

# Migratory Responses to Air Pollution Reduction: Evidence from Large-scale Desulfurization Programme\*

Štěpán Mikula<sup>†a,c</sup> and Mariola Pytliková<sup>‡b,c,d</sup>

<sup>a</sup>Masaryk University (MUNI)<sup>§</sup>

<sup>b</sup>CERGE-EI<sup>¶</sup>

<sup>c</sup>IZA, SYRI National Institute

<sup>d</sup>CReAM and CELSI

July 10, 2023

This paper examines the causal effects of significant improvement in air quality in formerly heavily polluted areas on migration and re-population patterns. In particular, we exploit a natural experiment in which desulfurization technologies were rapidly implemented in coal-burning power plants in the Czech Republic in the 1990s. These technologies substantially reduced the SO<sub>2</sub> concentration to below EU and WHO limits, without *per se* affecting economic activity. The results based on a difference-in-differences estimator imply that cleaning-up the air reduced emigration from previously heavily polluted municipalities by 24% and increased net migration by 78%. The results are validated in numerous robustness checks and supported by zero effects from placebo tests. Furthermore, we look at heterogeneous effects of cleaner air on population by education and age and find some evidence that the more educated tend to be more sensitive to air quality in their settlement behavior. Finally, we find that the migratory responses to cleaner air tend to be reinforced by existence of stronger social capital and richer man-made amenities. Thus, our results imply that strengthening social capital and investing in better facilities and public services could help to repopulate formerly polluted areas.

\*We would like to thank Peter Huber, Štěpán Jurajda, Christian Oschner, Paolo Zacchia, participants of the IZA Workshop on Environment and Labor Markets 2019, the 2nd CReAM/RWI Workshop on the Economics of Migration in Essen, YEM2019, SEAM2019, EEA2020, EALE2020, SMYE2021, CERGE/IAB Workshop on the Future of Labor Markets, 11th IOS/APB/EACES Summer Academy on Socioeconomic Consequences of Climate Change, Disasters, and Extreme Events and seminar participants in Padova University, University of Stavanger, NHH Norwegian School of Economics for their comments and suggestions. This research was funded in part by the Czech Science Foundation grant on “International migration: Drivers and Impacts” (GA20-31615S). This output was also supported by the Ministry of Education, Youth and Sports of the Czech Republic through the NPO project “Systemic Risk Institute” (LX22NPO5101). The usual disclaimer applies.

<sup>†</sup>stepan.mikula@econ.muni.cz

<sup>‡</sup>Corresponding author, mariola.pytlikova@cerge-ei.cz

<sup>§</sup>Masaryk University, Lipová 507/41a 602 00 Brno, Czech Republic.

<sup>¶</sup>CERGE-EI, a joint workplace of Center for Economic Research and Graduate Education, Charles University and the Economics Institute of the Czech Academy of Sciences, Politických vězňů 7, P.O. Box 882, 111 21 Prague 1, Czech Republic.

**Keywords:** Air pollution reduction, migration, natural experiment  
**JEL Codes:** Q53, J61, O15

# 1 Introduction

There is a general consensus that air pollution is harmful to human health and that it affects infant and adult mortality (see for instance Graff Zivin and Neidell 2013; Currie and Neidell 2005; Currie et al. 2009; Chay and Greenstone 2003; Newell et al. 2018; Selevan et al. 2000; Currie et al. 2014; Greenstone and Hanna 2014; Tanaka 2015; Schlenker and Walker 2015). A growing body of recent literature has documented the detrimental impacts of air pollution on a range of socio-economic outcomes, including health expenditures, labor supply, hours worked (Hanna and Oliva 2015; Aragon et al. 2017), long-run earnings (Isen et al. 2017), labor productivity (Graff Zivin and Neidell 2012; Chang et al. 2019; He et al. 2019), education outcomes such as test scores and school absences (Currie et al. 2009; Liu and Salvo 2017, etc.), long-term human capital accumulation (Graff Zivin and Neidell 2013; Bharadwaj et al. 2017), and cognition (Bishop et al. 2018). Given these serious adverse effects of exposure to air pollution, one would expect people to prefer to live and raise their children in environmentally clean areas, moving out of polluted areas. The empirical evidence coming from a few recent studies indeed tends to agree on air pollution being among strong migration push factors (Xu and Sylwester 2016; Chen et al. 2022)<sup>1</sup>.

What is however not fully understood is what happens to migration after improvement in air quality. Given that many countries, being increasingly aware of the harmful socio-economic and health impacts of environmental pollution, are pushing towards policies and reforms towards improved air quality<sup>2</sup>, the air quality improves in many countries over time.

1. Research-based evidence within the area of environmental migration has tended to focus on the role of climate change, temperature and precipitation variability, extreme weather events, droughts, crop failure, natural disasters or environmental degradation in migration (see Dillon et al. 2011; Mueller et al. 2014; Gray and Mueller 2012; Henry et al. 2004; Barrios et al. 2006; Marchiori et al. 2012; Cai et al. 2016). There are however two studies that focus on the effects of air pollution on migration. Specifically, Xu and Sylwester (2016) analyze the relationship between air pollution (approximated by PM<sub>2.5</sub>) and international migration from low and middle-income countries to OECD countries. They show that air pollution is positively associated with emigration (to OECD countries), especially from countries in Sub-Saharan Africa and Eastern Europe. However, this study was not able to identify any causal effects. This is problematic, as it is difficult to separate out the effect of pollution from that of economic opportunities. In particular, air pollution tends to be correlated with economic activities, as it might attract workers via better job opportunities and higher wages. In the migration literature, economic factors such as wages and employment are known to be among the main drivers of migration (Sjaastad 1962; Pedersen et al. 2008; Mayda 2010; Ortega and Peri 2013; Fidrmuc 2004; Clark et al. 2007, and others). The second study, by Chen et al. (2022), tried to overcome the empirical challenges of underpinning the causal relationship between air pollution and migration by using changes in the average strength of thermal inversions over five-year periods as an instrumental variable for air pollution levels. The results of their analyses show that air pollution is responsible for large changes in regional migration in China.

2. For instance, the Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, adopted in 1999, aims at limiting air emissions of particulate matter, sulphur dioxide, nitrogen oxides, VOCs, ammonia, setting national emission ceilings for the main air pollutants, which may not be exceeded by 2010. The Protocol was revised in 2012, with new ceilings agreed for 2020. At the EU level, there is, for instance, the 2005 EU Thematic Strategy on Air Pollution, which set out strategic policy objectives; the 2001 National Emission Ceilings Directive (NECD), which established national emission ceilings for 2010 for all Member

Knowing what are the migratory and population responses to cleaning-up the formerly very polluted areas due to the environmental policy measures is very important. To the best of our knowledge, this is the first study, which provides an evidence on the causal effects of rapid and significant improvement in air quality in formerly heavily polluted areas on migratory and re-population behaviour.

In our study, we exploit a natural experiment of power plants' desulfurization in the region of North Bohemia in the Czech Republic in order to uncover causal impacts of cleaning the extreme air pollution levels on migration. The North Bohemian region is characterized by multiple lignite-burning power plants, which were responsible for high-emissions of sulfur dioxide (SO<sub>2</sub>) polluting the entire area. However, between 1992 and 1998 the Czech power plants were obliged by law to install modern desulfurization technologies, which consequently led to a substantial drop in the emitted pollution, but did not affect the economic activity in the region *per se*. In fact, this technology-driven reduction in SO<sub>2</sub> emissions in the Czech Republic has been shown to be one of the most dramatic historical examples of pollution reduction in Europe (Vestreng et al. 2007). By utilizing this natural experiment, we make a two-fold contribution to the literature: we provide novel evidence to the environmental migration literature on migratory and de-population responses to significant improvement in air quality in formerly heavily polluted areas, as well as we add to the literature on the determinants of migration.

In our analysis, we compare differences in migration rates between the municipalities with the lowest and highest pollution levels in the pre- and post-desulfurization time-period. The results, based on a difference-in-difference estimator, show that the estimated effect of reduction in SO<sub>2</sub> concentrations on emigration has the expected negative sign and is statistically significant. The effect is large: emigration rates from formerly very polluted municipalities were on average 24% lower after the installation of desulfurization technologies compared to the control group of the least polluted municipalities. Further, we find the effects on emigration to be non-linear in the sense that the effect is much larger—almost twice as large—for municipalities that initially suffered from heavy SO<sub>2</sub> levels (annual mean concentration 50 and 60  $\mu\text{g}/\text{m}^3$ ) than it is for municipalities that initially suffered from lower pollution (40  $\mu\text{g}/\text{m}^3$ ). The results on immigration are less straightforward, as we do not find that improvements in air quality has had any statistically significant effect on immigration; however, this finding could be driven by the abolition of the generous pro-immigration benefits in the initially heavily polluted areas. Overall however, desulfurization contributed to the re-population of the region as it led to an increase in the net migration rate by 1.7 percentage points corresponding to approx. 78%

---

States on four main pollutants or finally the Ambient Air Quality Directives, which are setting local air quality limits, which may not be exceeded anywhere in the EU.

increase relative to the comparison group. These results suggest that the reduction in air pollution made previously heavily polluted municipalities more attractive for people to live in. All these results are validated by numerous robustness and placebo tests.

Additionally, in our analysis we dig deeper into possible mechanisms via which cleaning formerly very polluted areas might affect migration. Specifically, we investigate the role of economic benefits acting as anti-emigration policy and the role of social capital and man-made amenities in counteracting the effect of environmental pollution on migration. To do this, we exploit historical set-ups to study channels that are otherwise hard to disentangle. Our results, based on a triple difference estimator, show that anti-emigration policies had no impact on emigration decisions. Further, we find that migratory responses to air quality improvement tend to be stronger in municipalities with stronger local social capital and in municipalities with better-equipped with education, health, social care, culture and sport facilities. Our results thus imply that the effects of cleaning polluted areas on migration may be reinforced by stronger local social capital and man-made amenities. Finally, we look at heterogeneous migratory responses to air pollution by education and age and find some evidence that migratory responses to cleaner air seem to be more pronounced among the highly educated part of the population.

## 2 Experimental setup: History

In the Czech Republic<sup>3</sup>, as in its Eastern European counterparts, the communist regime (1948–1989) pushed for massive industrialization, with energy-hungry heavy industry at the center of the economy. The energy demands created by this industrialization were supposed to be met by making use of substantial lignite deposits in the North Bohemian region (see Appendix Figure A.1).<sup>4</sup> To reduce transportation costs, a new dense cluster of six lignite-burning power plant complexes (see Appendix Table A.1) was built in the vicinity of lignite mines over an area of 380 km<sup>2</sup>, i.e. the equivalent of a 20×20 kilometer square. These power plants were often built close to large cities, and little attention was paid to the well-being of local residents. Energy production was so high a priority that the government even moved a large part of the historical city of Most (a district capital) in order to enable the local mines to expand (see Appendix Figure A.2, for details see e.g., Spurny (2016)).

Power plants consumed about 2/3 of the lignite produced (Vaněk 1996); the rest was used in heat-production plants and home heating systems. The widespread use of

3. The Czech Republic was part of Czechoslovakia between 1918 to 1993.

4. We define the North Bohemian region as the administrative districts (“*okres*”) of Chomutov, Most, Teplice, Ústí nad Labem, Louny, and Litoměřice.

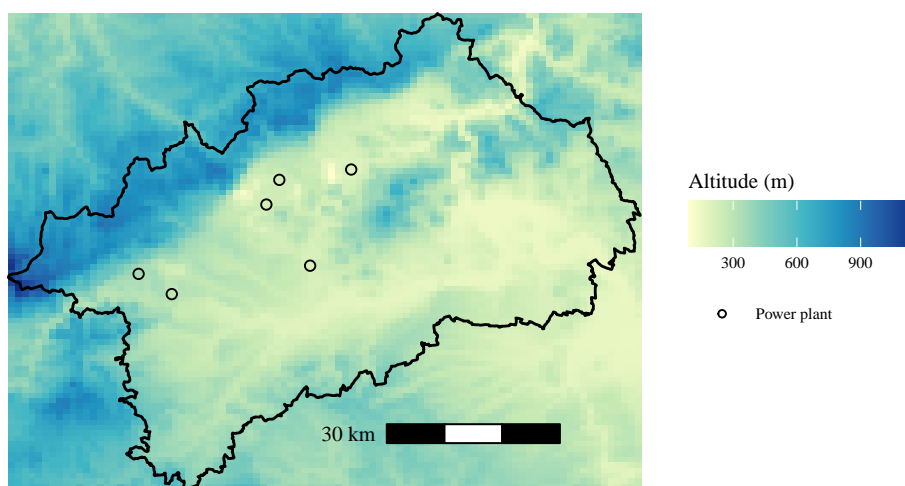


Figure 1: Altitude and power plant location in North Bohemia

Source: Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global (see Section 3).

sulfur-rich lignite resulted in high emissions of  $\text{SO}_2$ —a typical pollutant emitted by burning lignite. The high concentration of power plants within a relatively small area and their geographical location surrounded by mountains (see Figure 1) limited the dispersion of unfiltered emissions and therefore further scaled up  $\text{SO}_2$  concentrations in the region.

Figure 2 shows the long-term development of  $\text{SO}_2$  concentrations in the region from 1970 onwards (see Section 3 for details on our data). The concentration levels were remarkably stable from the beginning of the 1970s to the early 1990s. The annual mean  $\text{SO}_2$  concentration reached  $63 \mu\text{g}/\text{m}^3$  in the 1970s and  $78 \mu\text{g}/\text{m}^3$  in the 1980s, surpassing even Beijing’s average level of  $71 \mu\text{g}/\text{m}^3$  in 2000 (UNEP 2007) and almost four times exceeding the level of  $20 \mu\text{g}/\text{m}^3$ <sup>5</sup>, which is the EU annual limit (EU 2015) and World Health Organization (WHO) guideline for maximum 24-hour  $\text{SO}_2$  exposition (World Health Organization 2006).<sup>6</sup>

High concentrations of pollution caused rapid environmental deterioration. Several papers have studied how the air pollution affected the local population in North Bohemia. For instance, Kotěšovec et al. (2000) analyze mortality data from the period 1982–1998 and provide descriptive evidence of lower life-expectancy in the North Bohemian coal basin in comparison to cleaner regions of the Czech Republic (South Moravia and Prachatice).

5. Winter peak  $\text{SO}_2$  concentrations were even higher. For example, Pinto et al. (1998) compares the  $\text{SO}_2$  concentrations in Teplice district (“okres”) in 1993 ( $1600 \mu\text{g}/\text{m}^3$ ) to the London smog episode of December 1952, during which concentrations reached  $1800 \mu\text{g}/\text{m}^3$ .

6. WHO does not set an annual guideline because “compliance with the 24-hour level will assure low annual average levels” (World Health Organization 2006).

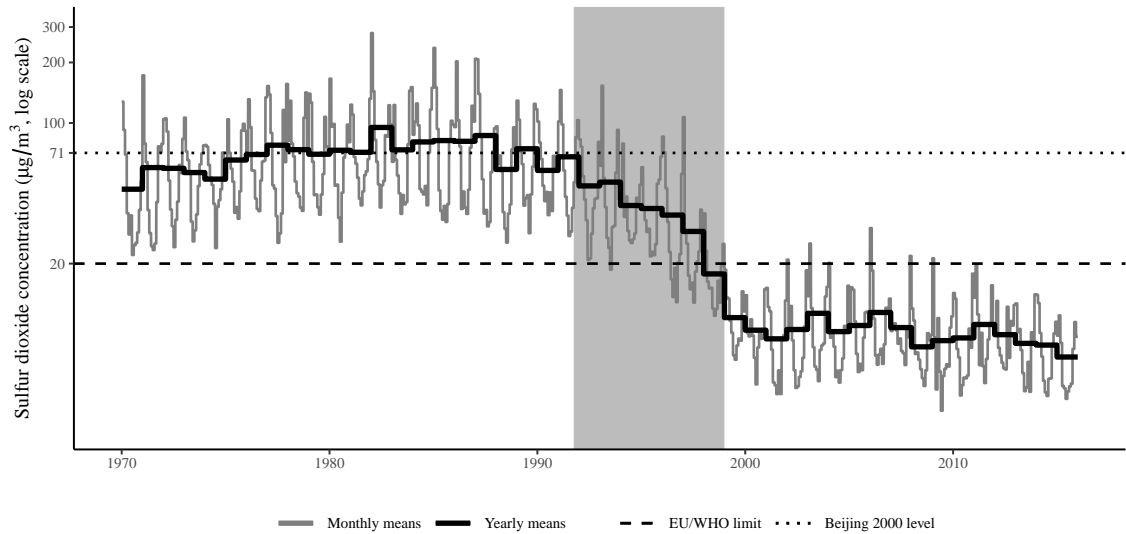


Figure 2: Development in SO<sub>2</sub> concentrations in the region over the period 1970–2015.

