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Why Do People Continue to Live Near Polluted Sites? Empirical Evidence from Southwestern Europe

Pierre Levasseur^{1,2} · Katrin Erdlenbruch^{1,3} · Christelle Gramaglia¹

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Abstract

Poverty is a major determinant for pollution exposure, according to the US location choice literature. In this paper, we assess the impact of socio-economic status on location choices in the European context. Our analysis relies on an original dataset of 1194 households living in polluted and non-polluted areas in three European countries: Spain, Portugal, and France. We use instrumental variables strategies to identify the socioeconomic causes of location choices. We show that low education, wealth, and income are main reasons for living in polluted areas. We provide several robustness checks testing for the exogeneity of selected instruments. We observe that unobserved heterogeneity tends to understate the impact of socioeconomic status on residence location. Interestingly, we highlight that an important proportion of intermediate social groups (especially young couples) are living in polluted areas, probably because of place attachment and affordable housing facilities. Similarly, we show that middle-income households have lower move-out intentions than other income groups. These latter results contrast the linear vision of environmental inequalities found in the USA.

Keywords Soil pollution exposure · Residential choice · Socioeconomic status · Environmental inequalities · Instrumental variables strategy

1 Introduction

Notwithstanding the strong development of locational choice models in recent decades, empirical evidence for the relationship between socioeconomic status and pollution exposure in Europe remains limited. In the USA, the existing literature identifies a negative correlation between socioeconomic status and exposure to pollution [1, 2]. Some authors also find evidence of a causal effect [3]: richer households tend to move away from polluted areas while poorer households are more likely to move in; hence, pollution is leading to social segregation. In Europe, the literature focused on the role of natural amenities, rather than pollution [4], to explain patterns of social segregation.

Results are ambiguous: Schaeffer et al. [5] found that natural amenities increase the mutual segregation between executives and other workers in the French region of Marseille, but not in the region of Grenoble. In the Netherlands, van Duijn and Rouwendal [6] showed that double earners prefer natural living environments while highly educated households placed more value on historical amenities. De Palma, Picard and Waddell [7] highlight the important role of the noise disamenity, next to natural amenities and transport amenities, in location choices in the area of Paris. Schaeffer et al. [5] conclude that location patterns ultimately depend on the interplay between natural and other amenities. According to sociological studies, the dual and linear definition of environmental inequalities should be contrasted in Europe. For instance, in French towns near hazardous industrial wastes, Flanquart, Hellequin and Vallet [8] observe an over-representation of households with moderate standards of living (and not the poorest). Inequalities resulting from pollution also vary from city to city [9]. In the end, there is a non-trivial relationship between

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environmental and social constraints, explaining what may be termed socio-environmental segregation.¹ In this paper, we study how socio-environmental segregation develops in polluted areas in Southwestern Europe.

Several theoretical pathways may lead certain social groups to disproportionately live in polluted areas [2]. First, industries tend to locate their polluting activities in ‘favorable’ geographic and economic areas, where land is available, the labor force is cheap, and transport networks are well developed. Second, households choose their residential location depending on their willingness to pay [10]: even if lower-income households would prefer to live in a cleaner area, they are not willing to pay the higher price. Hence, in the long run, poorer households (as well as certain ethnic groups) end up in more polluted areas [11].² Next, households in polluted areas have generally less ability to influence governments and may less easily mobilize against existing rules in favor of industries [2]. Finally, residents may accept a certain level of pollution exposure in exchange for compensation provided by the polluting firm [2,12], such as employment opportunities and direct investments in local amenities (e.g., parks, sports infrastructure, and cultural centers).³ Note that the over-representation of households with moderate standards of living observed by Flanquart et al. [8] in French polluted areas may be explained by this pathway. Moreover, place or community attachment might also explain the over-representation of intermediate social classes in polluted areas [13].

Given the ambiguities concerning residential preferences in Europe, this article aims to contribute to the literature by quantitatively identifying the factors that determine the probability of living in polluted areas. In addition, we investigate the main determinants of the intention to move out of polluted areas in the next 5 years. Note that we analyze the *admitted* determinants (i.e., economic and social circumstances), besides the more *hidden* (and often omitted) determinants such as community attachment and risk taking behavior [8,13,14]. Our methodological approach, based on an instrumental variables (IV) strategy, addresses potential

endogeneity issues due to reverse causality and unobserved heterogeneity in the relationship between household socioeconomic status and residential location. To our best knowledge, the use of IV strategy in this context is rare [15,16,17], which is another notable contribution of this study. The respondent’s height is used as main instrument, arguing that this factor is strongly correlated with socioeconomic status but exogenous to residential location. Our empirical tests validate the conditions that an instrument must satisfy.

Our analysis is based on an original dataset of 1194 households and 2787 individuals in three study areas in Southwestern Europe (Spain, Portugal, and France). Comparing the populations from several polluted areas with the populations from similar but non-polluted areas, our results emphasize the presence of strong environmental inequalities. The IV strategy shows that socioeconomic determinants (i.e., education, income, and wealth) have strong and negative effects on the probability of living in polluted areas. We clearly observe that observed heterogeneity such as place attachment and local facilities tend to understate the effects of socioeconomic status on residential location. In contrast to the results from the US literature, we confirm sociological assumptions that European polluted areas also seem to be an alternative for young families with lower-middle socioeconomic status who find an interest in affordable housing facilities and employment opportunities, services and infrastructures [8]. In line with these intuitions, we find that middle-income families seem to see advantages in remaining in polluted areas. As expected, households that are less risk averse and more attached to their community also tend to live in polluted areas. We conclude that such European-specific endogenous non-linearities contribute to make the effect of poverty on risky housing lower.

The structure of the article is the following. In Sect. 2, we describe the database and provide some contextual information about the case studies on which we base our analysis. In Sect. 3, we explain the methods we use to identify the main determinants of the probability of living and continuing to live in polluted areas versus living in cleaner ones. In Sect. 4, we present our results and, in Sect. 5, we conclude and discuss the related public policy implications.

