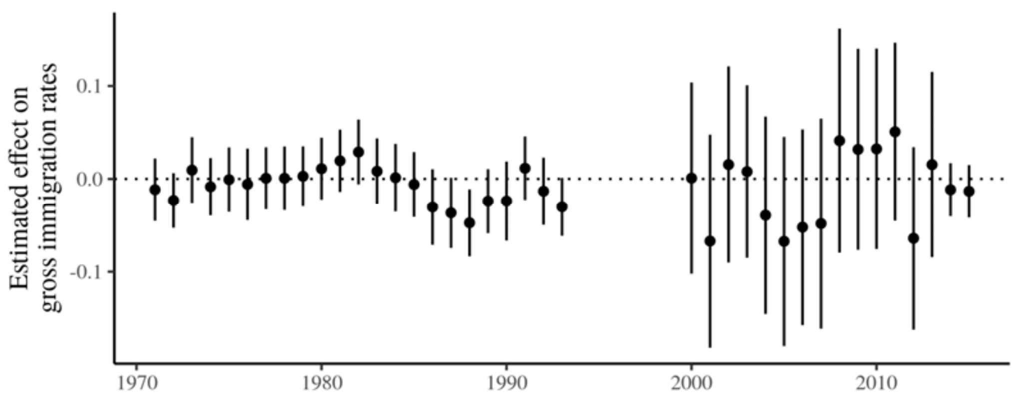
pooled as well as year-by-year – are insignificant throughout 1990-1993 suggesting that future expectations did not affect the immigration decisions.

Figure 8: Effect of sulfur dioxide concentrations in year-by-year (fully interacted) estimates

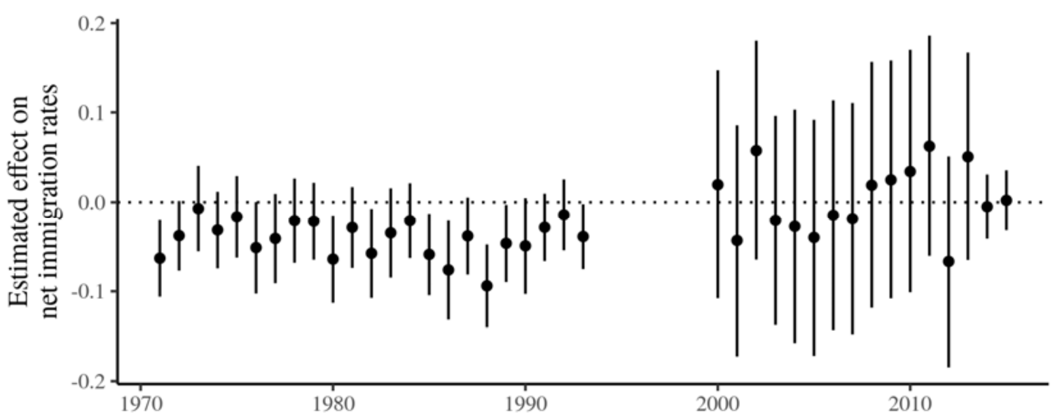
Gross emigration rate



Gross immigration rate



Net immigration rate



by high subsidies on house constructions (142% of average annual income, allegedly up to 1/3 of construction costs). On the other hand, the government clearly demonstrated a little will to reduce the pollution load and therefore the residents had no reason to expect brighter future (especially during winter inversions).

CONCLUSIONS AND FUTURE STEPS

In this paper, we look at emigration and net migration rates from areas in Northern Bohemia affected by extreme pollution levels in order to examine the effects of air pollution on migration. In order to underpin the causal effects of pollution on migration we exploit a natural experiment that arose from the fact that in years between 1994-1998 Czech power plants had to comply to an obligation set by law to install desulfurization technologies. This lead to a massive reduction in sulfur dioxide concentrations in the air in the affected areas. The results based on a difference-in-difference estimator show that the estimated effect of air pollution on emigration is positive and statistically significant. All the above results are validated by placebo tests, see the Appendix section. In the future version of the paper, we would like to add analyses focusing on heterogonous responses to pollution by different characteristics of migrants, for instance we will investigate whether the migration responses to air pollution differ by educational level, by different age categories, between men and females, and for families with children.

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Appendix

Map A: a Map of the Czech Republic, and the position of Region in North Bohemia under analyses.

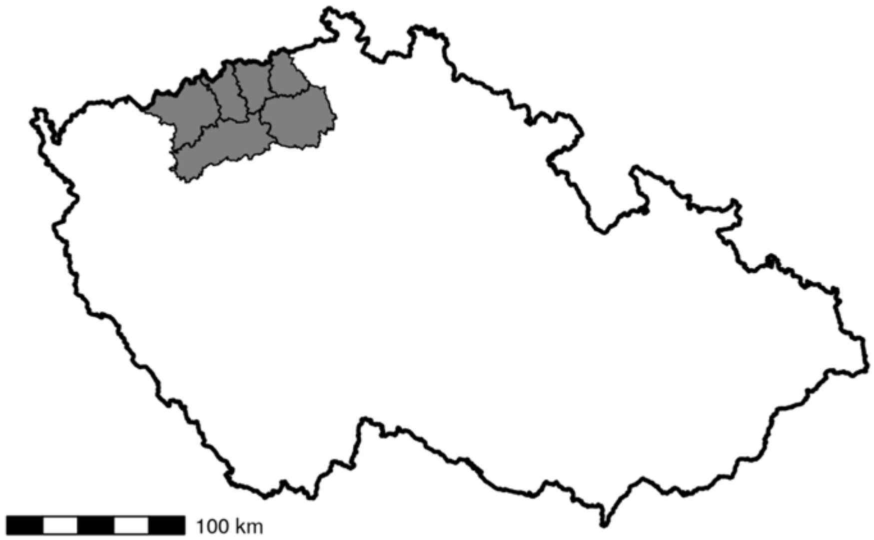

Table A1 Lignite-burning power plants in Northern Bohemia (Ústí nad Labem county)

Power plant	Construction	Desulfurization
Komořany	1951-1964	1993-1999
Ledvice	1967	1996-1998
Počerady	1970-1977	1994-1996
Prunéřov	1967-1968 (second unit 1981-1982)	1995-1996
Tušimice	1963-1967 (second unit 1974-1975)	1994-1997

Source: Power plant owners ČEZ (https://www.cez.cz/cs/vyroba-elektriny/uhelne-elektrarny/cr.html), and United Energy (https://www.ue.cz/historie-a-soucasnost).

Table A2: Placebo test

	Dependent variable		
	Gross immigration rate (%)	Gross emigration rate (%)	Net immigration rate (%)
	(1)	(2)	(3)
SO2 level in 1994 * (year in 1971-1979)	-0.006	-0.012	0.006
	(0.012)	(0.008)	(0.012)
SO2 level in 2000 * (year in 1980-1989)	-0.017	0.022	-0.039
	(0.037)	(0.027)	(0.043)
Settlement FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	4541	4541	4541
Adjusted R2	0.346	0.458	0.325

Observation period is limited to 1971-1989 with placebo treatment (sulfur dioxide concentrations achieved after desulfurization) is introduced by 1980. Standard errors clustered by settlement are reported in parentheses: $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.