Source: Czech Hydrometeorological Institute (CHMI, see Section 3); Limits by: World Health Organization (2006); Beijing pollution levels: UNEP (2007).

Dejmek et al. (1999) use data from Teplice (1994–1996) to show that higher particulate matter concentration is associated with a higher risk of intrauterine growth retardation.

The Czechoslovak communist government had been aware of these environmental problems and their likely impacts on public health since the early 1960s (Glassheim 2006; Vaněk 1996), yet took no action to mitigate them. Reducing pollution by decreasing energy production was not seen as an option among the communist leaders, as there were no alternative power sources available to fuel the planned industrial production, which grew steadily throughout the 1960s and 1970s (Glassheim 2006). Furthermore, any reduction in energy production that would have resulted in a reduction in mining activity might have been perceived unfavorably by miners (a prominent part of the “working class”) and the communist government was not willing to take that risk (Vaněk 1996). Technical means of desulfurization were also unavailable: the Soviet desulfurization technology was untested and not suitable for the Czech power plants (Kratochvíl 2011), while importing western technology would have been too expensive for a country struggling with a permanent lack of convertible currency (Vaněk 1996). Glassheim (2006) also hypothesizes that the government had rather little interest in reducing pollution and that the central government treated North Bohemia as “an experiment” in producing as much energy as possible with minimal costs.

The pollution associated with this “experiment” imposed a considerable burden on the local population, but they were willing to bear it—at least to some degree. Glassheim (2006) explains this attitude in the context of the post-World War II resettlement of the

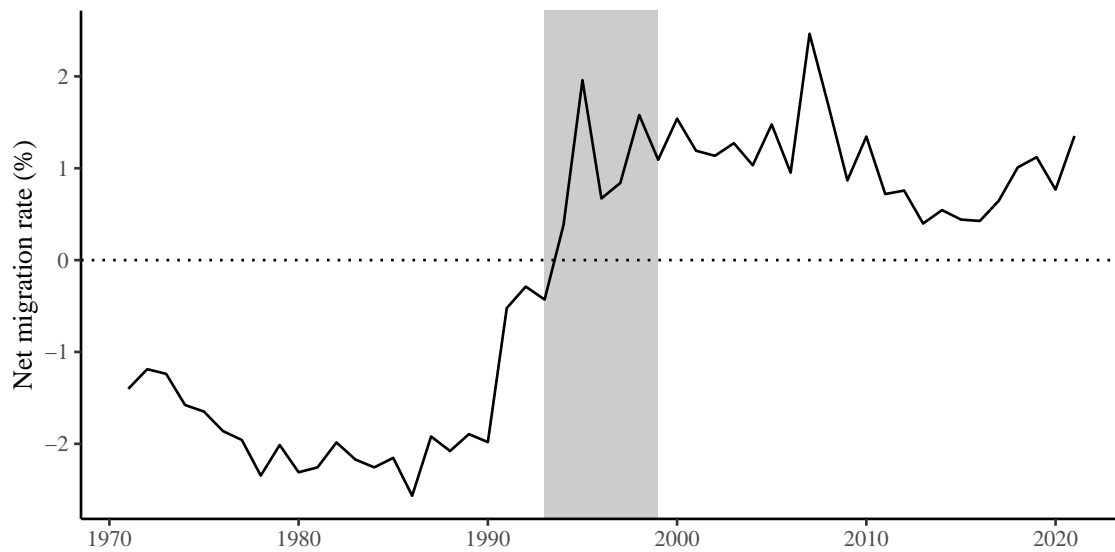


Figure 3: Net migration rate in North Bohemian municipalities (1971–2015)

Source: CZSO (see Section 3)

region: the North Bohemian region was originally primarily populated by ethnic Germans, who were forcibly expelled from the country in the aftermath of the Second World War.<sup>7</sup> The empty towns and villages were then resettled, largely by inhabitants from inland regions of today’s Czech Republic who had little or no ties to the region (see Guzi et al. 2021, for details on this resettlement process). Glasheim (2006) claims that, with the help of communist government propaganda, coal and coal mining, became pillars of the newly established regional identity. That identity may in turn have increased the new local population’s willingness to bear the environmental burden caused by heavily mining and burning coal. However, despite the fact that North Bohemia’s inhabitants may have been relatively more tolerant towards pollution than others, the region continued to experience negative net immigration rates throughout the 1970s and 1980s (see Figure 3).

This steady de-population tendency posed a threat to the regime’s production goals. Consequently, the government implemented a series of policies designed to quell it, in the form of various monetary and non-monetary benefits. Policies with the aim of attracting newcomers into the region were substantial and targeted high-skilled professionals in particular. For instance, newcomers could receive house-building subsidies (up to 186% of the average annual wage in 1985)<sup>8</sup> or recruitment benefits (up to 29% of the average annual wage in 1985).<sup>9</sup> On the other hand, the benefits designed to keep workers in the region

7. See Section 5.3.2 for a more detailed description.

8. 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 7<sup>th</sup> 2019).

9. For a comprehensive list of monetary and non-monetary benefits see Appendix Textbox A.1.



were more universal, but far less generous. Anyone who worked in the basin districts (four of the six districts in the region) for at least 10 years was eligible for an annual monetary benefit of 5.7% of the average annual wage in 1985. Locals used to refer to this as “burial benefit” (“*pohřebné*”).

In total, the various benefits paid raised the income of workers in North Bohemia above the country-wide level (Vaněk 1996). However, in the late 1980s, median wages slowly converged to the country level. According to Vaněk (1996) this convergence increased the North Bohemian population’s frustration, which grew under the lid of the authoritarian regime and eventually boiled over in 1989. The first environmental demonstration in Czechoslovakia took place on May 1989. A strong temperature inversion on November 8<sup>th</sup> 1989 then led to a call for demonstrations in North Bohemia and more than a thousand locals attended a series of demonstrations in Teplice between 11<sup>th</sup> and 13<sup>th</sup> November 1989. They demanded action to reduce air pollution, with slogans such as “We want healthy children!” and “We want clean air!”. Other cities in the North Bohemian coal basin later joined the protests (Vaněk 1996). On November 17<sup>th</sup> 1989, shortly after the series of demonstrations in Teplice, the major anti-regime demonstration which marked the beginning of the Velvet revolution and the fall of the communist regime in Czechoslovakia took place in Prague. It was thus not the Communist Party but rather the new government, sworn in on 10<sup>th</sup> December 1989, whose task it was to respond to these demands. The new government launched a complex process of political and economic transition, a fundamental part of which was to draw up legislation introducing policies that would improve the environment and the Czech population’s living conditions. Two major policies were adopted in the early years after the revolution that helped to reduce pollution in North Bohemia: (a) regulation of SO<sub>2</sub> emissions and (b) limitation of lignite mining.

Act no. 309, passed in 1991, set an obligation for the government to provide the general public with full and up-to-date information on air quality and emission sources and established a framework for the regulation of emissions and immissions. The law effectively required the installation of modern desulfurization technologies before December 31<sup>st</sup> 1998—i.e. within seven years.<sup>10</sup> This strict deadline forced existing power plants to implement desulfurization technologies swiftly. The first power plant (Komořany) commenced desulfurization in 1993. Others followed in 1994 and later. The last power plant in the region implemented desulfurization technologies in early 1999 (see Table A.1 in the Appendix).

The government (by Government Act no. 444/1991) also set limits on mining activity which, together with the drop in demand caused by the economic downturn during the

10. The law set an obligation for all emission sources to meet emission limits designed for newly built emission sources equipped with modern up-to-date technology by December 31<sup>st</sup> 1998.

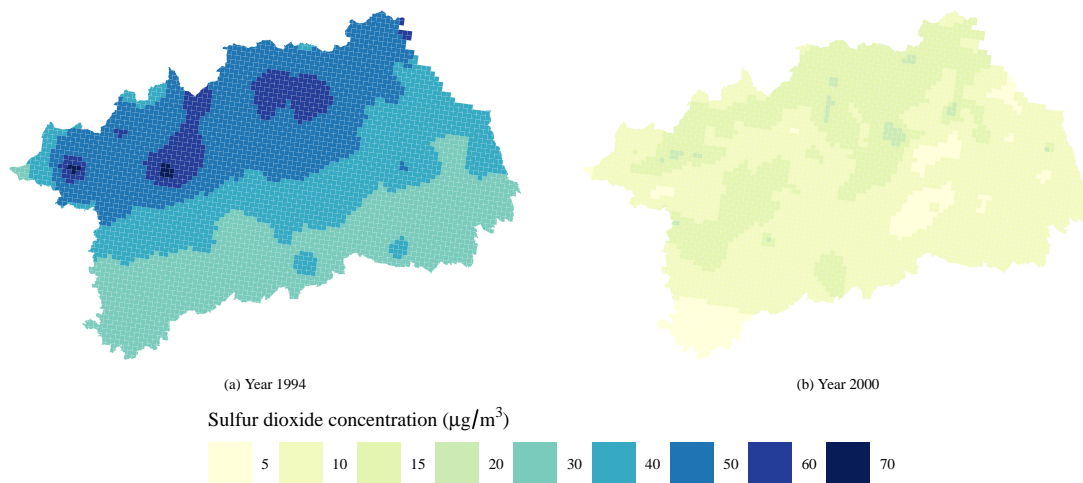


Figure 4: Spatial distribution of SO<sub>2</sub> concentrations in North Bohemia, year 1994 and 2000  
 Source: Czech Hydrometeorological Institute (CHMI, see Section 3)

transition period, led to a decrease in coal production during the 1990s, from 67 million metric tons in 1989 to 40 million metric tons in 2000 (see Figure A.4 in the Appendix). These regulations were later loosened (in 2008 and 2015), but never abolished.

These policies resulted in a rapid decline in SO<sub>2</sub> concentrations (see Figure 2). The mean concentrations in the most heavily polluted districts had dropped below the EU/WHO limit of 20 µg/m<sup>3</sup> by 1999. SO<sub>2</sub> concentrations then remained stable throughout the 2000s and 2010s.

Figure 4 shows the spatial distribution of SO<sub>2</sub> concentrations in North Bohemia in 1994, at the beginning of the desulfurization period (older data are not available) and after the completion of the desulfurization period, in 2000. Despite the fact that SO<sub>2</sub> concentrations were already slightly declining in 1994 (see Figure 2), the EU/WHO limit of 20 µg/m<sup>3</sup> was not met in any municipality in the region at that time. There was substantial variation in the pollution load between municipalities, with average SO<sub>2</sub> concentrations ranging from 30 to 70 µg/m<sup>3</sup>. After desulfurization, the average concentrations in the region dropped below 20 µg/m<sup>3</sup>. The Czech Hydrometeorological Institute (CHMI) dispersion model shows that all municipalities benefited from this substantial decrease in SO<sub>2</sub> emissions, as in the year 2000 the SO<sub>2</sub> concentrations ranged from 5 to 20 µg/m<sup>3</sup> and all the municipalities in the region met the EU/WHO 20 µg/m<sup>3</sup> SO<sub>2</sub> limit, regardless of how high their pollution loads had been in the pre-desulfurization period. The region-wide drop in SO<sub>2</sub> concentrations below the limits makes the change in SO<sub>2</sub> concentrations tightly correlated with pre-desulfurization levels (see Figure 5) with Pearson's  $\rho = -0.95$ .

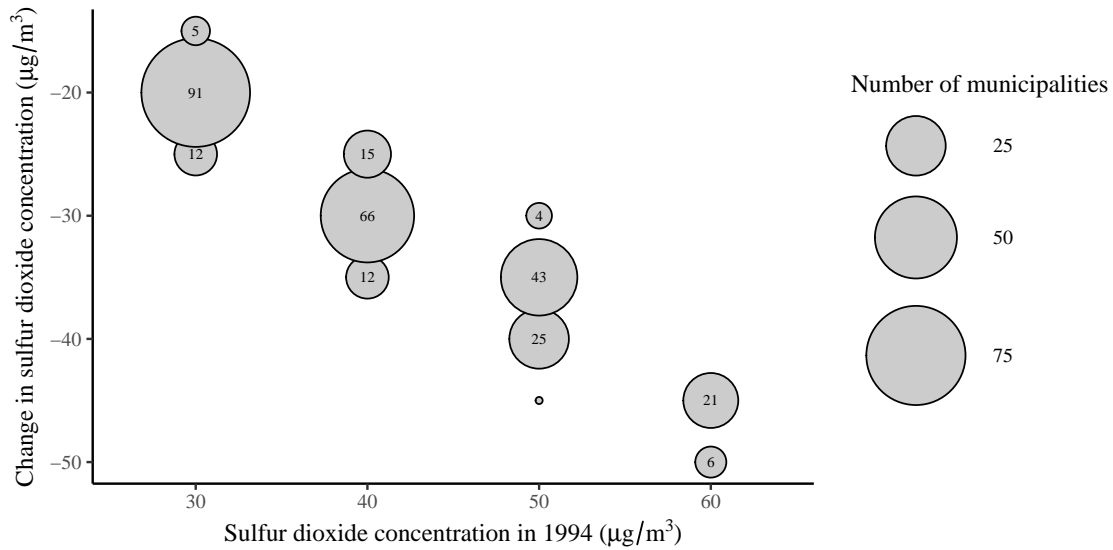


Figure 5: Change in SO<sub>2</sub> concentration between 1994 and 2000 by 1994 SO<sub>2</sub> concentration

The government policies that had been introduced previously to support immigration to North Bohemia and prevent emigration, which we discussed above, were abandoned along with the introduction of the new environmental regulations. The benefits for those who remained in the region long-term were initially maintained (via Acts No. 276/1991 and 471/1991), but were then abolished in early 1992 (via Act no. 1/1992, passed in December 1991).

### 3 Data

The primary data sets used in our empirical analysis are municipality-level data on residential migration and sulfur dioxide concentrations. The annual data on residential migration are compiled by the Czech Statistical Office (CZSO) from administrative records on permanent residence changes in the period from 1971 onwards.<sup>11</sup> People in the Czech Republic were and are legally obliged to register their place of permanent residence. Moreover, they are motivated to keep this registration up to date, as preferential access to some public services is granted on the basis of permanent residence (such as kindergartens, elementary schools or local health care). The dataset contains information on the numbers of people who moved in and out of each municipal area in each year. For the purposes of our analysis, we calculate annual municipality-level emigration and immigration rates as the number of movers per resident population, using those gross emigration and immigration levels, and population as of January 1<sup>st</sup>. Some records on residential migration, mostly from smaller

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

municipalities, are missing due to changes in municipality boundaries or because they were lost before the records were digitized.