2 Data

2.1 An Original Dataset

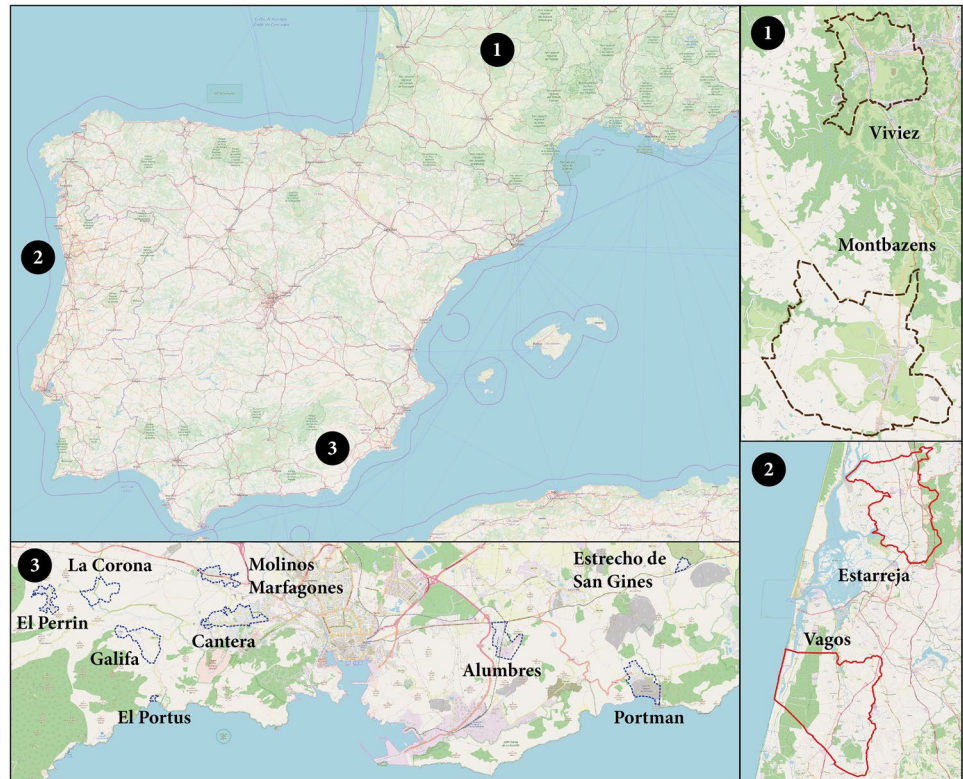
From October 2018 to January 2019, we conducted three household surveys of 1194 households in France, Portugal, and Spain, specifically designed to study the socioeconomic issues of pollution exposure. Using cadastral data, a random selection of housings was employed to guarantee the representativeness of study areas regarding demographic

¹ Similar terms can be found in the literature: Romero et al. [46] used the term ‘urban-environmental segregation’ when studying the impact of flood-risk on social segregation. Schaeffer and Tivadar [47] study ‘segregation based environmental inequalities’ measuring the spatial inequalities of social groups with respect to environmental amenities.

² Several multiplier effects can reinforce this pathway [2]: people tend to adopt homophile behavior, i.e. they tend to live near other people with similar ethnic, demographic or socioeconomic characteristics [26]; residents may influence the local amenities of their community, which in turn plays on future arrivals.

³ Compensations may also be set-up by the city hall, which may negotiate subsidies from the industry in exchange for the right to implant a polluting activity.

Fig. 1 Mapping of polluted and control areas. Source: OSM, authors' computation



and socioeconomic characteristics. We collected data of 684 households (1589 individuals) in polluted areas and of 510 households (1198 individuals) in corresponding control areas, creating an original comparative dataset, the “Comparative Survey on Pollution Exposure” (CSPE). More precisely, the CSPE is representative of the following polluted areas: Viviez in France (156 households and 293 individuals); the municipality of Estarreja in Portugal (300 households and 739 individuals); and three villages of the Spanish Sierra Minera (Portman, Estrecho de San Ginès and Alumbres) located to the east of Cartagena (228 households and 557 individuals). The non-polluted control areas are as follows: Montbazens in France (138 households and 309 individuals); the municipality of Vagos in Portugal (200 households and 437 individuals); and a group of villages (Portus, Galifa, Perin, La Corona, Cantera, and Molinos Marfagones) located to the west of Cartagena in Spain (172 households and 452 individuals). Polluted areas are well-known hotspots of pollution, as confirmed by the literature in geochemistry and mineralogy [18,19,20]. Pollution is spread in the polluted municipalities but does not spill over to the control areas. Control areas were selected using region-specific literature. For example, Inácio, Neves and Pereira [21] and Guihard-Costa et al. [22] explain that Estarreja and Vagos had the same natural amenities before the installation of the chemical complex in Estarreja. Similarly, the French Institute of Public Health used Montbazens as

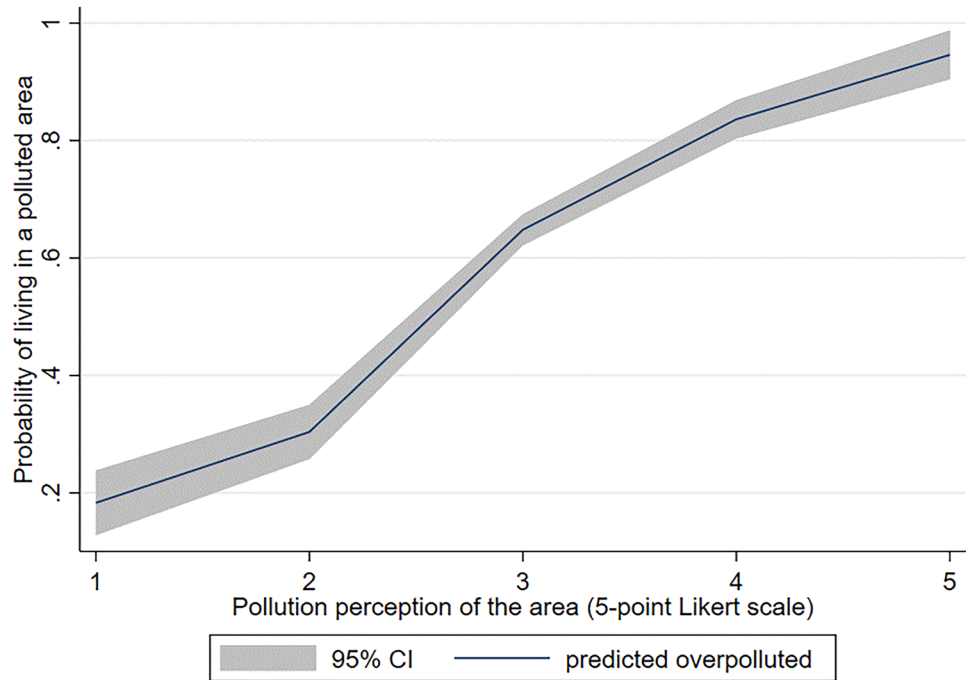
control area to infer the health effects of pollution exposure in Viviez [23]. Polluted and control areas are sufficiently close so that we are able to suppose that residential choices can be made either in one area or the other. The polluted and control study areas are shown in Fig. 1.

It is important to note that this quantitative survey was originally conducted to complete a set of well-documented qualitative interviews. Although the results of the qualitative field campaigns are not directly included in this article, they greatly contributed to our understanding of the study context and issues.