We utilize two sources of data on municipality-level air pollution. First, concentrations of SO<sub>2</sub> and other pollutants are measured by a network of ground measuring stations run by the Czech Hydrometeorological Institute (CHMI). This network is unfortunately too sparse to provide reliable municipality-level pollution data and therefore not optimal for our empirical analysis, but it does at least enable us to observe the long-term development of overall SO<sub>2</sub> concentrations in the region for our descriptive evidence (as depicted in Figure 2).<sup>12</sup> Our second source of data on municipality-level pollution concentration comes from a proprietary CHMI dispersion model, which takes into account local meteorological and topographic conditions as well as pollution source characteristics. The detailed resolution of the dispersion model on a 1 km grid allows us to capture pollution distribution at municipality level, represented by coordinates of their reference points, and provides us with the richer data we need for our empirical analysis.<sup>13</sup> We use data from two iterations of the model: for 1994 (the oldest iteration available) and for the year 2000 (the year after the desulfurization programme completion). The CHMI dispersion model provides pollution-level categories rather than predictions on a continuous scale. The model categorizes municipalities into five groups by SO<sub>2</sub> concentrations in 1994: 30, 40, 50, 60, and 70 µg/m<sup>3</sup>; and four groups in 2000: 5, 10, 15, and 20 µg/m<sup>3</sup> (see Figure 4).<sup>14</sup>

We also make use of data on municipalities' population characteristics from decennial population censuses. Municipality-level census data on population, education and age structure are available for the 1980, 1991, 2001, and 2011 censuses. For the period from 1991 onwards, the CZSO has also published yearly data on municipalities' population structure, compiled from census and registry data.<sup>15</sup> Furthermore, we exploit information from the 1930 Census on the ethnic composition of the municipalities' population in 1930.<sup>16</sup>

Lastly, we employ several other datasets in our analysis. We use the ArcČR 500 v3.3 map collection to define the administrative borders of the examined municipalities and to

12. Data from individual measuring stations are available from CHMI website: [https://www.chmi.cz/files/portal/docs/uoco/historicka\\_data/OpenIsko\\_data/index.html](https://www.chmi.cz/files/portal/docs/uoco/historicka_data/OpenIsko_data/index.html). Frequent changes in the measuring network (in the locations, number of stations, and technology used) do not allow us to construct consistent long-term time series for the individual measuring stations.

13. The municipal reference point, as defined by the CZSO, is placed at a social central point within each municipality (such as in the front of a church or town hall).

14. Figure A.3 in the Appendix compares values predicted by the dispersion model with annual averages from ground measuring stations. The Figure shows that the dispersion model somewhat overestimate the pollution concentrations. On the other hand it correctly orders measuring stations by SO<sub>2</sub> concentrations.

15. Census data are accessible at the website of the CZSO (<https://www.czso.cz/csu/sldb/home>) or are available upon request. The yearly data on age structure are not publicly available.

16. The data were digitized by Guzi et al. (2021). They use aggregation rules provided by the CZSO to match current and historical municipalities.

make geospatial visualizations.<sup>17</sup> Further, we obtain altitude data from remotely sensed elevation grid data from the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global.<sup>18</sup> The altitude of each municipality is defined as the altitude at the municipality reference point. The driving distances between the municipalities are calculated using Open street map (OSM) data<sup>19</sup> and GraphHopper navigation software (version 7.0). To capture the yearly municipality-level unemployment rate we use administrative data on registered unemployment. These data are unfortunately only available from 2001 onwards.<sup>20</sup> Our data on man-made amenities come from the MOS database on regions and municipalities, administered by the CZSO.<sup>21</sup>

### 3.1 Estimation sample

Our identification exploits the variation of SO<sub>2</sub> concentration over time and space—i.e., among municipalities in North Bohemia (which are our units of observation) and between the pre- and post-desulfurization period.

The spatial distribution of SO<sub>2</sub> concentration is taken from the CHMI dispersion model, the oldest available iteration of which is for the year 1994—the first year of the widespread implementation of desulfurization technologies. With no other data available, we use this iteration to capture pre-desulfurization levels of SO<sub>2</sub> concentration across the North Bohemian municipalities. The validity of the spatial distribution in 1994 for the spatial distribution in the entire pre-desulfurization period is limited by changes in emission sources over time. Therefore, we limit our sample to the period after the construction of the last coal-burning power plant in the area was completed in 1982. Between 1983 and 1993 there were no changes in the structure (i.e., in the number, location or power output) of the region’s major emission sources. The use of spatial distribution of pollution levels from 1994 for the whole pre-desulfurization period is further justified by the remarkable stability of SO<sub>2</sub> levels in both the pre- and post-desulfurization periods evidenced in the data from the CHMI network of stations (see Figure 2).

As we mentioned above, environmental concerns were one of the issues central to the 1989 protests. People expected the new government to take decisive measures to improve the environment. The government swiftly addressed this demand by passing several laws and regulations in 1991. To ensure that our results are not driven by (legitimate) expectations

17. This map collection, developed by ARCDATA PRAHA, is available at <https://www.arcdata.cz/produkty/geograficka-data/arccr-500> (last accessed on June 26<sup>th</sup> 2019).

18. For data access see <https://www2.jpl.nasa.gov/srtm/dataprod.htm> (last accessed on December 4<sup>th</sup> 2019).

19. The OSM database for the Czech Republic was downloaded from [geofabrik.de](https://www.geofabrik.de) on May 1<sup>st</sup> 2023.

20. The data collected by the Czech Labor Office is available from <https://portal.mpsv.cz/sz/stat/nz/uzem> (last accessed on June 26<sup>th</sup> 2019).

21. Historical records from the MOS database are not publicly accessible, but can be purchased from the CZSO—see <https://vdb.czso.cz/mos/>.

for the future improvement of the environment, we exclude the period 1990–1991 from our estimation sample. Moreover, migration behavior in the 1990s is likely to have been driven by expectations of a future cleaner environment, fueled by the ongoing desulfurization process, rather than by actual pollution levels. As a result, we define the pre-desulfurization period as the years 1983–1989 and the post-desulfurization period as the years 2000–2015.

The CHMI dispersion model calculates SO<sub>2</sub> concentrations in five levels between 30 and 70 μg/m<sup>3</sup> in 1994, which we use to essentially categorize municipalities based on their pre-desulfurization pollution levels. The highest level of 70 μg/m<sup>3</sup> is calculated for only one municipality: the district capital Chomutov. As we estimate the effect of desulfurization for each pollution level to reflect the potentially non-linear effect of air pollution, the effect for this pollution level would be estimated using only one independent observation. Therefore, we exclude Chomutov from the estimation sample used in our main analysis, and work with only four 1994 SO<sub>2</sub> concentration levels (30, 40, 50 and 60 μg/m<sup>3</sup>) to categorize the municipalities according to pollution<sup>22</sup>. Overall, our baseline estimation sample thus contains data for 301 municipalities for the years 1983–1989 and 2000–2015, a total of 6,229 data-points.

### 3.2 Descriptive evidence

The region we examine has a specific topography which, together with the location of lignite deposits, determined the relationship between pollution load and municipalities' characteristics. Mines and power plants were located at the feet of the mountains on the border with (East) Germany. These mountains limited the dispersion of emissions. As a result, more polluted municipalities tended to be located in higher altitudes and closer to the border.

As can be seen in Table 1, the more polluted municipalities also seem to be substantially larger in terms of population. Despite the existing differences in population size, the population structure in terms of education and age across the groups of municipalities is comparable (see Tables A.2 and A.3 in Appendix). The more polluted municipalities were more heavily affected by post-war expulsion and resettlement: the pre-war share of ethnic Germans was more than twice as high in highly polluted municipalities as in the least polluted municipalities in our sample (see Table 1).

Regarding population movement, both emigration and immigration rates differed between the pre- and post-desulfurization periods, see Table 2, Panel A and B. The mean emigration rate in the pre-desulfurization period reached 5.2% and the immigration rate 3.1%. After desulfurization, which reduced the SO<sub>2</sub> concentration to below EU and WHO

22. However, we re-run our analysis with all the data, including Chomutov, as part of our robustness checks.

Table 1: Descriptive statistics: Population, pollution load, and other time-invariant characteristics by SO<sub>2</sub> concentration

	Year	Municipalities in estimation sample					
		All	By SO <sub>2</sub> concentration (1994)				
			30 $\mu\text{g}/\text{m}^3$	>30 $\mu\text{g}/\text{m}^3$			
				All	40 $\mu\text{g}/\text{m}^3$	50 $\mu\text{g}/\text{m}^3$	60 $\mu\text{g}/\text{m}^3$
(1)	(2)	(3)	(4)	(5)	(6)		
SO <sub>2</sub> concentration ( $\mu\text{g}/\text{m}^3$ )	1994	40.63 (0.56)		46.58 (0.51)			
	2000	11.11 (0.17)	9.68 (0.19)	11.92 (0.23)	10.16 (0.28)	13.42 (0.35)	13.89 (0.41)
Population	1980	2189.87 (457.29)	880.11 (182.86)	2870.08 (683.48)	1526.87 (438.12)	4129.21 (1476.15)	3771.27 (2062.93)
	1991	2327.62 (530.05)	886.37 (176.41)	3130.13 (813.91)	1615.58 (497.38)	4748.40 (1848.96)	3598.15 (2016.66)
	2001	2110.81 (464.42)	824.90 (162.69)	2830.39 (714.02)	1393.43 (402.67)	4355.64 (1654.62)	3656.07 (1973.76)
	2011	2145.70 (457.30)	865.46 (162.45)	2862.10 (702.80)	1409.48 (387.07)	4394.44 (1630.81)	3722.59 (1944.76)
			286.32 (8.08)	242.96 (9.38)	310.57 (11.10)	266.52 (12.32)	350.31 (19.49)
Terrain roughness index (TRI)		2.48 (0.082)	1.78 (0.072)	2.87 (0.11)	2.70 (0.17)	3.20 (0.16)	2.56 (0.25)
Share of ethnic Germans (%)	1930	54.24 (2.23)	26.81 (3.73)	69.66 (2.07)	60.56 (3.60)	77.84 (2.11)	79.28 (3.30)
Municipalities (n)		301	108	193	93	73	27

Notes: Table reports means and standard errors in parentheses.

Table 2: Migration rates by period and SO<sub>2</sub> concentration

	Municipalities in estimation sample					
	All	By SO <sub>2</sub> concentration (1994)				
		30 μg/m <sup>3</sup>	>30 μg/m <sup>3</sup>			
			All	40 μg/m <sup>3</sup>	50 μg/m <sup>3</sup>	60 μg/m <sup>3</sup>
(1)	(2)	(3)	(4)	(5)	(6)	
<i>Panel A: Emigration rate</i>						
Post-desulfurization period (%)	3.46 (0.074)	3.09 (0.092)	3.67 (0.10)	3.56 (0.12)	3.84 (0.20)	3.62 (0.21)
Pre-desulfurization period (%)	5.21 (0.22)	3.77 (0.15)	5.85 (0.30)	5.08 (0.41)	6.46 (0.48)	5.89 (0.69)
Difference (p.p.)	-1.74*** (0.20)	-0.68*** (0.15)	-2.18*** (0.27)	-1.52*** (0.40)	-2.62*** (0.42)	-2.27*** (0.54)
<i>Panel B: Immigration rate</i>						
Post-desulfurization period (%)	4.58 (0.11)	4.05 (0.13)	4.88 (0.16)	4.54 (0.19)	5.26 (0.32)	5.01 (0.27)
Pre-desulfurization period (%)	3.05 (0.12)	2.59 (0.18)	3.26 (0.16)	3.48 (0.27)	2.99 (0.22)	3.46 (0.43)
Difference (p.p.)	1.53*** (0.17)	1.46*** (0.21)	1.62*** (0.23)	1.06*** (0.32)	2.27*** (0.39)	1.55*** (0.55)
<i>Panel C: Net migration rate</i>						
Post-desulfurization period (%)	1.12 (0.074)	0.96 (0.081)	1.21 (0.11)	0.99 (0.12)	1.42 (0.22)	1.39 (0.19)
Pre-desulfurization period (%)	-2.16 (0.25)	-1.18 (0.19)	-2.60 (0.35)	-1.60 (0.41)	-3.47 (0.57)	-2.43 (0.89)
Difference (p.p.)	3.28*** (0.29)	2.14*** (0.21)	3.80*** (0.40)	2.58*** (0.46)	4.89*** (0.71)	3.82*** (0.94)
Municipalities (n)	301	108	193	93	73	27

Notes: Table reports means and robust standard errors clustered by municipality in parentheses. Differences are tested for statistical significance: \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%.

limits, the emigration rate dropped by 1.7 percentage points, while the immigration rate rose by 1.5 percentage points (see column (1) in Table 2).

These changes in emigration and immigration are reflected in the development of the net migration rates<sup>23</sup>, see Table 2, Panel C, which shows that in the pre-desulfurization period, the region experienced a negative net immigration rate with a mean of -2.2% per year despite the pro-immigration and anti-emigration policies in place at the time. The mean net migration rate in the post-desulfurization period rose by 3.3 percentage points to 1.1%. Further, Figure 3 shows long-term development in the average net migration rate over the years 1971–2015. As can be seen, the net migration rate turned to positive after the beginning of the desulfurization process. This evidence suggests that the substantial

23. Defined as immigration minus emigration by population.



reduction in air pollution brought about through desulfurization increased the region's attractiveness.

The same patterns hold for differences between the least- and the worst- polluted municipalities in the estimation sample. The emigration rate from the worst-polluted municipalities exceeded the emigration rate from the least-polluted municipalities by between 1.3 and 2.7 p.p. in the pre-desulfurization period. This gap substantially narrowed, to 0.5–0.7 p.p., after desulfurization. The development of the immigration rate was less dynamic. In the pre-desulfurization period, the worst-polluted municipalities experienced slightly higher immigration rates (by 0.4 up to 0.9 p.p.) relative to the least-polluted municipalities. After desulfurization the gap slightly increased (by 0.5 up to 1.2 p.p.).

If we look at changes in the emigration and immigration rates within municipality-groups between the pre- and post-desulfurization periods, the third rows in Panels A and B of Table 2 show that the least-polluted municipalities experienced the smallest decrease in emigration rate relative to more heavily-polluted municipalities, whereas the increase in immigration rate in the least-polluted municipalities was only slightly lower or comparable to other groups of municipalities with higher pollution levels. These changes signal a possible higher relative increase in attractiveness in formerly highly polluted municipalities than in formerly less polluted municipalities, after the environment had become cleaner. Developments in net migration, shown in Panel C of Table 2, again mirror the development in emigration and immigration rates. Clearly, the more polluted a particular municipality was in the past, the more attractive it became for re-population after the air had become substantially cleaner thanks to the implementation of desulfurization technology at the power plants.

Figure 6 shows development in the emigration and immigration rates, respectively, by pollution levels, from 1983 through to 2015, including the whole of the desulfurization period (1994–1999). As Figure 6 reveals, there was a strong decline in emigration rates shortly after the fall of communism; that decline was particularly sharp in 1991, when the new environmental legislation was adopted. The emigration rates dropped at this stage for all groups of municipalities, even those whose pollution levels were still high at that time. This could be due to expectations of a future reduction in pollution supported by the new legislation.

On the contrary, the fall of communism seems not to have any clear immediate effect on immigration rates, as can be seen in Figure 6: the overall increase in immigration rates did not start until mid-nineties, once the implementation of desulfurization technology at the power-plants was already effective.

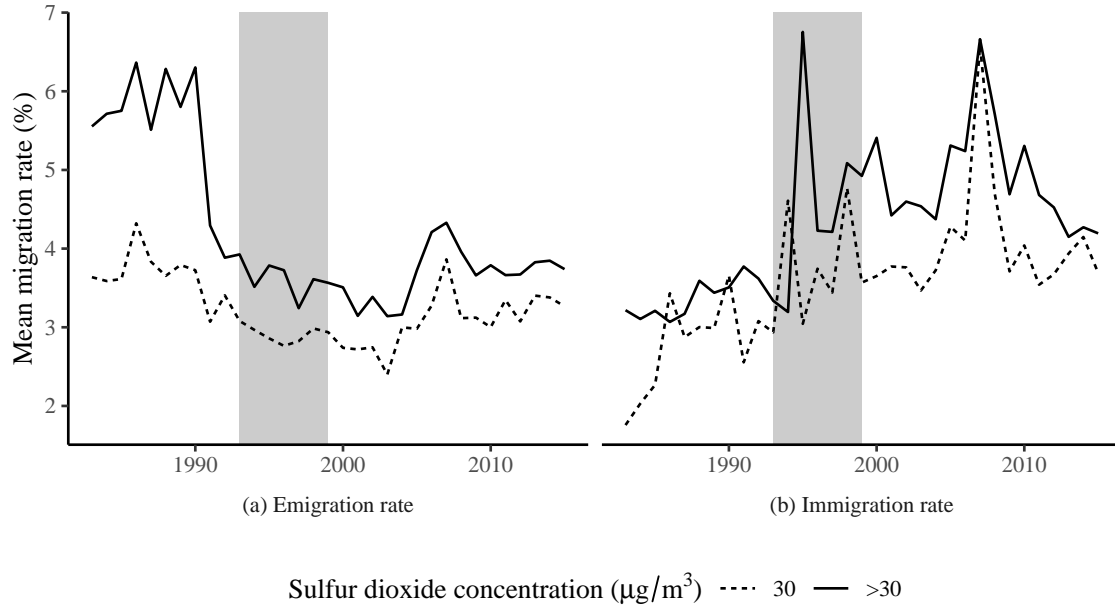


Figure 6: Migration rates in municipalities in North Bohemia by 1994  $\text{SO}_2$  concentration, years 1983–2015

Source: CZSO (see Section 3)

## 4 Identification strategy and empirical specification

Our identification strategy rests on comparing differences in migration rates between municipalities with the lowest and highest levels of pollution in the pre- and post-desulfurization periods. To do so, we employ the difference-in-differences (DID) framework, which ensures that our estimates are not driven by substantial country-wide changes that affected all municipalities alike (such as the fall of communism and institutional changes in the transition period). To estimate the impacts of pollution on migration, we estimate the following regression:

$$mig_{it} = \gamma \text{SO}40_i p_t + \sum_k \beta_k l_k + \theta_p + \theta_i + \varepsilon_{it} \quad (1)$$

where  $mig$  is the migration rate in municipality  $i$  and in year  $t$  (we estimate separate models for emigration, immigration and net migration rate),  $p_t$  is a dummy variable, which is equal to 1 for the post-desulfurization period (2000–2015) and 0 for the pre-desulfurization period (1983–1989).