2.2 Context of the Study Areas

A detailed description of the context of our study areas is given in Appendix 1. In a nutshell, our Southwestern European sample makes it possible to observe the three stages that characterize several polluted areas around the world: (i) ex-mining towns (Portman and ESG); (ii) a heavy metal industry undergoing technological reconversion (Viviez); and (iii) active (petro-)chemical complexes (Estarreja, and Alumbres). Table 4 in the Appendix 1 provides means of several important variables of our study in polluted and control areas as well as mean-comparison tests. Figures 5 and 6 in the Appendix 1 describe at more length the main reasons that motivate residents to live in the respective areas and their intentions to move out. Table 5 in the Appendix 1

Fig. 2 Respondent's pollution perception and probability of living in polluted areas. Fractional polynomial estimates are used. Source: Authors' calculation from the CSPE database



provides mean-comparison tests for these reasons between polluted and control areas.

3 Methods

In this article, we study the determinants of two types of outcome indicators. First, we create a binary variable “living in a polluted area” which takes the value 1 for households living in a study area, and 0 for households living in a control area. This allows us to analyze the reasons why households live in each area. Next, we create a binary response variable that identifies households who plan to move out in the next five years. This allows us to explore potential dynamics in the environmental injustice process. In both cases, we estimate the probability of the outcome indicator being 1, using linear probability models. Referring to the theoretical pathways discussed in Sect. 2, our empirical analysis especially captures *long-term* effects between household socio-economic indicators and pollution exposure. Indeed, the industrial sites we study have been settled since at least the 1950s (i.e., for more than two generations). In other words, while the oldest residents might remain for emotional reasons, several current residents already made their (re)location choice as a function of their economic constraints and their willingness to pay for a clean environment.

3.1 Descriptive Statistics

Let us first describe some of the features of our dataset. As shown in Fig. 2, the respondent's pollution perception of the

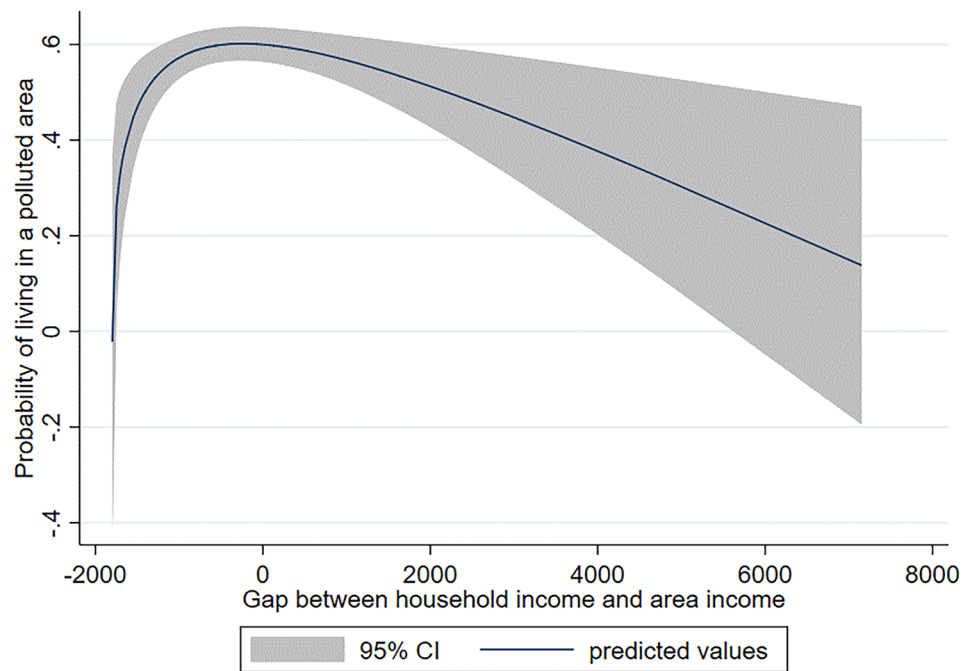
area (measured with a 1-to-5 Likert scale) is strongly correlated with the probability of living in a polluted area. Hence, the question is why people continue to live in polluted areas, even if they know about related pollution issues.

Figure 3 shows that the probability of living in a polluted area decreases when household incomes differ from the average community income. As observed by Guo and Bhat [24], the lower the absolute gap, the higher the risk of living in a polluted area.

However, Fig. 4 suggests that it is not mainly the poorest households (Q1) who live in polluted areas nor the richest households as expected (Q4 and Q5), but a lower-middle class (Q2 and Q3).⁴ Nonetheless, this result should be interpreted with caution given that there might be endogeneity problems.

⁴ When endogeneity problems are suspected (e.g., reverse causality and unobserved heterogeneity) and may bias classical estimates such as OLS or Probit, an IV strategy is commonly used in applied economics to perform unbiased fitted coefficients [28]. In our study context for instance, the presence of reverse causality and unobserved heterogeneity might overstate or understate the real impact of poverty on the probability of living in a polluted area. By introducing exogenous variations strongly correlated to poverty status but uncorrelated to residential location (i.e., the instrument), IV models only capture the effect of poverty status on pollution exposure that transits through the instrument. If the selected instruments meet both conditions (i.e., being relevant and having no direct link with residential location), one can conclude that fitted coefficients are unbiased and a causal impact is observed. In other words, IV estimates will identify the effect of exogenous variations in poverty status (that transits through the instrument) on the probability of living in polluted areas.

Fig. 3 Income gaps in polluted areas. Fractional polynomial estimates are used. Source: Authors' calculation from the CSPE database



Figures 7 and 8 in Appendix 1 give some additional information on the way pollution perception is distributed in the sample, namely that it increases with income (except for the highest quantile in polluted areas) and length of residence.

3.2 Empirical Challenges

Apart from pollution and industrial features, our sample of polluted and non-polluted areas may initially differ in terms of ecological and historical attractiveness.⁵ In other words, it is impossible to be sure that our selected control areas are perfect counterfactuals of our selected polluted areas. A perfect counterfactual means that these control areas would evolve in the same way as the polluted areas if they had also benefited from the installation of an industrial site (or a mining company). Given that our control areas are potentially imperfect counterfactuals, simply comparing polluted and non-polluted samples might lead to a selection bias. Hence, the main challenge is to deal with endogeneity problems. First, our estimations could be biased because of the presence of reverse causality between household socioeconomic status and pollution exposure. Not only pollution reduces housing prices that potentially attracts poor households, but also polluting industries may emit residuals that are toxic for human health [25]. Daily exposure to these

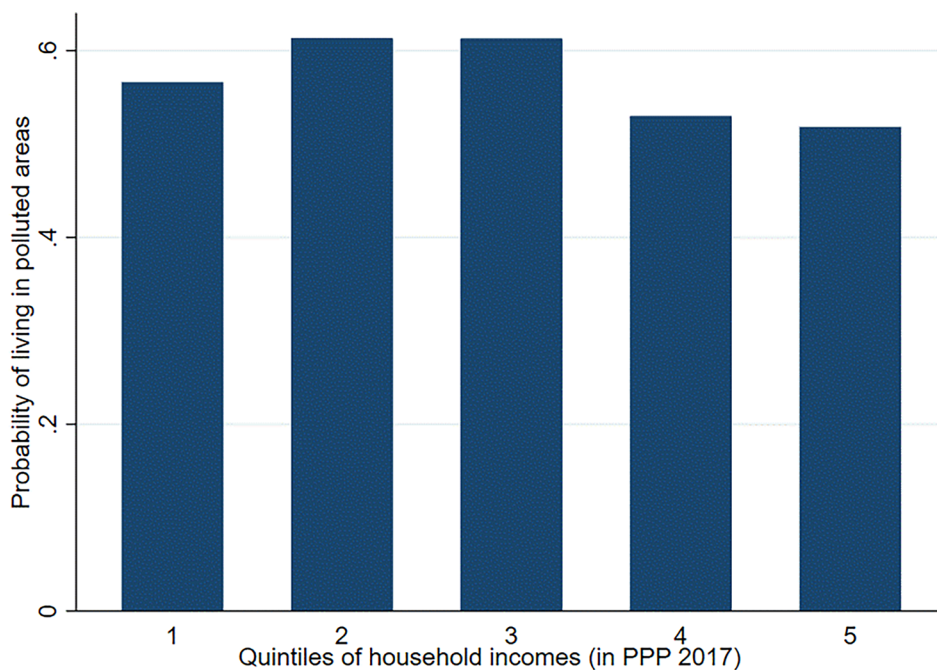
chemical residues may affect the capacity for socioeconomic advancement of residents through loss of productivity. Second, another source of endogeneity may originate from the omission of factors simultaneously correlated with household socioeconomic status and outcome indicators. In our context, we assume that heterogeneous environmental and geographical preferences may bias the estimates. Indeed, these preferences can be simultaneously correlated with socioeconomic status and the unexplained part of (re)location choice, and thus bias estimations. It is widely recognized that different social groups have specific perceptions and preferences about health, pollution and space and thus different ability to pay for desirable community amenities like a clean environment, natural spaces, nice landscapes, quality schools, public safety, employment accessibility, and accessible retail outlets [2]. To neutralize such a selection bias, we use an IV strategy that allows the effect of household socioeconomic status to be robustly assessed.⁶ Xu and Sylwester [17] used a similar approach to assess the impact of area air pollution on emigration flows.

Another challenge is to correct the expected intra-group correlation within polluted villages that could reduce the variance of certain factors, and thus overestimate their significance. Indeed, it is well known that households tend to live among or relocate around groups of households with similar incomes [26]. Moreover, the presence (or absence)

⁵ We also tested other covariates such as housing price and employment indicators, but we do not include them in the model because of collinearity with indicators for socioeconomic status.

⁶ Note that β_i and ε are not identical in Eq. 1 and Eq. 2. This notation is used by convention and hence enhances readability of the equations.

Fig. 4 Household incomes (in \$PPP) and probability of living in polluted areas. Source: Authors' calculation from the CSPE database



of public facilities is an important predictor of residential choice [24], which could reinforce the intra-correlation within an area. To control for the potential intra-group correlations within villages, cluster robust standard errors are systematically estimated at the village level (i.e., the standard errors are not calculated at the individual level but at the village level), see Wooldridge [27].

3.3 The Model

Based on Schirmer, Eggermond and Axhausen [26], we frame our estimation models on the following dimensions measured at the household level: socioeconomic (income, education, and wealth), demographic (age group proportions, gender proportion, marital status), and housing factors (housing size). In exploratory estimations, we also investigate the influence of community-based factors (length of residence and family network) and respondent-based factors (risk taking behavior). Table 6 in the Appendix 2 describes the explanatory variables that we tested.⁷ More formally, we consider a structural equation with θ designing the functional form of the equation. In the first place, we use a linear probability model (see for example [28], p. 454). Hence, OLS regressions are performed for Eq. 1:

$$P(y = 1|\mathbf{x}) = \theta(\mathbf{x}\boldsymbol{\beta}) = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \varepsilon \quad (1)$$

⁷ Note that β_i , ε , and y are not identical in Eq. 3 and equations Eq. 1 and Eq. 2. This notation is used by convention.

with y being the dependent variable “living in a polluted area” and \mathbf{x} the following types of explanatory variables: x_1 socio-economic factors, x_2 demographic factors, x_3 community factors, x_4 individual factors; β_i the corresponding estimated coefficients and ε the error term. Despite the comprehensive set of observed factors included in the analysis, these models potentially remain sensitive to endogeneity problems, mainly due to reverse causality and variations in unobserved individual preferences (landscape preference, geographical location, specific local amenities, place attachment, etc.). Mathematically, β_1 is biased if socioeconomic factors are correlated with ε (i.e., the unexplained part of the variance of the dependent variable). Therefore, to establish a causal inference regarding socioeconomic factors, we apply an IV strategy based on two-stage least square (2SLS) estimations as follows Wooldridge [28]:

$$\begin{cases} P(y = 1|x) = \theta(\mathbf{x}\boldsymbol{\beta}) = \beta_0 + \beta_1\hat{x}_1 + \beta_2x_2 + \varepsilon, \\ F(x_1) = \gamma_0 + \gamma_1z + \gamma_2x_2 + \rho, \end{cases} \quad (2)$$

with y the dependent variable, \mathbf{x} the explanatory variable and ε the error term as above, \hat{x}_1 the estimated socio-economic factors, F the functional form of the estimation of socioeconomic factors, z the instruments, γ_i the corresponding estimated coefficients, and ρ the corresponding error term.⁸ As suggested by Angrist and Pischke [29], we only integrate exogenous control factors in the IV model in order to focus on the causal impacts of household education, wealth and

⁸ We also tested the model using IV-Probit estimations. As the results are relatively similar, we only report 2-SLS estimates.

income. Thus, we only control for demographic and housing heterogeneity across households (i.e., age group proportions, gender proportion, marital status, housing size, and country fixed effects). Indeed, the inclusion of potential endogenous control factors (e.g., owning a garden, length of residence, family network, and health risk behavior) could bias IV estimates insofar as we cannot be sure whether these factors are determinants or consequences of living in polluted areas. In the first step regression, we linearly regress socioeconomic factors on instruments and covariates. Then, the fitted values of socioeconomic indicators from the first-stage are included in the structural equation to neutralize the unobserved part of the variance of the dependent variable correlated with socioeconomic factors. In other words, assuming exogenous instruments, fitted values of socioeconomic status are suitably independent of omitted factors (ϵ). This means that the model no longer has endogeneity problems and produces consistent estimates.