To capture the overall effect of the reduction in air pollution due to desulfurization, we interact the dummy variable for the post-desulfurization period with an indicator variable ( $\text{SO}40$ ) for municipalities whose  $\text{SO}_2$  concentrations in the pre-desulfurization period were

greater than or equal to  $40 \mu\text{g}/\text{m}^3$ .<sup>24</sup> Specification (1) also contains a full set of municipality fixed effects, including a constant that controls for all time-invariant differences (such as geographical location, natural amenities or post-World War II resettlement heritage) and hence ensures that we are estimating the effect of the municipality's  $\text{SO}_2$  concentrations. We also include an indicator variable for the post-desulfurization period ( $\theta_t$ ). To capture possible time-variant regional characteristics, we divide the region into three areas orthogonal to pollution levels<sup>25</sup> and include a linear trend ( $l$ ) specific for each area and period.

As the effect of desulfurization could potentially be non-linear in the pre-desulfurization  $\text{SO}_2$  concentrations, we also estimate the following specification (2):

$$mig_{it} = \sum_j \gamma_j \text{SO}_i p_t + \sum_k \beta_k l_k + \theta_p + \theta_i + \varepsilon_{it} \quad (2)$$

where the effect is estimated separately for each category of municipalities (a vector of indicator variables  $\text{SO}$ ) defined by pre-desulfurization  $\text{SO}_2$  concentrations ( $40$ ,  $50$ , and  $60 \mu\text{g}/\text{m}^3$ ). The category of the least polluted municipalities ( $30 \mu\text{g}/\text{m}^3$ ) is our reference group in both specifications. The reference category exceeds the EU/WHO  $20 \mu\text{g}/\text{m}^3$  limits for developed countries by 50%. The parameters therefore represent a lower bound estimate of the true effect of desulfurization, which decreased pollution levels to or below the  $20 \mu\text{g}/\text{m}^3$  limit in all municipalities.

In an alternative specification, we define the treatment variable as a change in  $\text{SO}_2$  concentration levels between pre- and post-desulfurization period. Results reported in Table A.5 in Appendix are numerically almost identical to our baseline estimates. This is due to the close correlation ( $\rho = -0.95$ ) between the pre-desulfurization  $\text{SO}_2$  levels and the air pollution reduction the municipalities experienced during the desulfurization period.<sup>26</sup>

24. The pre-desulfurization  $\text{SO}_2$  concentrations are a good approximation for the reduction in air pollution, since desulfurization reduced pollution levels to below the EU and WHO limits in all municipalities (see Figure 4).

25. The areas are defined using the border between the basin and the remainder of the region (i.e., the South-West to North-East axis); we divide this border into three equally long segments and assign each municipality to the nearest one. Area is then defined as the set of municipalities nearest to a specific segment.

26. We further perform the parallel trends assumption test, which we discuss and present in the Appendix section B. The test reveals no divergence in trends in the pre-desulfurization period (1983–1989) for emigration and immigration rate, whereas for net migration rate the test is weaker.

## 5 Empirical Results

### 5.1 Main Results

Tables 3 and 4 present estimates of our parameters of interest from regressions (1) and (2) for interaction term of post-desulfurization period and dummies for categories of municipalities that suffered higher SO<sub>2</sub> concentrations in the pre-desulfurization period, capturing the impacts of air pollution reduction—thanks to the adoption of new technology in power plants—on migration rates.

The estimates from regression (1), presented in Table 3, show that the adoption of desulfurization technology affected emigration from municipalities with pre-desulfurization SO<sub>2</sub> concentrations of 40 μg/m<sup>3</sup> or higher. The desulfurization of powerplants and the resulting cleaner environment in these formerly heavily polluted areas decreased emigration rates by 1.4 percentage points, which corresponds to an approx. 24% decline in emigration rate. The impact on the immigration rate is statistically insignificant. Overall, desulfurization contributed to the re-population of the region as it led to an increase in the net migration rate by 1.7 percentage points (approx. 78%) relative to the comparison group. These results suggest that the reduction in air pollution made previously heavily polluted municipalities more attractive for people to live in.

The estimates of the non-parametric regression (2), presented in Table 4, show that the impacts of air pollution reduction tend to be non-linear in pre-desulfurization pollution levels. In particular, we find that the effect of the decline of SO<sub>2</sub> concentrations on emigration from municipalities with heavy initial SO<sub>2</sub> pollution levels (50 and 60 μg/m<sup>3</sup>) is statistically significant and about two times higher than the effect on emigration from municipalities in the category with 40 μg/m<sup>3</sup> SO<sub>2</sub> concentrations. Specifically, the emigration rate in the two initially most heavily polluted categories of municipalities drops by 1.7 and 1.6 p.p. respectively, relative to the initially least polluted category; this corresponds to 26% and 27% lower emigration rates, respectively.

The results for immigration and net migration rates show that both rates increased relative to the reference group in municipalities whose initial SO<sub>2</sub> concentration exceeded 40 μg/m<sup>3</sup>. Municipalities whose pre-desulfurization SO<sub>2</sub> concentrations were as high as 50 μg/m<sup>3</sup> experienced a statistically significant increase in immigration and net immigration rate, by 1.1 and 2.8 p.p. respectively. The estimates for municipalities whose pre-desulfurization SO<sub>2</sub> levels were 60 μg/m<sup>3</sup> are somewhat lower and statistically insignificant for immigration rate; our results show that they experienced an 1.8 p.p. increase in net immigration rate compared to the reference group of the least polluted municipalities.

We acknowledge that estimates must be interpreted with caution as the reduction in air pollution took place in parallel to the abolition of anti-depopulation policies. The analysis

Table 3: Main results

	Dependent variable		
	Emigration rate (%)	Immigration rate (%)	Net migration rate (%)
	(1)	(2)	(3)
Pre-desulfurization SO <sub>2</sub> concentration > 30 μg/m <sup>3</sup> × Post-desulfurization period	-1.381*** (0.282)	0.313 (0.335)	1.695*** (0.470)
R2 Adj.	0.337	0.139	0.133
Num.Obs.	6229	6229	6229

Notes: Table reports  $\gamma$  coefficients from Equation (1). All model specifications include constant, municipality and period fixed effects, and linear trends for each area and period. Robust standard errors clustered by municipality are reported in parentheses: \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%. The reference category for SO<sub>2</sub> concentration is 30 μg/m<sup>3</sup>.

Table 4: Main results: non-linear

	Dependent variable		
	Emigration rate (%)	Immigration rate (%)	Net migration rate (%)
	(1)	(2)	(3)
Pre-desulfurization SO <sub>2</sub> concentration = 40 μg/m <sup>3</sup> × Post-desulfurization period	-0.879** (0.397)	-0.533 (0.378)	0.346 (0.562)
Pre-desulfurization SO <sub>2</sub> concentration = 50 μg/m <sup>3</sup> × Post-desulfurization period	-1.700*** (0.419)	1.061** (0.484)	2.760*** (0.729)
Pre-desulfurization SO <sub>2</sub> concentration = 60 μg/m <sup>3</sup> × Post-desulfurization period	-1.588*** (0.469)	0.171 (0.567)	1.760** (0.856)
R2 Adj.	0.339	0.142	0.140
Num.Obs.	6229	6229	6229

Notes: Table reports  $\gamma$  coefficients from Equation (2). All model specifications include constant, municipality and period fixed effects, and linear trends for each area and period. Robust standard errors clustered by municipality are reported in parentheses: \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%. The reference category for SO<sub>2</sub> concentration is 30 μg/m<sup>3</sup>.

presented in section 5.3.1 shows that the abolition of these policies had no impact on emigration rates. Therefore, we interpret our estimates on emigration rates as causal effects. However, our estimates for immigration and net migration rates cannot be interpreted as such, as we cannot disentangle the effects of reducing air pollution from the effects of abolishing substantial pro-immigration benefits due to the lack of individual-level data. The estimates for immigration rates suggest two possible explanations: (a) The substantial pro-immigration benefits provided in pre-desulfurization period were sufficient to compensate (to some extent) for the disutility from air pollution; or (b) The poor environment in pre-desulfurization period gave the region a bad reputation, which deterred people from moving into the region even after pollution levels had radically decreased.

## **5.2 Robustness analysis and placebo tests**

### **5.2.1 Economic factors and unemployment**

There is a concern with respect to our main findings that the environmental policies introduced in the early 1990s both pushed for desulfurization and, at the same time, limited lignite mining. Desulfurization was achieved through the adoption of new technologies, and therefore *per se* had no or little impact on the labor market. On the other hand, new limits on lignite mining, together with the overall decline during the so-called transition recession, led to mine closures, which may have adversely affected local labor markets, in particular in the more polluted municipalities situated close to mines and power plants. In effect, such a negative shock could affect the migratory responses to air pollution reduction we find in our baseline estimates, as reported in Table 3.

In order to tackle these concerns, we re-estimate regression (1) with additional controls consisting of the municipality-level unemployment rate, defined as the share of registered unemployed on the working-age population (15–64) in the given municipality in the previous year. We report the results in Table 5, in column (1). The municipality-level unemployment data are available only for the periods 2001–2011 and 2013–2015, which limits our post-desulfurization period, and thus the number of observations drops by 15%. We assume the unemployment rate to have been equal to zero before the fall of communism – i.e., in the pre-desulfurization period. The results reported in Table 5, column (1), show no deviation from our baseline estimates (presented in Table 3); the coefficient for the unemployment rate is insignificant and close to zero.

### **5.2.2 Post-desulfurization pollution levels**

The environmental policies introduced in the 1990s decreased SO<sub>2</sub> concentrations to below the EU/WHO limits in the post-desulfurization period. Still, although these administrative

Table 5: Robustness analysis

	Unemploy. rate	SO <sub>2</sub> conc. in post-desulf. period	Education and age structure	Inclusion of Chomutov	Balanced panel	Exclusion of outliers	Adjusted standard errors
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Panel A: Emigration rate</i>							
Pre-desulfurization SO <sub>2</sub> concentration > 30 µg/m <sup>3</sup> × Post-desulfurization period	-1.393*** (0.300)	-1.144*** (0.286)	-1.461*** (0.287)	-1.357*** (0.280)	-1.344*** (0.292)	-1.068*** (0.207)	-1.381*** (0.506)
Unemployment rate (%)	-0.016 (0.019)						
Post-desulfurization SO <sub>2</sub> concentration = 10 µg/m <sup>3</sup> × Post-desulfurization period		-0.379 (0.352)					
Post-desulfurization SO <sub>2</sub> concentration = 15 µg/m <sup>3</sup> × Post-desulfurization period		-0.950* (0.501)					
Post-desulfurization SO <sub>2</sub> concentration = 20 µg/m <sup>3</sup> × Post-desulfurization period		0.415 (0.474)					
R2 Adj.	0.339	0.339	0.341	0.337	0.372	0.334	0.337
Num.Obs.	5326	6229	6229	6252	4485	6164	6229
<i>Panel B: Immigration rate</i>							
Pre-desulfurization SO <sub>2</sub> concentration > 30 µg/m <sup>3</sup> × Post-desulfurization period	0.516 (0.356)	-0.008 (0.354)	0.234 (0.311)	0.298 (0.333)	0.482 (0.341)	0.285 (0.260)	0.313 (0.666)
Unemployment rate (%)	-0.006 (0.043)						
Post-desulfurization SO <sub>2</sub> concentration = 10 µg/m <sup>3</sup> × Post-desulfurization period		0.703 (0.534)					
Post-desulfurization SO <sub>2</sub> concentration = 15 µg/m <sup>3</sup> × Post-desulfurization period		1.385** (0.654)					
Post-desulfurization SO <sub>2</sub> concentration = 20 µg/m <sup>3</sup> × Post-desulfurization period		0.482 (0.575)					
R2 Adj.	0.133	0.140	0.149	0.139	0.149	0.173	0.139
Num.Obs.	5326	6229	6229	6252	4485	6164	6229
<i>Panel C: Net migration rate</i>							
Pre-desulfurization SO <sub>2</sub> concentration > 30 µg/m <sup>3</sup> × Post-desulfurization period	1.910*** (0.495)	1.136** (0.478)	1.695*** (0.449)	1.655*** (0.464)	1.826*** (0.488)	1.386*** (0.342)	1.695 (1.196)
Unemployment rate (%)	0.011 (0.031)						
Post-desulfurization SO <sub>2</sub> concentration = 10 µg/m <sup>3</sup> × Post-desulfurization period		1.082 (0.759)					
Post-desulfurization SO <sub>2</sub> concentration = 15 µg/m <sup>3</sup> × Post-desulfurization period		2.335** (0.999)					
Post-desulfurization SO <sub>2</sub> concentration = 20 µg/m <sup>3</sup> × Post-desulfurization period		0.067 (0.765)					
R2 Adj.	0.123	0.137	0.145	0.132	0.167	0.219	0.133
Num.Obs.	5326	6229	6229	6252	4485	6099	6229

Notes: Table reports  $\gamma_j$  coefficients from Equation (1). All model specifications include constant, municipality, year and area by year fixed effects. In column (1) the baseline specification (2) is extended with the one-year-lagged unemployment rate in the municipality, in column (2) with SO<sub>2</sub> concentrations in the post-desulfurization period (with 5 µg/m<sup>3</sup> as the reference level), and in column (3) interpolated (nearest-neighbor interpolation) values for age structure (shares of age groups 20–29, 30–39, 40–49, 50–59, and 60–69 on total population) and education structure (shares of secondary and tertiary educated on the population aged 15+). In column (4) the estimation sample includes the city of Chomutov. In column (5) the estimation sample is balanced by excluding municipalities for which migration records are missing. In column (6) municipality-year data-points within each year's top 1% values for emigration and immigration rate are excluded from the sample. In case of net migration rate each year's top and bottom 1% values are excluded. Column (7) contains baseline parameter estimates with Conley standard errors with 40 km cutoff reported in parentheses. Robust standard errors clustered by municipality are reported in parentheses in columns (1)–(6); \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%. The reference category for SO<sub>2</sub> concentration in the pre-desulfurization period is 30 µg/m<sup>3</sup>.

limits were met, some variation in the pollution load across the examined municipalities remained (see Figure 4 and Table 1). To test whether post-desulfurization pollution levels played any role in migration behavior, we re-estimate regression (1) with controls for post-desulfurization  $\text{SO}_2$  concentrations. The estimate for the emigration reported in Table 5, column (2), does not deviate significantly from the baseline estimates. At the same time the estimate for the immigration rate is close to zero and insignificant when controlling for post-desulfurization pollution levels.