The case-control design of our database does not allow the use of locality-specific data as instruments such as meteorological variations (e.g., inadequate variation across the study areas). For this reason, we use the reported height (in meters) of the respondent as main IV to instrument socioeconomic factors. The literature abounds with works showing a strong relationship between individual height and socioeconomic status. Indeed, there is a vicious cycle between small height and poverty, namely due to the hazardous consumptions of mothers during pregnancy (e.g., smoking, and alcoholism), micronutrient deficiencies during childhood, schooling and labor market discrimination, and productivity loss due to lower cognitive skills [30,31]. In brief, not only poor households make smaller children but also smaller individuals have lower success in school and employment as well as lower earnings [32,33]. Even if the negative correlation between poverty and height is expectedly strong, which is the former condition for a valuable instrument, the exogeneity condition is always debatable. Unfortunately, there is no perfect instrument in observational data. Indeed, according to the health economics literature, a child's exposure to pollution might affect growth and then adult height, which may lead to bias IV estimates. For example, Currie and Neidell [34] observed significant impacts of air pollution peaks on infant mortality risks. In connection with our topic, during the English industrial revolution, Bailey, Hatton and Inwood [35] found a negative relationship between adult height and intense inhalation of coal smoke in young childhood. However, this study is only correlational and does not identify a causal effect. Epidemiological studies identified a critical window from maternal gestation to early childhood (around age 2) in which a child's physical and intellectual growth is highly dependent on environmental factors such as feeding practices and mother consumptions [36]. Moreover, Selevan, Kimmel and Mendola [37] reported that the health

risk related to heavy metal absorption decreases significantly after age 6. Thus, one can assume that a chronic exposure to pollutants occurring up to a certain age may impair body development. Rosales-Rueda and Triyana [38] achieved in identifying a causal impact of maternal exposure to air pollution peaks on child's height-for-age some years later, but this effect is relatively small and only significant when such risky maternal inhalations occur during the gestation period. Hence, pollution is unlikely to affect the individual growth if the individual starts to be exposed after a certain age. To check for the exogeneity of the respondent's height, we run IV estimates employing several sample restrictions: (i) including only respondents who are not born in the area; (ii) households in which the respondent was at least 4 years old when they moved in the area; (iii) households in which the respondent was at least 18 years old when they moved in the area. To our understanding, if the estimates remain significant in these restricted samples, it means that the effect of pollution exposure on height is mainly due to socioeconomic status. In contrast, if the estimates do not remain significant in the restricted samples, it means that reverse causality problems tend to overstate the effect of poverty on pollution exposure. Furthermore, we provide an additional test of exogeneity by comparing the correlations between the length of area residence and height in polluted areas and control areas. Such a correlation might cast doubt about the identifying assumption.

Next, we consider an additional instrument to implement over-identification tests: the respondent's parental education (a dummy variable identifying if at least one of both parents completed high school). While the correlation between the parent's and children's education is obvious, the exogeneity of parental education with residential location is reasonably questionable. For instance, Bayer, Keohane and Timmins [39] suggest that one's current location is highly dependent on parental location, the latter being highly correlated to the level of parental education. However, this concern is alleviated when we restrict the sample to individuals who were already 18 years old when they moved in the area. For them, there is no assumed correlation between parental location and current location. Regarding the over-identification test, if we accept the null hypothesis of no correlation between the instruments and the error term, it means that the latter instrument is valid, based on the assumption that the respondent's height is exogenous, or inversely.

Lastly, to identify the determinants that influence the decision to leave a polluted area, we regress the intention to move out in the next 5 years on several factors interacted with the fact of living in a polluted area versus living in a cleaner area. We consider that such a model specification (shown in Eq. 3) is not particularly affected by endogeneity-related biases. Indeed, an inverse causality bias is not prevalent since the intention to move out is unlikely to affect

current income, education or wealth, except if households with move-out intentions work more in order to save money and cover the costs of relocation. While the latter assumption is unlikely to occur, to our extent, we find no reason to think that unobserved factors are simultaneously correlated with socioeconomic status and emigration intentions. In fact, by applying a similar IV strategy as in Eq. 2, we do not detect the presence of potential endogeneity problems. Hence, we only run linear probability estimations based on OLS for Eq. 3:

$$P(y = 1|x) = \theta(\mathbf{x}\boldsymbol{\beta}) = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_5x_5 + \beta_6[x_1 * x_5] + \varepsilon, \quad (3)$$

where y being the dependent variable “intention to move out,” and \mathbf{x} the following types of explanatory variables: x_1 socio-economic factors, x_2 demographic factors, x_3 community factors, x_4 individual factors, x_5 living in polluted areas; variables x_1 and x_5 are tested in interaction, as shown in the last parenthesis; β_i are the corresponding estimated coefficients and ε the error term.⁹

4 Results

4.1 OLS and 2SLS Estimates

To test the impact of households’ socioeconomic status on the probability of living in polluted areas, we apply an IV strategy based on 2SLS estimations.¹⁰ Table 1 depicts the results for three different indicators of household’s socioeconomic status: the number of educated adult members in the household (at least completed a high school diploma), a 7-score wealth index and the logarithm of monthly household income corrected in purchasing power parities (PPP) based on 2017 US dollars. For each socioeconomic indicator, we run linear probability models using OLS, just-identified 2SLS and over-identified 2SLS estimators. In just-identified 2SLS estimates, the respondent’s height is used as instrument, whereas in over-identified 2SLS estimates we add the parents’ level of education as second instrument.

In Table 1, OLS estimates show very slight correlations between socioeconomic status and residential location. Except for education where the fitted coefficient is significant (column 1), wealth and income indicators have a

negative but non-significant relationship with the probability of living in polluted areas (columns 4 and 7). By instrumenting socioeconomic status by the respondent’s height, just-identified IV estimates show significant and negative impacts of education, wealth, and income on the probability of living in polluted settings (columns 2, 5, and 8). For instance, column 2 exhibits that one extra-educated adult in the household reduces the probability of living in a polluted area by 46 percentage points (almost 6 times stronger than OLS estimates). Similarly, an increase of monthly incomes by 10% significantly decreases the risk of living in a polluted area by 6.5% (more than 10 times stronger than OLS estimates). Over-identified IV estimates show similar results, even if the instrumented coefficients are a bit lower (columns 3, 6, and 9).