### 5.2.3 Population and education structure

Even though the municipalities in our sample were comparable in education and demographic structure throughout the observation period, we try in the next step to take care of possible differences in population structure that might have affected migration behavior. We re-estimate regression (2) with a number of additional demographic controls, such as the share of secondary and tertiary educated and the share of age cohorts (20–29, 30–39, 40–49, 50–59, 60–69) on the population. All those controls enter the regression lagged by one year. We obtain the data on population characteristics primarily from decennial censuses held in 1980, 1991, 2001, and 2011. In order to make use of the entire wealth of our data, we use interpolate yearly values for the years between census years. For the population structure between 1991 and 2015, we use census data adjusted with population registry data from the CZSO.<sup>27</sup> We interpolate the remaining missing values using nearest-neighbor interpolation.<sup>28</sup> The results from our main regression (1) controlling for these municipality-level demographic characteristics are reported in column (3) of Table 5 and show that the estimated coefficients do not differ when controlling for these demographic characteristics.

### 5.2.4 Other robustness checks

In the next step, we run a number of further robustness checks and re-estimate regression (1) using differently specified samples. First, we include the only municipality with a pre-desulfurization  $\text{SO}_2$  concentration of  $70 \mu\text{g}/\text{m}^3$  (the district capital Chomutov) into our data sample. Including the district capital in the sample has virtually no effect on estimated migratory responses in comparison to the baseline estimates, see column (4) of Table 5.

Next, we restrict our data sample to a balanced panel of municipalities and exclude municipalities for which migration records are missing. As can be seen from Table 5, column (5), balancing the panel has no impact on our results.

27. The dataset is not publicly available, but can be purchased from the CZSO for academic use.

28. The results obtained with piece-wise linear interpolation do not deviate significantly; these results are available upon request.



We then proceed to test the robustness of our results to the presence of potential outliers. These outliers may occur due to mine expansions (as in the case of the city of Most) or other unobserved factors such as natural disasters. To the best of our knowledge, there is no comprehensive database of such events that would enable us to control for them. In order to check that our results are not driven by such outliers, we re-estimate regression (2) using a sample without the top 1% observations for each year for emigration and immigration rate, and without top and bottom 1% for net migration rate. As can be seen from Table 5, column (6), the estimated coefficients are similar and statistically significant, although slightly lower in magnitude by up to 0.4 p.p.

In our final robustness check, we adjust standard errors for spatial auto-correlation with a procedure suggested by Conley (1999). The Conley standard errors are larger than the robust clustered standard errors, see Table 5, column (7). However, the estimate for emigration rate remains statistically significant at 1% level.

### **5.2.5 Placebo tests**

In our main analysis, we treat the 1992–1999 desulfurization period as an event that triggered changes in residential migration. However, the identified effect could be caused by some other event that coincided with desulfurization. To exclude that possibility, we perform two placebo tests. Specifically, we split the true pre- and post-desulfurization periods into (a) placebo pre- (1983–1986,) and (b) placebo post-desulfurization (2008–2015 respectively) periods and re-estimate regression (2) separately for each of those two “placebo” periods as if the desulfurization tech adoption had happened in 1986 with analysis limited to the years 1983–1989, or in 2006 with analysis limited to the years 2000–2015. The idea is that if we find that “placebo desulfurization” had any effect on migration, there would be reason to be suspicious about our main estimates. We present estimates from these placebo analyses in Table 6, with estimates for the 1983–1989 period shown in Panel A, and estimates for the 2000–2015 period shown in Panel B. As can be seen from the results, none of the placebo estimates are statistically significant, which supports the results of our main analysis presented above.

Table 6: Placebo tests

	Dependent variable		
	Emigration rate (%)	Immigration rate (%)	Net migration rate (%)
	(1)	(2)	(3)
<i>Panel A: Pre-desulfurization period (placebo cutoff at 1987)</i>			
Pre-desulfurization SO <sub>2</sub> concentration > 30 µg/m <sup>3</sup>	-0.006	-0.291	-0.284
× Post-desulfurization period	(0.260)	(0.253)	(0.332)
R2 Adj.	0.579	0.342	0.502
Num.Obs.	1413	1413	1413
<i>Panel B: Post-desulfurization period (placebo cutoff at 2007)</i>			
Pre-desulfurization SO <sub>2</sub> concentration > 30 µg/m <sup>3</sup>	-0.095	-0.340	-0.245
× Post-desulfurization period	(0.130)	(0.223)	(0.223)
R2 Adj.	0.257	0.168	0.056
Num.Obs.	4816	4816	4816

Notes: Table reports  $\gamma_j$  coefficients from Equation (1). All model specifications include constant, municipality and post-desulfurization fixed effects, and linear trends for each area and period. Robust standard errors clustered by municipality are reported in parentheses: \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%. The reference category for SO<sub>2</sub> concentration is 30 µg/m<sup>3</sup>.

## 5.3 Factors shaping the migratory response to air pollution

### 5.3.1 The role of anti-emigration government policies

The baseline results in Table 3 suggest that higher pollution loads made staying in the given municipality less desirable, i.e., acted as a strong push factor. This effect could, however, have been partially affected by the government policies in place in the pre-desulfurization era, which were designed to keep workers in the area and may have compensated the disutility from air pollution.

Eligibility for anti-emigration benefits was determined by location and length of work. Only those who worked in municipalities in the basin districts for a period of more than 10 years were eligible for benefits in the form of an annual monetary transfer of 2,000 Czechoslovak crowns (i.e., 5.7% of the average annual wage in 1985). This monetary benefit was abolished in early 1992 along with the introduction of new environmental regulations.

To disentangle the role of these anti-emigration government policies from the effects of air pollution reduction on emigration, we utilize the fact that workers were eligible for these benefits in some of the municipalities in our sample (hereafter “qualifying municipalities”), whereas workers based in other municipalities were not eligible (hereafter “non-qualifying municipalities”). Figure 7 shows that the qualifying municipalities were clustered in a

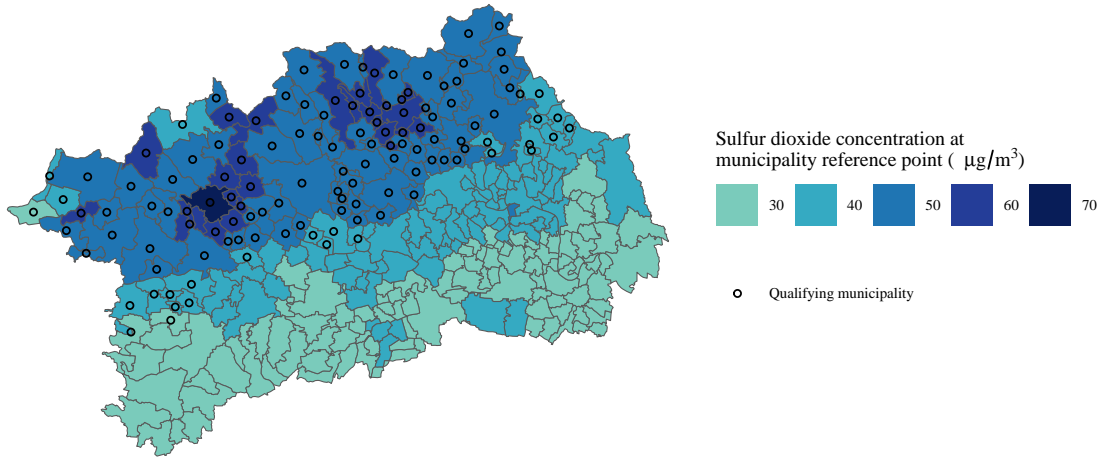


Figure 7: SO<sub>2</sub> concentrations in 1994 and qualifying municipalities in the pre-desulfurization period

Source: Czech Hydrometeorological Institute (CHMI), ArcČR 500 v3.3, see Section 3.

compact area within the northern part of North Bohemia. Eligibility was correlated with pollution load: all the municipalities in areas with initial SO<sub>2</sub> concentrations with 50 µg/m<sup>3</sup> and higher were eligible for benefits, whereas there was variation in eligibility among the less polluted municipalities. The share of qualifying municipalities in our estimation sample is 32% ( $n = 35$ ) among the least polluted and 74% ( $n = 69$ ) among municipalities with SO<sub>2</sub> concentrations equal to 40 µg/m<sup>3</sup>.

To disentangle the effects of air pollution and anti-emigration benefits, we extend the baseline specification (2) to triple DID using eligibility for benefits as an additional dimension, yielding the following specification:

$$mig_{it} = \sum_j \gamma_j SO_{ip_t} + \sum_j \delta_j SO_{ip_t} b_i + \alpha p_t b_i + \sum_k \beta_k l_k + \theta_p + \theta_i + \varepsilon_{it} \quad (3)$$

where  $b_i$  is an indicator variable for qualifying municipalities. We estimate equation (3) on a sample limited to municipalities whose pre-desulfurization SO<sub>2</sub> concentrations were equal to or below 40 µg/m<sup>3</sup>.

The results of our triple difference empirical specification are presented in column (1) of Table 7. As can be seen, the triple difference term is insignificant, suggesting that anti-emigration policies had no impact on emigration decisions.

Workers' municipality of residence could, however, have been different from the municipality in which they worked, and it was the latter that in fact influenced the workers' eligibility for benefits. To account for potential distortions, we construct a continuous treatment intensity measure reflecting the importance of benefits for each municipality.

Table 7: Impact of monetary benefits on migratory response to air pollution

	Eligibility for benefits	
	Indicator variable	Treatment intensity
	(1)	(2)
Pre-desulfurization SO <sub>2</sub> concentration = 40 μg/m <sup>3</sup> × Eligibility for benefits × Post-desulfurization period	-1.138 (1.619)	-0.587 (1.933)
Pre-desulfurization SO <sub>2</sub> concentration = 40 μg/m <sup>3</sup> × Post-desulfurization period	-0.683** (0.314)	-0.583* (0.313)
Post-desulfurization period × Eligibility for benefits	0.500 (1.150)	-0.422 (1.346)
Adjusted R <sup>2</sup>	0.245	0.245
Observations	4,007	4,007

Notes: Table reports  $\gamma_j$  coefficients from Equation (3) with the emigration rate as a dependent variable. All model specifications include constant, municipality and post-desulfurization fixed effects, and linear trends for each area and period. Robust standard errors clustered by municipality are reported in parentheses: \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%. The reference category for SO<sub>2</sub> concentration is 30 μg/m<sup>3</sup>.

For each municipality, we use 1991 census data to calculate the share of economically active residents working in municipalities eligible for benefits. Figure 8 shows minimum variation in the intensity measure across all groups of municipalities except those with pre-desulfurization SO<sub>2</sub> concentrations of 40 μg/m<sup>3</sup>. This is not surprising, since those municipalities are typically located on the border between qualifying and non-qualifying areas (see Figure 7). This outcome suggests that the region's inhabitants commuted short distances (i.e., their municipalities of work and residence had similar levels of pollution).

In the next step, we re-estimate regression (3) with  $b_i$  being the treatment intensity measure in municipality  $i$ . The results are shown in column (2) in Table 7.

The triple difference term is statistically insignificant for both specifications. None of our results, therefore, indicates that benefits influenced the observed effect on the emigration rate.

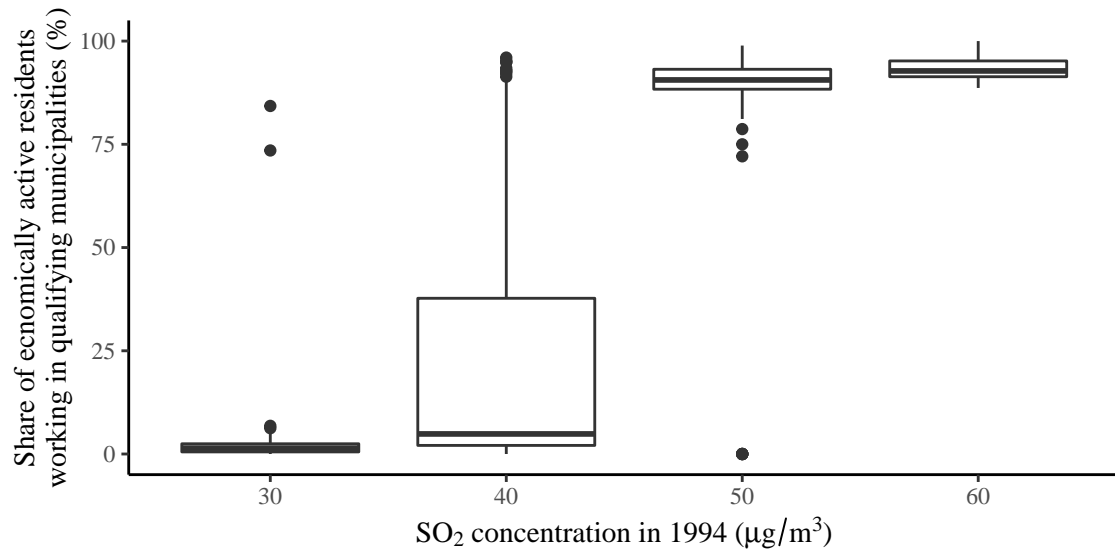


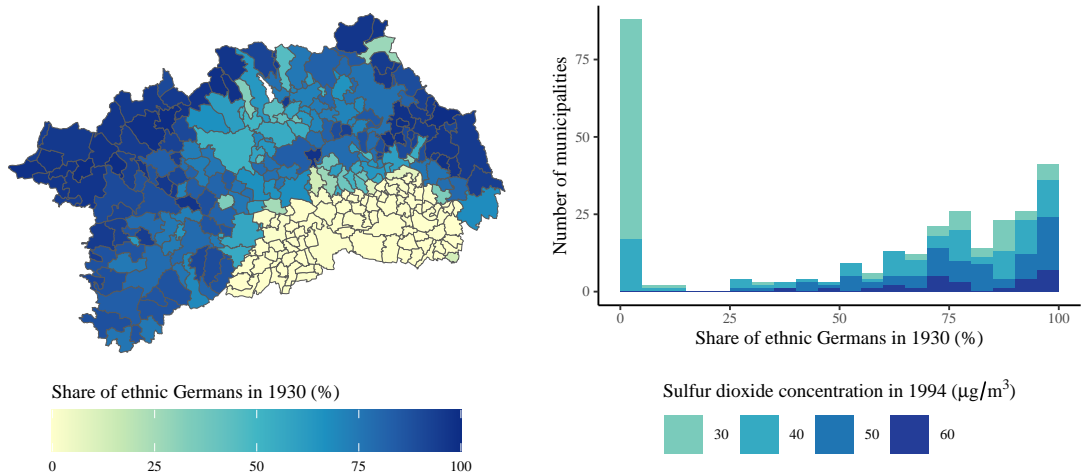
Figure 8: Share of population working in qualifying municipalities on economically active population (1991) by SO<sub>2</sub> concentration in municipality of residence (1994).

### 5.3.2 The role of social capital and attachment to local communities

Residents' migratory response to pollution depends on their willingness to suffer the negative amenity, and on their willingness to accept the utility losses related to emigration, such as the costs of leaving their familiar place, their family and friends. Greater attachment to their communities could increase residents' utility losses from migration, or migration costs, and should therefore decrease migratory responses to air pollution and air pollution reduction. To dig deeper into this link, we exploit another natural experiment offered by the history of the examined region.

North Bohemia was one of the regions of Czechoslovakia affected by the post-war expulsion of ethnic Germans (64% of the population of the region in 1930). The expulsion of ethnic Germans, who lived in ethnically well-segregated municipalities (see Figure 9), in turn allowed ethnic Czechs to come to the vacated municipalities, seize German properties, and settle there. However, these settlers had minimal ties to the region and among themselves.

As noted above, government propaganda sought at the time to build up a new regional identity based on coal and coal mining. Such an identity may have increased the inhabitants' tolerance to coal-related pollution. However, regional identity was not the only phenomenon missing in the resettled municipalities. The expulsion of the original residents had destroyed local social capital (i.e., social ties among municipal inhabitants) in the affected municipalities. Theoretical models developed by David et al. (2010), and



(a) Spatial distribution of ethnic Germans in 1930 (b) Municipalities by share of ethnic Germans in 1930 and SO<sub>2</sub> concentration in 1994

Figure 9: Distribution of ethnic Germans in 1930

Source: Czech Hydrometeorological Institute (CHMI), ArcČR 500 v3.3, Guzi et al. (2021). For details see Section 3.