The higher magnitudes of fitted coefficients from IV estimates suggest that OLS estimates strongly understate the impact of socioeconomic status on residential choices, probably due to a selection bias and unobserved heterogeneity. More specifically, the difference between OLS and IV results may be due to unobserved factors correlated with household socioeconomic status. Indeed, according to the sociological literature (e.g., [8]), polluted areas have several *omitted* characteristics that may attract lower-middle social classes to live there, such as employment opportunities and accessibility, housing facilities, and other advantages (e.g., community satisfaction and attachment). In accordance with this assumption, Table 1 shows that young and lower-middle aged people tend to live more often in polluted areas, either in a couple or as singles. Likewise, coefficients for housing size are significant and positive in all fitted models, corroborating the assumption that households with lower socioeconomic status can live in larger houses at affordable prices in polluted areas. Furthermore, Table 7 in the Appendix 2, examining the factors that are correlated with the probability of living in a polluted area, clearly confirms the disproportional attraction of young families with lower-middle socioeconomic status. We find a U-inverted relationship between the wealth index or income and the probability of living in polluted areas.¹¹ Moreover, housing size is an important predictor of this probability.¹² Other control factors are tested in

⁹ The turning point is around 1918 \$PPP per month and household, i.e., 1113 euros in Portugal, 1230 euros in Spain, and 1489 euros in France, corresponding to lower-middle incomes in each country.

¹⁰ An alternative model specification adding interaction terms between age groups proportions and housing size shows that housing size particularly increases the probability of living in polluted areas for the 30–45 age group (not shown).

¹¹ We measure the environmental health risk aversion by asking the respondent to evaluate on a 1-to-5 Likert scale his/her willingness to live in a polluted area that may decrease by 5 years old his/her life expectancy.

¹² To be suitable, an instrument must meet two conditions: (i) it must be a non-weak predictor of the endogenous variable conditional on control variables; and (ii) it must not be directly related to the error component in the structural equation (i.e., not be correlated with the unexplained part of the probability of living in a polluted area). The second condition, called exclusion restriction assumption, means that our instruments should not directly correlate with the probability of living in a polluted area through channels other than the household socioeconomic status [28].