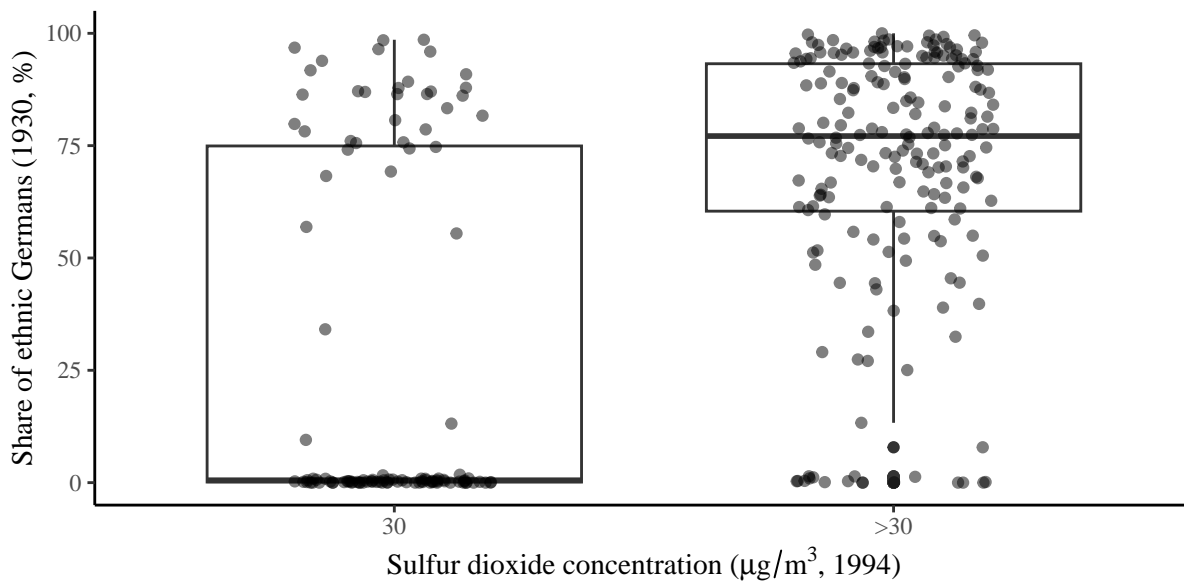


Figure 10: Pollution in 1994 and share of ethnic Germans in 1930

Bräuninger and Tolciu (2011) suggest that a negative shock to social capital, such as this one, could shift a municipality into a stable equilibrium characterized by lower levels of social capital and higher emigration.

Guzi et al. (2021) use municipality-level data for the Czech Republic for the period 1971–2015 to identify the persistent long-run effect of resettlement on residential migration. They find that the expulsion of ethnic Germans and subsequent resettlement increased emigration rates in most affected resettled municipalities (municipalities with a pre-war share of ethnic Germans above 90%) by 0.6–0.7 p.p. relative to comparable least affected municipalities (municipalities with a pre-war share of ethnic Germans below 10%) located nearby. Guzi et al. (2021) also suggest that lower social capital is the driving mechanism behind this causal effect. They document that the inhabitants of the resettled municipalities do not differ in terms of values or general pro-social behavior, but in terms of having less local social capital: they are less likely to be members of local clubs or to organize local public events.

Building on Guzi et al. (2021), we use the share of ethnic Germans from the last pre-war census held in 1930 as a proxy variable for the stock of local social capital. We note that in the case of North Bohemia, the variable could also capture the possible effect of propaganda-supported regional identity related to coal-mining. We assume that these effects should be in opposite directions. To test the impact of local social capital on the pollution-migration link, we split the sample by the cutoff of 50% of ethnic Germans in the local population in 1930 and re-estimate the regression (2) for both samples.

The results reported in column (1) of Table 8 show that the cleaner air tend to decrease emigration rate more in municipalities with less social capital, i.e., those formerly dominated by ethnic Germans. This suggests that local social capital can compensate for the disutility caused by air pollution.

Results for immigration rate presented in column (2) are less clear. Decrease in air pollution tend to correlated with an increase in immigration rate in with municipalities formerly dominated by ethnic Germans and with a decrease in municipalities that were dominated by ethnic Czechs. However, similarly to the main results we cannot disentangle the impact of abolition of pro-immigration policies and decrease in air pollution.

### **5.3.3 The role of man-made amenities**

Like local social capital, the availability of man-made amenities, such as schools, libraries, health care facilities, sports stadiums, etc., could potentially mitigate the effect of air pollution on residential migration as it could make the municipalities more attractive to live in or move into. To investigate whether this factor shapes migratory responses to air pollution, we exploit the variation in man-made amenities availability in the region.

Table 8: Social capital and migratory response to air pollution

	Dependent variable		
	Emigration rate (%)	Immigration rate (%)	Net migration rate (%)
	(1)	(2)	(3)
<i>Panel A: Municipalities with 1930 share of ethnic Germans <math>\leq</math> 50%</i>			
Pre-desulfurization SO <sub>2</sub> concentration > 30 $\mu\text{g}/\text{m}^3$ × Post-desulfurization period	-0.681** (0.313)	-0.896* (0.455)	-0.215 (0.494)
R2 Adj.	0.168	0.133	0.120
Num.Obs.	2207	2207	2207
<i>Panel B: Municipalities with 1930 share of ethnic Germans &gt; 50%</i>			
Pre-desulfurization SO <sub>2</sub> concentration > 30 $\mu\text{g}/\text{m}^3$ × Post-desulfurization period	-1.921*** (0.661)	1.604** (0.719)	3.526*** (1.137)
R2 Adj.	0.340	0.130	0.143
Num.Obs.	3999	3999	3999

Notes: Table reports  $\gamma_j$  coefficients from Equation (2). All model specifications include constant, municipality and post-desulfurization fixed effects, and linear trends for each area and period. Robust standard errors clustered by municipality are reported in parentheses: \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%. The reference category for SO<sub>2</sub> concentration is 30  $\mu\text{g}/\text{m}^3$ .

To measure the availability of man-made amenities at the municipal level, we use the number of facilities and utilities in each municipality using 1993 data collected by the Czech Statistical Office, CZSO.<sup>29</sup> We categorize man-made amenities into three groups: (a) Education, health and social care facilities (hospitals, retirement homes, etc.), (b) Culture and sports facilities (libraries, cinemas, football fields, etc.), and (c) Public administration facilities and public utilities (job centers, courts, etc.; sewerage, water supply system, etc.).<sup>30</sup>

The number of facilities and public utilities increases in population (with Spearman's  $\rho$  between 0.72 and 0.86). The availability of amenities is also correlated between amenity groups with Spearman's  $\rho$  between 0.67 and 0.74.

In the centrally planned socialist economy, man-made amenities could have been allocated to compensate for the air pollution. We cannot exclude this option. However, man-made amenity endowment is only weakly correlated with SO<sub>2</sub> concentration levels in the pre-desulfurization period (with Spearman's  $\rho$  between 0.05 and 0.24). Similarly, one could imagine that municipalities richer in local social capital could be able to lobby more efficiently and to obtain more (often government-funded) man-made amenities. However,

29. The dataset does not contain information on the quality or capacity of the amenities. 1993 is the first iteration of the source database available. For a number of public administration facilities, data for 1993 is not available and we therefore use 1994 data.

30. For the full list of facilities, see Appendix Textbox A.2.



Table 9: Man-made amenities in the municipality

	Dependent variable					
	Emigration rate (%)		Immigration rate (%)		Net migration rate (%)	
	Sample		Sample		Sample	
	Below median	Above median	Below median	Above median	Below median	Above median
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A: Education and health facilities</i>						
Pre-desulfurization SO <sub>2</sub> concentration > 30 μg/m <sup>3</sup>	-2.115***	-0.703**	0.213	0.102	2.328***	0.805*
× Post-desulfurization period	(0.508)	(0.301)	(0.529)	(0.320)	(0.620)	(0.468)
R2 Adj.	0.331	0.397	0.137	0.191	0.159	0.191
Num.Obs.	3152	3061	3152	3061	3152	3061
<i>Panel B: Culture and sports facilities</i>						
Pre-desulfurization SO <sub>2</sub> concentration > 30 μg/m <sup>3</sup>	-1.128***	-1.106***	0.957	-0.449	2.085**	0.657
× Post-desulfurization period	(0.423)	(0.330)	(0.712)	(0.337)	(0.851)	(0.426)
R2 Adj.	0.364	0.297	0.137	0.158	0.145	0.157
Num.Obs.	3034	3179	3034	3179	3034	3179
<i>Panel C: Public administration facilities and public utilities</i>						
Pre-desulfurization SO <sub>2</sub> concentration > 30 μg/m <sup>3</sup>	-1.855***	-1.100***	1.652**	-0.317	3.507***	0.783**
× Post-desulfurization period	(0.517)	(0.278)	(0.713)	(0.328)	(0.906)	(0.374)
R2 Adj.	0.353	0.322	0.140	0.181	0.158	0.157
Num.Obs.	3294	2919	3294	2919	3294	2919

Notes: Table reports  $\gamma_j$  coefficients from Equation (2). All model specifications include constant, municipality and post-desulfurization fixed effects, and linear trends for each area and period. Robust standard errors clustered by municipality are reported in parentheses: \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%. The reference category for SO<sub>2</sub> concentration is 30 μg/m<sup>3</sup>.

the pre-war share of ethnic Germans is not correlated with the availability of man-made amenities (Spearman's  $\rho$  between  $-0.08$  and  $0.13$ ).<sup>31</sup>

To assess the impact of man-made amenities on shaping migration response to air pollution, we split the estimation sample by median amenity availability in each amenity group and re-estimate regression (1) for all six resulting sub-samples.

Tables 9 and 10 provide the results for each amenity group and municipalities split into categories below- and above- the median for each amenity group. The tables differ according to how we calculate the amenities availability. In Table 9, we calculate the availability of man-made amenities as the sum of amenities located in the respective municipalities. In the alternative specification, presented in Table 10, we allow for residents making use of the man-made amenities located in nearby municipalities in addition to their municipality of residence. The alternative amenity availability measure is calculated as the sum of man-made amenities within a 20 km driving distance. The results estimated in the baseline and alternative specifications effectively set bounds for the estimates that

31. For descriptive statistics on the availability of man-made amenities see Appendix Table A.4.

Table 10: Man-made amenities within a 20 km driving distance

	Dependent variable					
	Emigration rate (%)		Immigration rate (%)		Net migration rate (%)	
	Sample		Sample		Sample	
	Below median	Above median	Below median	Above median	Below median	Above median
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A: Education and health facilities</i>						
Pre-desulfurization SO <sub>2</sub> concentration > 30 μg/m <sup>3</sup>	-1.438***	-0.837**	1.082*	-1.175***	2.520***	-0.338
× Post-desulfurization period	(0.465)	(0.359)	(0.590)	(0.410)	(0.840)	(0.389)
R2 Adj.	0.362	0.319	0.140	0.143	0.106	0.188
Num.Obs.	3052	3161	3052	3161	3052	3161
<i>Panel B: Culture and sports facilities</i>						
Pre-desulfurization SO <sub>2</sub> concentration > 30 μg/m <sup>3</sup>	-1.547***	-1.123***	1.224**	-0.932**	2.771***	0.191
× Post-desulfurization period	(0.494)	(0.293)	(0.590)	(0.358)	(0.864)	(0.404)
R2 Adj.	0.368	0.278	0.135	0.152	0.120	0.172
Num.Obs.	3029	3184	3029	3184	3029	3184
<i>Panel C: Public administration facilities and public utilities</i>						
Pre-desulfurization SO <sub>2</sub> concentration > 30 μg/m <sup>3</sup>	-1.944***	-0.817***	1.476**	-0.548	3.420***	0.269
× Post-desulfurization period	(0.555)	(0.274)	(0.590)	(0.356)	(0.965)	(0.378)
R2 Adj.	0.376	0.216	0.142	0.126	0.158	0.095
Num.Obs.	3144	3069	3144	3069	3144	3069

Notes: Table reports  $\gamma_j$  coefficients from Equation (1). All model specifications include constant, municipality and post-desulfurization fixed effects, and linear trends for each area and period. Robust standard errors clustered by municipality are reported in parentheses: \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%. The reference category for SO<sub>2</sub> concentration is 30 μg/m<sup>3</sup>.

would be obtained for man-made amenity availability calculated using weights decreasing in distance and leveling off at 0 for a distance greater than 20 km.

In general, these estimates are in line with our main results for the impact of air pollution reduction based on regression (1) model specification. However, the estimated effects tend to be larger in municipalities with below-median availability of man-made amenities. The same pattern holds for both man-made amenities measures. These results suggest that the availability of man-made amenities can compensate in part for the disutility caused by air pollution and thus reduce migratory responses to air pollution reduction.

## **6 Air pollution reduction and changes in population structure by education and age**

We might expect heterogeneous migratory responses to pollution by education and age, since highly educated people may have better knowledge or understanding of the detrimental effects of air pollution on health and thus may be more sensitive to air pollution. On the other hand, the expected effect on different age groups is ambiguous. Younger people might be more concerned about settling down and raising their children in environmentally polluted areas. At the same time older people after retiring from their jobs may wish to move to cleaner areas. In the next step, we try to shed some light on these possible heterogeneous responses. Given that our data do not allow us to pin down individuals and their characteristics, nor numbers of migrants by education, age, etc., we make use of municipality-level census data on the educational and age structure of the municipal populations. We are interested in whether the reduction in air pollution had any effect on the changes in municipal populations' educational and age composition over time. To investigate that, we re-estimate regression (1) with demographic and educational structure measures as the dependent variables. In particular, we estimate this specification for each age category within the population (0–19, 20–29, 30–39, 40–49, 50–59, 60–69) as a share of the total population and with the shares of primary, secondary, and tertiary educated inhabitants on the adult population (15 years and older).

The age structure and education data are available only from the decennial censuses held in 1980, 1991, 2001, 2011. We associate the 1980 and 1991 census years with the pre-desulfurization period and the 2001 and 2011 censuses with the post-desulfurization period.

The results, reported in Table 11, do show some tendency to population ageing in worse polluted municipalities after the desulfurization. Results on education structure show a small positive, yet weakly significant, effect on the share of tertiary educated residents, supporting the hypothesis that more educated people tend to be more sensitive to air pollution in their settlement behavior.

Table 11: Impact of air pollution on age and education structure

	Dependent variable								
	Age structure			Education structure			Education structure		
	(shares of age groups on total population, %)								
	0-19	20-29	30-39	40-49	50-59	60-69	Primary	Secondary	Tertiary
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Pre-desulfurization SO <sub>2</sub> concentration > 30 μg/m <sup>3</sup>	-1.505***	-0.304	-0.009	0.129	0.373	0.542*	0.046	-0.882	0.443**
× Post-desulfurization period	(0.392)	(0.285)	(0.272)	(0.283)	(0.310)	(0.327)	(0.709)	(0.658)	(0.216)
R2 Adj.	0.723	0.403	0.285	0.345	0.290	0.427	0.918	0.883	0.725
Num.Obs.	1151	1151	1151	1151	1151	1151	1151	1151	1151

Estimates in columns (1)–(9) are based on data from decennial censuses. All model specifications include municipality, year and area by year fixed effects. Robust standard errors clustered by municipality are reported in parentheses: \*, \*\*, and \*\*\* denote statistical significance at 10%, 5% and 1%. The reference category for SO<sub>2</sub> concentration is 30 μg/m<sup>3</sup>.

## 7 Conclusions

Using a unique natural experiment resulting from the implementation of modern technology in power plants that vastly reduced air pollution, in this paper we have examined the effect of air pollution reduction on migratory behavior.

In particular, we have looked at residential migration rates for municipalities in the North Bohemian region of the Czech Republic that previously suffered from extreme pollution levels. In order to examine the causal effects of air pollution reduction on migration, we exploit the fact that between 1992 and 1999, Czech power plants were required by law to adopt modern desulfurization technologies. This led to a massive reduction in SO<sub>2</sub> concentrations in the air in the area to levels below the relevant EU/WHO limits.

Our results, based on a difference-in-difference estimator, show that the reduction in SO<sub>2</sub> concentrations had a negative effect on emigration. This effect is large and statistically significant: emigration rates from initially highly polluted municipalities were 24% lower after the desulfurization technologies were adopted, compared to the least polluted baseline group of municipalities. Further, the effects of air pollution on emigration seem to be non-linear: the effect effect is about twice as large in municipalities that initially suffered extreme SO<sub>2</sub> pollution levels (50 and 60  $\mu\text{g}/\text{m}^3$  of SO<sub>2</sub>) as it is in municipalities with an initial pollution load of 40  $\mu\text{g}/\text{m}^3$ . The effect on net migration is also enormous: the adoption of desulfurization technology led to an increase by 1.7 p.p. in net migration in the initially highly polluted municipalities, which corresponds to an approx. 78% increase in net migration rate compared to the baseline group of the least polluted municipalities. This suggest that the extreme polluted areas became more attractive to live in after the air became cleaner. Our main results are supported by a number of robustness checks and placebo tests.