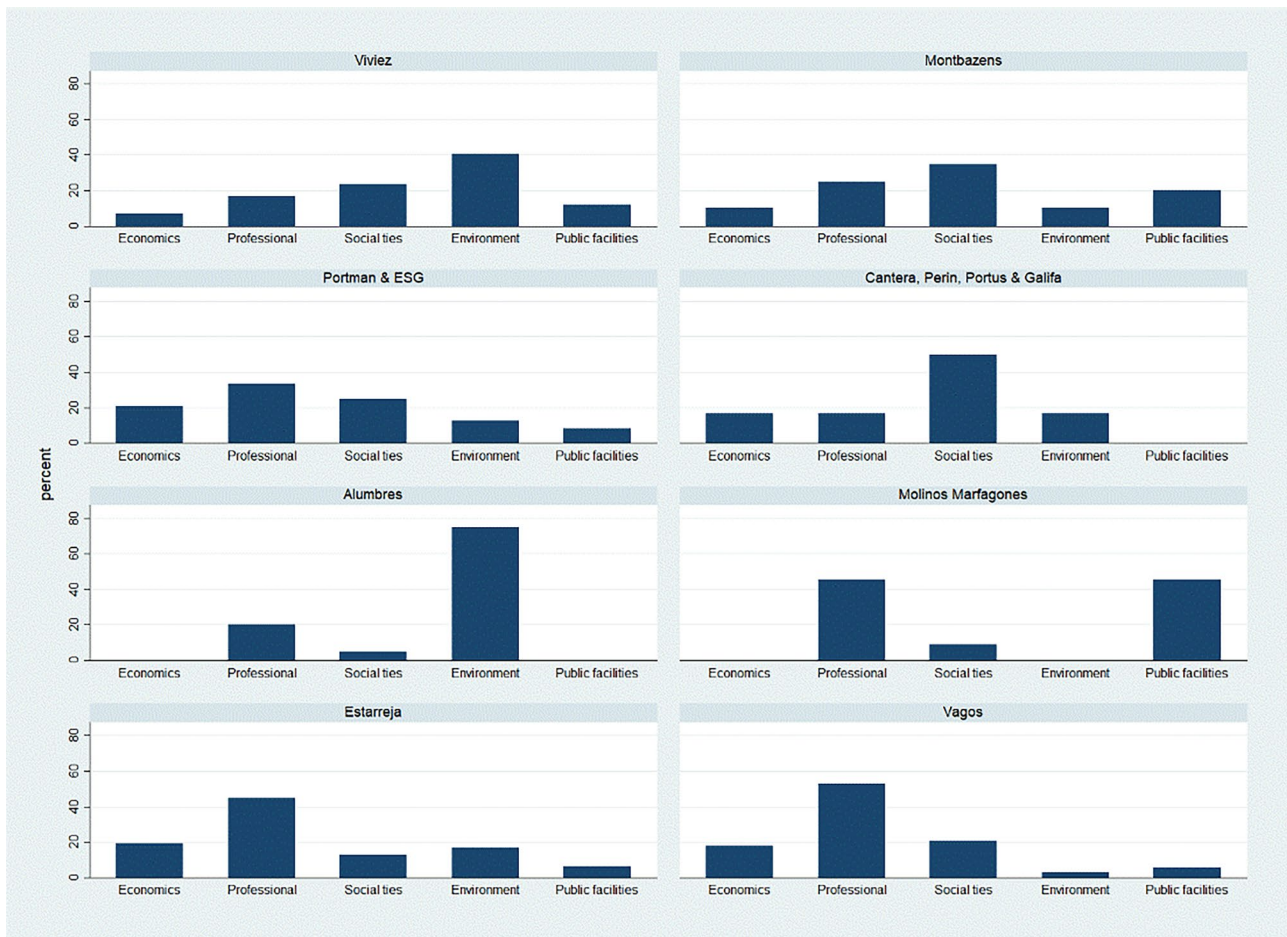


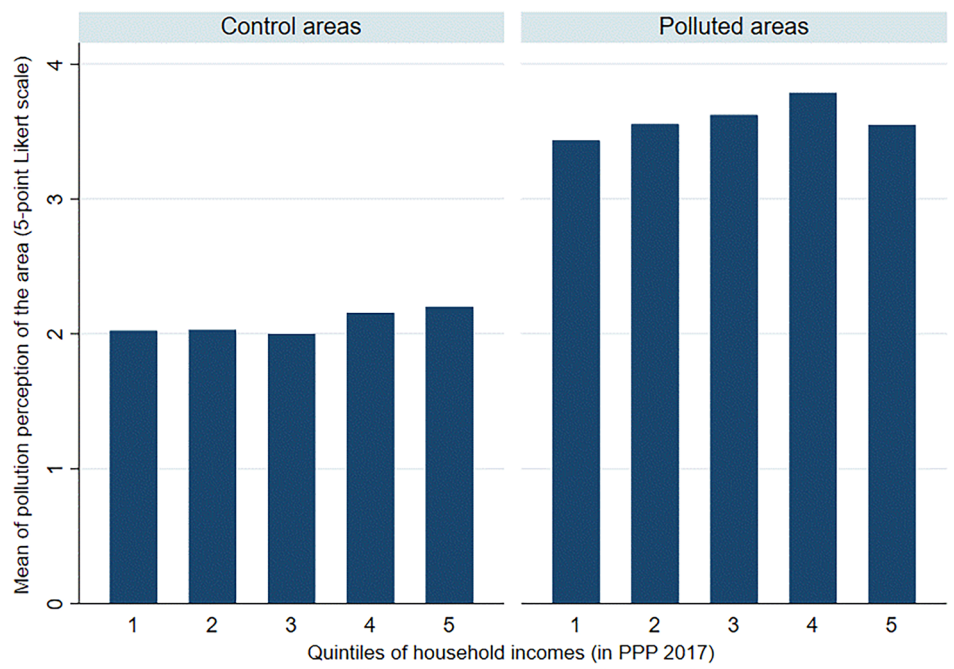
Fig. 6 Main mentioned reason for move-out intentions in the next 5 years

of its proximity to coal mines and rail facilities. In 1871, an international company undertook large-scale industrialization of the site by extracting, transforming, and exporting zinc. In 1922, the site became a pioneer in adopting electrolytic techniques to chemically extract zinc from zinc blende. Although zinc extraction ended in 1987, the company continues to process zinc. In addition, the company helped develop new industries, namely the recycling of cadmium residuals and plastics. As a result of the zinc melting activity, the soils in the areas are contaminated with high concentrations of lead, cadmium, and arsenic [23]. Considering the economic and community indicators listed in Table 4, Viviez looks more like Portman/ESG (an ex-mining site) than Alumbres and Estarreja (active industrial sites). Compared to Montbazens (control area), Viviez has lower housing prices, household incomes and employment rates, as well as a lower perceived availability of public services and retail outlets.

Additional descriptive statistics about the study areas are provided in Table 5.

Table 5 shows that “professional reasons” are particularly mentioned as a motivation for living in Alumbres and Estarreja. Table 5 also shows that residents more often mention to have chosen to live in Viviez and Portman/ESG for “interesting economic reasons” (e.g., affordable housing price) compared to residents from non-polluted areas, who more often mention “environmental amenities” as residential motivation. This result is not surprising given the presence of an active industry supplying various jobs in both areas. Furthermore, strong community attachment and satisfaction are characteristics that are highlighted in several active industrial sites in Europe. However, perceived area attractiveness is significantly lower in these active sites (Viviez and Alumbres), compared to their respective control groups. This might be due to the presence of smokes, smells, and noises. Figure 5 summarizes the main reasons for living in the area: “social

Fig. 7 Pollution perception in polluted and control areas as a function of household income

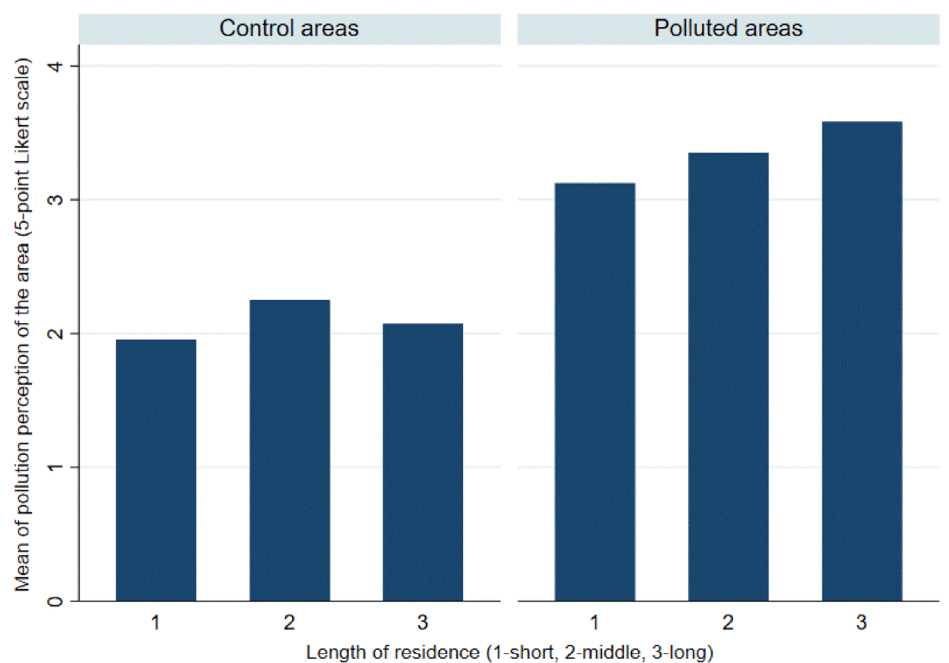


ties" play an important role for all study areas, even more than "professional reasons" and "economic reasons".

Table 5 also shows stronger intentions to move out for residents from Viviez and Alumbres compared to their respective control groups. In these two municipalities, "environmental issues" appear as the most mentioned motivation for moving out. In contrast, "environmental issues" do not appear as a specific move-out issue in Portman/ESG and Estarreja, compared to their respective counterparts. On

the other hand, area attractiveness perceptions in Portman/ESG and Estarreja do not differ from their respective control areas. This absence of significant gap is not so surprising since, in both areas, there are close environmental amenities that residents can enjoy despite the presence of pollution (e.g., lagoon, sea, or ocean). In addition, pollution is not directly visible in Portman/ESG (i.e., mines closed since 1990) and can be relatively far in Estarreja for people living in other *freguesias* than Beduido & Veiros (where

Fig. 8 Pollution perception in polluted and control areas as a function of length of residence in the area



the chemical complex is located). In the same way, Table 5 does not show significant differences regarding move-out intentions in Portman/ESG and Estarreja, compared to their respective control group. Figure 6 summarizes main reasons for moving out mentioned by the respondents in each area.

Figures 7 and 8 show that pollution perception is always higher in polluted areas than in control areas. Figure 7 underlines that pollution perception is increasing with

income except for the highest income quantile in polluted areas. Figure 8 underlines that pollution perception in polluted areas is growing with the length of residence.