Furthermore, we have dig deeper into additional factors that might possibly have influenced migration in the focus period. In our analysis, we have found that anti-emigration policies in the form of benefits did not affect the air pollution – migration relationship. However, the results show also that population responses to air quality improvement tend to be stronger in municipalities with stronger local social capital and in municipalities better-equipped with education, health, social care, culture and sport facilities. Finally, we have also found some evidence that more educated people tend to be more sensitive to air pollution in their settlement behaviour.

To sum up, in this paper we have presented novel evidence on positive effects of cleaning previously heavily polluted areas on migration into the areas. We find that that anti-emigration economic benefits provided by the government did not prevent people from emigration in case of extreme pollution levels, whereas we find that the migratory response to cleaning the previously polluted areas seem to be reinforced to some extent by

the existence of strong local social capital and the availability of man-made city amenities. Overall, policies aiming to prevent regional de-population or aiming in attracting more people to move in should support initiatives to clean up the region's environments and to establish stronger social capital and man-made amenities.

## References

- Aragon, Fernando M, Juan Jose Miranda, and Paulina Oliva. 2017. "Particulate Matter and Labor Supply: The Role of Caregiving and Non-linearities." *Journal of Environmental Economics and Management* 86:295–309.
- Barrios, Salvador, Luisito Bertinelli, and Eric Strobl. 2006. "Climatic Change and Rural–urban Migration: The Case of Sub-Saharan Africa." *Journal of Urban Economics* 60 (3): 357–371.
- Bharadwaj, Prashant, Matthew Gibson, Joshua Graff Zivin, and Christopher Neilson. 2017. "Gray Matters: Fetal Pollution Exposure and Human Capital Formation." *Journal of the Association of Environmental and Resource Economists* 4 (2): 505–542.
- Bishop, Kelly C, Jonathan D Ketcham, and Nicolai V Kuminoff. 2018. "Hazed and Confused: The Effect of Air Pollution on Dementia," no. 24970.
- Bräuning, Michael, and Andreia Tolciu. 2011. "Should I Stay or Should I Go? Regional Mobility and Social Capital." *Journal of Institutional and Theoretical Economics JITE* 167 (3): 434–444.
- Cai, Ruohong, Shuaizhang Feng, Michael Oppenheimer, and Mariola Pytlikova. 2016. "Climate Variability and International Migration: The Importance of the Agricultural Linkage." *Journal of Environmental Economics and Management* 79:135–151.
- Chang, Tom Y, Joshua Graff Zivin, Tal Gross, and Matthew Neidell. 2019. "The Effect of Pollution on Worker Productivity: Evidence from Call Center Workers in China." *American Economic Journal: Applied Economics* 11 (1): 151–172.
- Chay, Kenneth Y, and Michael Greenstone. 2003. "The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession." *The Quarterly Journal of Economics* 118 (3): 1121–1167.
- Chen, Shuai, Paulina Oliva, and Peng Zhang. 2022. "The effect of air pollution on migration: evidence from China." *Journal of Development Economics* 156:102833.

- Clark, Ximena, Timothy J Hatton, and Jeffrey G Williamson. 2007. "Explaining US Immigration, 1971–1998." *The Review of Economics and Statistics* 89 (2): 359–373.
- Conley, Timothy G. 1999. "GMM estimation with cross sectional dependence." *Journal of econometrics* 92 (1): 1–45.
- Currie, Janet, and Matthew Neidell. 2005. "Air Pollution and Infant Health: What Can We Learn from California's Recent Experience?" *The Quarterly Journal of Economics* 120 (3): 1003–1030.
- Currie, Janet, Matthew Neidell, and Johannes F Schmieder. 2009. "Air Pollution and Infant Health: Lessons from New Jersey." *Journal of Health Economics* 28 (3): 688–703.
- Currie, Janet, Joshua Graff Zivin, Jamie Mullins, and Matthew Neidell. 2014. "What Do We Know about Short- and Long-term Effects of Early-life Exposure to Pollution?" *Annual Review of Resource Economics* 6 (1): 217–247.
- David, Quentin, Alexandre Janiak, and Etienne Wasmer. 2010. "Local Social Capital and Geographical Mobility." *Journal of Urban Economics* 68 (2): 191–204.
- Dejmek, Jan, Sherry G Selevan, Ivan Benes, Ivo Solansky, and Radim J Sram. 1999. "Fetal Growth and Maternal Exposure to Particulate Matter during Pregnancy." *Environmental Health Perspectives* 107 (6): 475–480.
- Dillon, Gregory K, Zachary A Holden, Penelope Morgan, Michael A Crimmins, Emily K Heyerdahl, and Charles H Luce. 2011. "Both Topography and Climate Affected Forest and Woodland Burn Severity in Two Regions of the Western US, 1984 to 2006." *Ecosphere* 2 (12): 1–33.
- Fidrmuc, Jan. 2004. "Migration and Regional Adjustment to Asymmetric Shocks in Transition Economies." *Journal of Comparative Economics* 32 (2): 230–247.
- Glassheim, Eagle. 2006. "Ethnic Cleansing, Communism, and Environmental Devastation in Czechoslovakia's Borderlands, 1945–1989." *The Journal of Modern History* 78 (1): 65–92.
- Graff Zivin, Joshua, and Matthew Neidell. 2012. "The Impact of Pollution on Worker Productivity." *American Economic Review* 102 (7): 3652–73.
- . 2013. "Environment, Health, and Human Capital." *Journal of Economic Literature* 51 (3): 689–730.

- Gray, Clark L, and Valerie Mueller. 2012. "Natural Disasters and Population Mobility in Bangladesh." *Proceedings of the National Academy of Sciences* 109 (16): 6000–6005.
- Greenstone, Michael, and Rema Hanna. 2014. "Environmental Regulations, Air and Water Pollution, and Infant Mortality in India." *American Economic Review* 104 (10): 3038–72.
- Guzi, Martin, Peter Huber, and Stepan Mikula. 2021. "The Long-term Impact of the Resettlement of the Sudetenland on Residential Migration." *Journal of Urban Economics* 126:103385.
- Hanna, Rema, and Paulina Oliva. 2015. "The Effect of Pollution on Labor Supply: Evidence from a Natural Experiment in Mexico City." *Journal of Public Economics* 122:68–79.
- He, Jiaxiu, Haoming Liu, and Alberto Salvo. 2019. "Severe Air Pollution and Labor Productivity: Evidence from Industrial Towns in China." *American Economic Journal: Applied Economics* 11 (1): 173–201.
- Henry, Sabine, Bruno Schoumaker, and Cris Beauchemin. 2004. "The Impact of Rainfall on the First Out-migration: A Multi-level Event-history Analysis in Burkina Faso." *Population and Environment* 25 (5): 423–460.
- Isen, Adam, Maya Rossin-Slater, and W Reed Walker. 2017. "Every Breath You Take Every Dollar You'll Make: The Long-term Consequences of the Clean Air Act of 1970." *Journal of Political Economy* 125 (3): 848–902.
- Kotěšovec, F, J Skorkovský, J Brynda, Annette Peters, and Joachim Heinrich. 2000. "Daily Mortality and Air Pollution in Northern Bohemia: Different Effects for Men and Women." *Central European Journal of Public Health* 8 (2): 120–127.
- Kratochvíl, Ivan. 2011. *Život není jen náhoda*. Prague: Academia.
- Liu, Haoming, and Alberto Salvo. 2017. "Severe Air Pollution and School Absences: Longitudinal Data on Expatriates in North China," no. 11134.
- Marchiori, Luca, Jean-Francois Maystadt, and Ingmar Schumacher. 2012. "The Impact of Weather Anomalies on Migration in Sub-Saharan Africa." *Journal of Environmental Economics and Management* 63 (3): 355–374.
- Mayda, Anna Maria. 2010. "International Migration: A Panel Data Analysis of the Determinants of Bilateral Flows." *Journal of Population Economics* 23 (4): 1249–1274.



- Mueller, Valerie, Clark Gray, and Katrina Kosec. 2014. "Heat Stress Increases Long-term Human Migration in Rural Pakistan." *Nature Climate Change* 4 (3): 182–185.
- Newell, Katherine, Christiana Kartsonaki, Kin Bong Hubert Lam, and Om Kurmi. 2018. "Cardiorespiratory Health Effects of Gaseous Ambient Air Pollution Exposure in Low and Middle Income Countries: A Systematic Review and Meta-analysis." *Environmental Health* 17 (1): 41.
- Ortega, Francesc, and Giovanni Peri. 2013. "The Effect of Income and Immigration Policies on International Migration." *Migration Studies* 1 (1): 47–74.
- Pedersen, Peder J, Mariola Pytlikova, and Nina Smith. 2008. "Selection and network effects—Migration Flows into OECD Countries 1990–2000." *European Economic Review* 52 (7): 1160–1186.
- Pinto, JP, RK Stevens, RD Willis, R Kellogg, Y Mamane, J Novak, J Šantroch, I Beneš, J Lenicek, and V Bureš. 1998. "Czech Air Quality Monitoring and Receptor Modeling Study." *Environmental Science & Technology* 32 (7): 843–854.
- Schlenker, Wolfram, and W Reed Walker. 2015. "Airports, Air Pollution, and Contemporaneous Health." *The Review of Economic Studies* 83 (2): 768–809.
- Selevan, Sherry G, Libor Borkovec, Valerie L Slott, Zudova Zdena, Jiri Rubes, Donald P Evenson, and Sally D Perreault. 2000. "Semen Quality and Reproductive Health of Young Czech Men Exposed to Seasonal Air Pollution." *Environmental Health Perspectives* 108 (9): 887–894.
- Sjaastad, Larry A. 1962. "The Costs and Returns of Human Migration." *Journal of Political Economy* 70 (5, Part 2): 80–93.
- Spurný, Matěj. 2016. *Most do budoucnosti: laboratoř socialistické modernity na severu Čech*. Charles University in Prague, Karolinum Press.
- Tanaka, Shinsuke. 2015. "Environmental Regulations on Air Pollution in China and Their Impact on Infant Mortality." *Journal of Health Economics* 42:90–103.
- UNEP. 2007. *Beijing 2008 Olympic Games: An Environmental Review*.
- Vaněk, Miroslav. 1996. *Nedalo se tady dýchat: ekologie v českých zemích v letech 1968 až 1989*. Ustav pro soudobé dějiny AV ČR.

Vestreng, Vigdis, Gunnar Myhre, Hilde Fagerli, Stefan Reis, and Leonor Tarrason. 2007. “Twenty-five Years of Continuous Sulphur Dioxide Emission Reduction in Europe.” *Atmospheric Chemistry and Physics* 7 (13): 3663–3681.

World Health Organization. 2006. *Air Quality Guidelines: Global Update 2005: Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur Dioxide*. World Health Organization.

Xu, Xu, and Kevin Sylwester. 2016. “Environmental Quality and International Migration.” *Kyklos* 69 (1): 157–180.

## A Appendix

### A.1 Additional Figures and Tables



Figure A.1: Location of the region in the Czech Republic

Source: ArcČR 500 v3.3

Table A.1: Lignite-burning power plants in North Bohemia

Power plant	Construction	Desulfurization
Komořany	1951–1964	1993–1999
Ledvice	1967	1996–1998
Počerady I and Počerady II	1970–1977	1994–1996
Prunéřov	1967–1968 (second unit 1981–1982)	1995–1996
Tušimice I and Tušimice II	1963–1967 (second unit 1974–1975)	1994–1997
Litvínov T200 and T700	1942–1958	1996

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>). Last accessed January 30, 2019.



Figure A.2: Effect of mining on city of Most

Source: Collection of historical orthophotos available at <https://mapy.mesto-most.cz/portal/WAB?cfg=most-do-minulosti> (last accessed on September 4, 2019).

Table A.2: Descriptive statistics: Population structure by year and SO<sub>2</sub> concentration

	Year	Municipalities in estimation sample					
		All	By SO <sub>2</sub> concentration (1994)				
			30 µg/m <sup>3</sup>	>30 µg/m <sup>3</sup>			
				All	40 µg/m <sup>3</sup>	50 µg/m <sup>3</sup>	60 µg/m <sup>3</sup>
(1)	(2)	(3)	(4)	(5)	(6)		
Share of 0–19 age group (%)	1980	30.40	28.87	31.20	31.09	31.75	30.07
		(0.26)	(0.39)	(0.33)	(0.50)	(0.51)	(0.82)
	1991	29.03	27.90	29.65	29.33	30.29	29.01
		(0.26)	(0.40)	(0.33)	(0.51)	(0.56)	(0.46)
	2001	23.07	22.45	23.42	23.22	23.96	22.67
(0.21)		(0.33)	(0.27)	(0.37)	(0.50)	(0.57)	
2011	21.12	20.64	21.38	20.89	22.08	21.17	
		(0.22)	(0.34)	(0.28)	(0.45)	(0.38)	(0.63)
Share of 20–29 age group (%)	1980	14.47	14.03	14.71	14.53	14.96	14.59
		(0.16)	(0.28)	(0.19)	(0.30)	(0.27)	(0.50)
	1991	11.64	11.72	11.59	11.43	11.94	11.19
		(0.16)	(0.23)	(0.20)	(0.27)	(0.32)	(0.67)
	2001	16.61	16.64	16.60	16.64	16.74	16.08
(0.15)		(0.27)	(0.18)	(0.26)	(0.30)	(0.55)	
2011	11.98	11.94	12.01	11.93	12.25	11.61	
		(0.17)	(0.25)	(0.22)	(0.33)	(0.35)	(0.49)
Share of 30–39 age group (%)	1980	13.93	13.32	14.25	14.07	14.34	14.58
		(0.16)	(0.24)	(0.20)	(0.32)	(0.30)	(0.54)
	1991	13.53	13.43	13.58	13.33	13.65	14.18
		(0.14)	(0.23)	(0.18)	(0.26)	(0.31)	(0.42)
	2001	12.29	11.91	12.51	12.30	12.64	12.83
(0.13)		(0.22)	(0.17)	(0.27)	(0.25)	(0.39)	
2011	16.65	16.18	16.92	16.66	17.17	17.19	
		(0.16)	(0.28)	(0.20)	(0.32)	(0.30)	(0.47)
Share of 40–49 age group (%)	1980	10.33	10.06	10.47	10.15	10.76	10.76
		(0.12)	(0.22)	(0.14)	(0.19)	(0.25)	(0.28)
	1991	15.15	14.53	15.49	15.34	15.53	15.85
		(0.19)	(0.26)	(0.25)	(0.40)	(0.38)	(0.44)
	2001	14.57	14.08	14.85	14.46	15.01	15.73
(0.14)		(0.23)	(0.17)	(0.24)	(0.28)	(0.50)	
2011	13.33	12.70	13.68	13.46	13.71	14.33	
		(0.14)	(0.21)	(0.18)	(0.31)	(0.26)	(0.26)
Share of 50–59 age group (%)	1980	12.50	12.70	12.40	12.05	12.59	13.01
		(0.15)	(0.26)	(0.18)	(0.27)	(0.31)	(0.39)
	1991	10.83	10.78	10.85	10.64	11.10	10.88
		(0.14)	(0.25)	(0.17)	(0.24)	(0.31)	(0.34)
	2001	15.13	14.85	15.28	15.05	15.38	15.80
(0.19)		(0.28)	(0.25)	(0.36)	(0.45)	(0.46)	
2011	14.34	14.46	14.26	14.24	14.14	14.67	
		(0.15)	(0.29)	(0.18)	(0.29)	(0.24)	(0.42)
Share of 60–69 age group (%)	1980	8.99	9.72	8.61	8.99	7.96	9.14
		(0.15)	(0.24)	(0.18)	(0.25)	(0.31)	(0.35)
	1991	11.38	11.97	11.04	11.32	10.70	11.06
		(0.20)	(0.32)	(0.25)	(0.38)	(0.43)	(0.40)
	2001	9.18	9.55	8.97	9.25	8.71	8.68
(0.13)		(0.21)	(0.17)	(0.23)	(0.31)	(0.27)	
2011	13.49	13.94	13.24	13.43	13.13	12.87	
		(0.18)	(0.26)	(0.24)	(0.32)	(0.48)	(0.38)

Notes: Table reports means and standard errors in parentheses.

Table A.3: Descriptive statistics: Education structure by year and SO<sub>2</sub> concentration

	Year	Municipalities in estimation sample					
		All	By SO <sub>2</sub> concentration (1994)				
			30 µg/m <sup>3</sup>	>30 µg/m <sup>3</sup>			
				All	40 µg/m <sup>3</sup>	50 µg/m <sup>3</sup>	60 µg/m <sup>3</sup>
(1)	(2)	(3)	(4)	(5)	(6)		
Share of primary educated (%)	1980	59.76 (0.49)	59.76 (0.82)	59.76 (0.61)	58.90 (0.91)	60.81 (1.02)	59.71 (1.23)
	1991	47.72 (0.47)	47.06 (0.74)	48.09 (0.60)	48.98 (0.97)	47.50 (0.93)	46.90 (1.19)
	2001	32.43 (0.37)	31.74 (0.66)	32.83 (0.45)	33.03 (0.70)	32.97 (0.73)	31.73 (0.80)
	2011	23.65 (0.31)	23.30 (0.51)	23.85 (0.38)	24.11 (0.60)	23.78 (0.61)	23.13 (0.70)
Share of secondary educated (%)	1980	37.64 (0.45)	37.80 (0.76)	37.56 (0.56)	38.53 (0.82)	36.70 (0.96)	36.80 (1.21)
	1991	49.45 (0.43)	50.45 (0.69)	48.89 (0.55)	48.26 (0.88)	49.26 (0.84)	49.85 (1.10)
	2001	62.76 (0.34)	63.86 (0.55)	62.14 (0.42)	62.21 (0.66)	61.93 (0.64)	62.47 (0.89)
	2011	64.17 (0.31)	65.69 (0.47)	63.32 (0.39)	63.80 (0.57)	62.38 (0.66)	64.25 (0.80)
Share of tertiary educated (%)	1980	1.31 (0.073)	1.31 (0.12)	1.30 (0.092)	1.33 (0.14)	1.30 (0.15)	1.21 (0.19)
	1991	1.89 (0.095)	2.00 (0.16)	1.82 (0.12)	1.89 (0.19)	1.79 (0.18)	1.68 (0.24)
	2001	2.99 (0.10)	2.94 (0.17)	3.02 (0.13)	3.02 (0.20)	3.03 (0.21)	2.99 (0.32)
	2011	5.86 (0.17)	5.48 (0.28)	6.06 (0.21)	5.89 (0.32)	6.15 (0.34)	6.42 (0.46)

Notes: Table reports means and standard errors in parentheses.

Table A.4: Descriptive statistics: Man-made amenities availability

	Year	Municipalities in estimation sample					
		All	By SO <sub>2</sub> concentration (1994)				
			30 µg/m <sup>3</sup>	>30 µg/m <sup>3</sup>			60 µg/m <sup>3</sup>
(1)	(2)	(3)	(4)	(5)	(6)		
Education and health facilities in the municipality (n)	1993	5.29 (0.96)	2.75 (0.64)	6.72 (1.45)	4.67 (1.42)	9.23 (3.15)	7.19 (3.57)
Culture and sports facilities in the municipality (n)	1993	5.76 (1.08)	3.48 (0.38)	7.03 (1.66)	4.28 (0.85)	11.75 (4.25)	4.11 (1.29)
Public administration and utilities in the municipality (n)	1993	6.59 (0.21)	5.72 (0.30)	7.07 (0.27)	6.53 (0.35)	7.45 (0.49)	7.96 (0.63)
Education and health facilities within 20 km driving distance (n)	1993	287.44 (6.22)	236.88 (7.37)	315.76 (8.09)	291.41 (9.99)	334.68 (15.50)	349.89 (17.61)
Culture and sports facilities within 20 km driving distance (n)	1993	307.42 (7.91)	269.39 (8.92)	328.72 (11.00)	319.65 (12.82)	341.51 (21.95)	326.37 (28.51)
Public administration and utilities within 20 km driving distance (n)	1993	350.29 (6.69)	378.99 (9.76)	334.21 (8.70)	375.20 (11.03)	295.96 (15.02)	293.59 (20.06)

Notes: Table reports means and standard errors in parentheses.

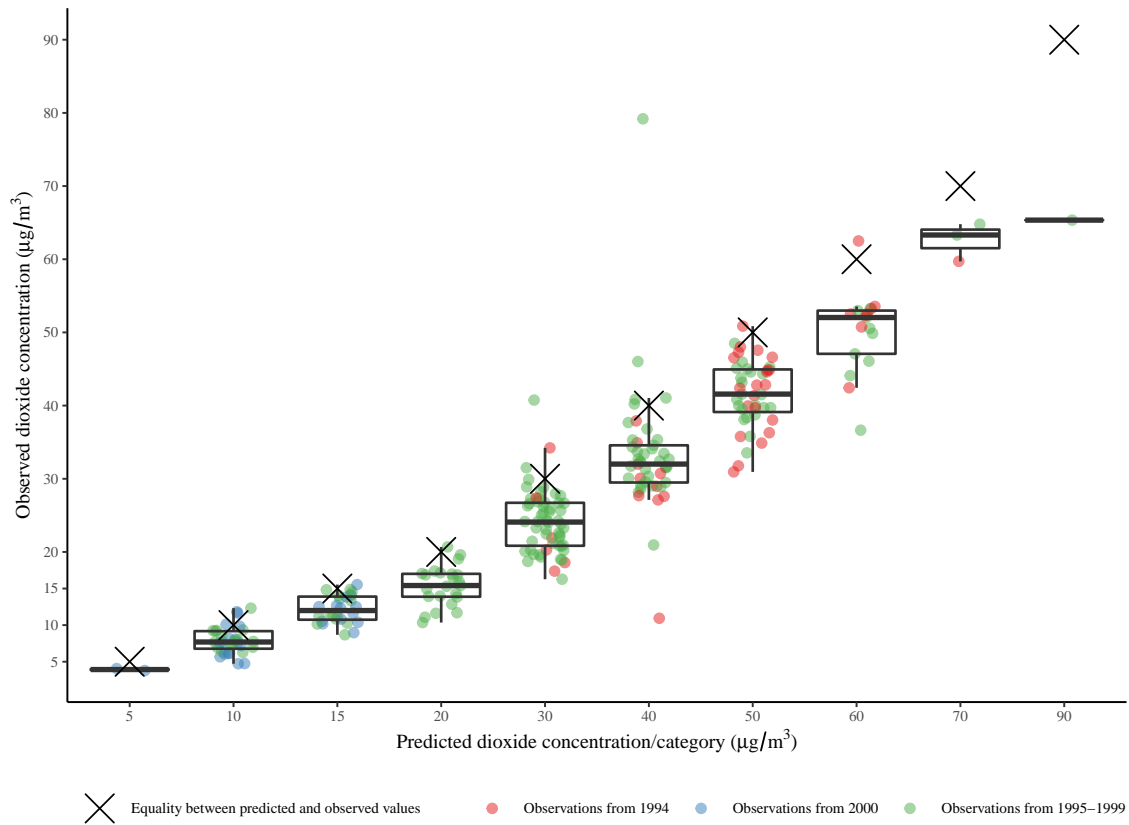


Figure A.3: Predicted and observed SO<sub>2</sub> concentrations

Source: Czech Hydrometeorological Institute

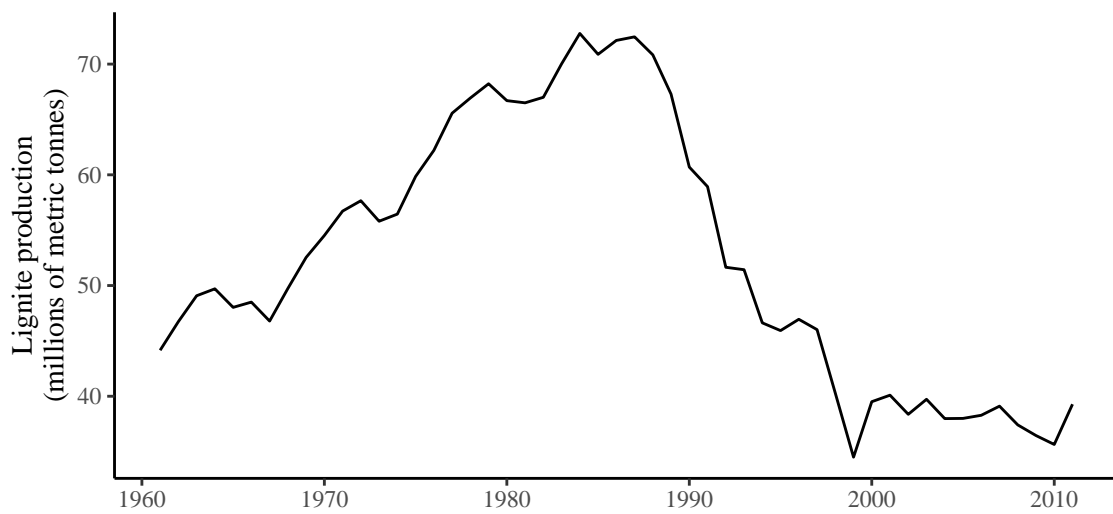


Figure A.4: Lignite mining in North Bohemia

#### Textbox A.1: Pro-immigration and anti-emigration measures

- The government provided house-building subsidies for newcomers in order to attract people into the region. These subsidies had a maximum value of 65,000 Czechoslovak crowns (CSK) (186% of the average annual wage in 1985). Highly-skilled professionals were also given preferential access to public housing.
- Enterprises also often paid recruitment benefits of up to 10,000 CSK (29% of the average annual wage in 1985).
- The government granted special benefits for medical doctors and pharmacists (see act of the government No. 37/1984): a recruitment benefit of 10,000 CSK to those who promised to stay in the area for at least five years, a 10,000 pay rise for high performers not available elsewhere, and special stipends for those who agreed to stay for at least six years.
- Those who had worked in the basin districts for at least 10 years were eligible for a monetary benefit of 2,000 CSK per year (5.7% of the average annual wage in 1985).
- The government limited the mobility of highly-qualified workers (medical doctors, pharmacists, teachers, and selected technical professions) from the region. Vaněk (1996) states that professionals who tried to move out of the area found themselves unable to find jobs or housing in their destination region. Vaněk (1996) claims that this policy was executed on an informal basis from the beginning of the 1980s. In 1984 the policy was incorporated into Act No. 37/1984 (only for medical doctors and pharmacists). That regulation was abolished (both *de facto* and *de iure*) in 1986.
- The authorities did not inform the public about the health risks or pollutant concentrations, although in the late 1980s, a limited warning system was implemented (e.g., yellow flags or signs were mounted on public transport vehicles during temperature inversions).
- The government provided free or heavily subsidized short-term (holiday) accommodation in clean mountain areas to children during temperature inversions.



Table A.5: Results of an alternative specification with treatment variable being specified as a change in SO<sub>2</sub> concentration levels

	Dependent variable		
	Emigration rate (%)	Immigration rate (%)	Net migration rate (%)
	(1)	(2)	(3)
Decrease in SO <sub>2</sub> concentration × Post-desulfurization period	-0.067*** (0.016)	0.025 (0.019)	0.091*** (0.029)
Adjusted R <sup>2</sup>	0.337	0.139	0.134
Observations	6,229	6,229	6,229

Notes: Table reports  $\gamma$  coefficients from Equation (1) with treatment variable being defined as a change between pre- and post-desulfurization SO<sub>2</sub> concentration (i.e., SO<sub>2</sub> in 1994 – SO<sub>2</sub> in 2000). All model specifications include constant, municipality and post-desulfurization fixed effects, and linear trends for each area and period. Robust standard errors clustered by municipality are reported in parentheses: \*, \*\* and \*\*\* denote statistical significance at 10%, 5% and 1%.

#### Textbox A.2: Man-made amenities by group

- **Education, health and social care facilities:** Adult protective service facilities; Community health centers; Emergency medical service facilities; Hospitals; Child protective service facilities; Kindergartens; Language schools; Primary and secondary schools; Retirement homes; Spas; Universities; Vocational education institutes.
- **Culture and sports facilities:** Amphitheatres (natural); Athletic fields; Cinemas; Free time centers (for children); Galleries; Gyms; Museums; Other sport facilities; Public libraries; Sports stadiums; Swimming pools; Theaters; Zoos (animal parks).
- **Public administration facilities and public utilities:** Courts and legal system facilities; Firefighting squads; Firefighting facilities; Gas supply networks; Job centers; Other offices; Police stations; Post offices; Urban planning offices; Waste management facilities; Watter supply networks.

## B Parallel trends in pre-treatment period

The difference-in-differences framework used in the main part of the paper assumes the presence of parallel trends in the pre-treatment period. In this part of the paper we provide an indicative test of this assumption by estimating the following regression:

$$mig_{it} = \sum_j \gamma_{jt} SO40_i \theta_t + \beta_i SO40_i + \xi_{it} \quad (4)$$

where air pollution level category (SO40) is interacted with year fixed effects ( $\theta_t$ ), and the year 1989 is used as a reference. We estimate regression (4) on a sub-sample limited to the pre-treatment period. Point estimates with 95% confidence intervals (calculated using robust standard errors clustered by municipality) for coefficient  $\gamma$  are reported in Figure B.5. The results suggest that the parallel trends assumption holds. Only the estimate of  $\gamma$  for net migration rate in 1986 is significant at 5% level.

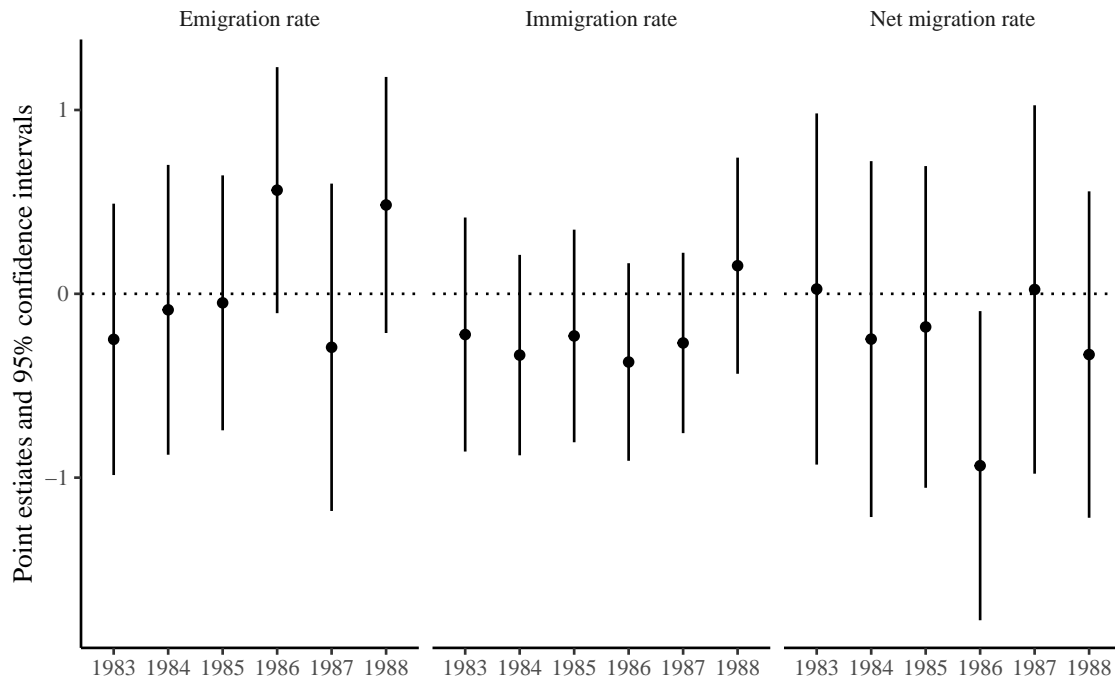


Figure B.5: Parallel trend assumption test