Appendix 2. Additional materials

Table 6 Description of variables

| Variable name | Description |
|---|---|
| Living in polluted areas (dummy) | Takes the value 1 if the household lives in a polluted area (Viviez, Sierra Minera, Estarreja) and 0 if it lives in a control area (Montbazens, Catargena West, Vagos) |
| Intention to move out in the next 5 years (dummy) | Takes the value 1 if the household plans to move out of the community in the next five years, 0 otherwise |
| Number of children (lower than 17 years old) | Quantity of children in the household |
| Number of young adults (18–29 years old) | Quantity of young adults in the household |
| Number of lower-middle age adults (30–44 years old) | Quantity of lower-middle age adults in the household |
| Number of higher middle age adults (45–64 years old) | Quantity of higher-middle age adults in the household |
| Number of old adults (higher than 65 years old) | Quantity of old adults in the household |
| Number of male members | Quantity of male members in the household |
| Respondent is in a couple (dummy) | Takes the value 1 if the respondent is in a couple (married or free union), 0 otherwise |
| Respondent is single (dummy) | Takes the value 1 if the respondent is single, 0 otherwise |
| Number of members with foreign parents | Quantity of adult members with foreign parents in the household |
| Number of rooms | Number of rooms in the housing |
| Having a garden (dummy) | Takes the value 1 if the housing has a private garden, 0 otherwise |
| Presence of family members around (dummy) | Takes the value 1 if there are family members living in the same community, 0 otherwise |
| Lifetime in the area (in year) | Duration of residence in the community in years |
| Willingness to live in a polluted land that decreases life expectancy by 5yo (1-to-5 scale) | The scale varies from 1 “a very low willingness to live in a place that may reduce life expectancy by 5 years old” to 5 “a very high willingness to take this risk” |
| Number of members who obtained a high-school grade | Number of household members who obtained a high-school diploma |
| Wealth index (0-to-7 score) | Wealth index is the sum of the following owned (or not) assets: former house, second house, car, air conditioner, computer, cellphone, and financial assets. Thus, the wealthiest households have a score of 7 while the most deprived household a score of 0 |
| ln(monthly total household income) | Before being log-transformed, monthly total household incomes are corrected using purchasing power parities (PPP) based on 2017 US dollars: 0.581 for Portugal, 0.641 for Spain and 0.776 for France |
| Respondent’s height | Height of the respondent in meters |
| Respondent’s parental education | Takes the value 1 if at least one parent of the respondent obtained a high-school diploma, 0 otherwise |

Source: Authors’ computation from the CSPE database

Table 7 Factors correlated to the probability of living in polluted areas (OLS estimates)

| | (1) | (2) |
|---|-------------------------------------|-------------------------------------|
| Number of children (lower than 17 years old) | – 0.002 (– 0.06) | – 0.013 (– 0.48) |
| Number of young adults (18–29 years old) | 0.021 (0.64) | 0.026 (0.76) |
| Number of lower-middle adults (30–44 years old) | – 0.003 (– 0.07) | 0.011 (0.24) |
| Number of higher middle adults (45–64 years old) | – 0.039 (– 1.49) | – 0.043 (– 1.06) |
| Number of old adults (higher than 65 years old) | – 0.061* (– 2.06) | – 0.079* (– 1.94) |
| Number of male members | – 0.024 (– 1.03) | – 0.007 (– 0.22) |
| Respondent is in a couple (dummy) | 0.036 (1.34) | 0.073** (2.36) |
| Respondent is single (dummy) | 0.074 (1.53) | 0.119** (2.36) |
| Number of members with foreign parents | 0.086*** (3.18) | 0.080*** (3.00) |
| Number of rooms | 0.044*** (3.89) | 0.046*** (3.37) |
| Having a garden (dummy) | – 0.161** (– 2.69) | – 0.146** (– 2.33) |
| Presence of family members around (dummy) | 0.156** (2.25) | 0.174** (2.73) |
| Lifetime in the area (in year) | 0.004*** (5.03) | 0.004*** (5.37) |
| Willingness to live in a polluted land that decreases life expectancy by 5yo (1-to-5 scale) | 0.084** (2.52) | 0.080** (2.42) |
| Wealth index (0-to-7 score) | 0.112*** (3.23) | |
| Square of wealth index | – 0.017** (– 2.73) | |
| ln(incomePPP) | | 1.083** (2.37) |
| Square of ln(incomePPP) | | – 0.073** (– 2.44) |
| Constant | – 0.119 (– 0.47) | – 4.052** (– 2.37) |
| Country fixed effects | Yes | Yes |
| Observations | 1,144 | 939 |
| R-square | 0.139 | 0.153 |

Source: Authors' calculation from the CSPE database

(1) Standard errors are robust to intra-group correlation. Significance levels are ***1%, **5%, *10%

(2) Wealth index is the sum of the following owned (or not) assets: former house, second house, car, air conditioner, computer, cellphone and financial assets. Thus, the wealthiest households have a score of 7 while the most deprived household a score of 0.

(3) Before being log-transformed, household incomes are corrected using purchasing power parities (PPP) based on 2017 US dollars: 0.581 for Portugal, 0.641 for Spain, and 0.776 for France.

Table 8 First-step estimates in IV model, linear regression of household socioeconomic status on instruments and control variables

| | Number of educated members | Number of educated members | Wealth index | Wealth index | ln(income) | ln(income) |
|---|----------------------------------|----------------------------------|---------------------|---------------------|---------------------|---------------------|
| Height of the respondent (in meters) | 1.252*** (4.09) | 1.157*** (3.64) | 1.611*** (3.57) | 1.490*** (3.30) | 0.943*** (4.54) | 0.866*** (4.15) |
| Parental education of the respondent (at least a high-school diploma) | | 0.433*** (5.13) | | 0.333*** (3.11) | | 0.266*** (5.21) |
| Number of children (lower than 17 years old) | 0.006 (0.07) | − 0.011 (− 0.15) | 0.055 (1.10) | 0.029 (0.57) | 0.036 (0.90) | 0.027 (0.61) |
| Number of young adults (18–29 years old) | 0.607*** (9.86) | 0.538*** (7.58) | 0.248*** (3.74) | 0.193*** (3.09) | 0.267*** (5.50) | 0.228*** (4.58) |
| Number of lower-middle age adults (30–44 years old) | 0.498*** (7.14) | 0.440*** (7.88) | 0.349*** (4.33) | 0.310*** (3.72) | 0.367*** (10.29) | 0.350*** (9.59) |
| Number of higher middle age adults (45–64 years old) | 0.351*** (7.50) | 0.343*** (9.30) | 0.373*** (4.94) | 0.365*** (4.47) | 0.268*** (7.97) | 0.275*** (8.33) |
| Number of old adults (higher than 65 years old) | 0.131** (2.13) | 0.126** (2.36) | − 0.044 (− 0.42) | − 0.041 (− 0.41) | 0.149*** (4.83) | 0.170*** (5.21) |
| Number of male members | − 0.082 (− 1.50) | − 0.061 (− 0.99) | − 0.028 (− 0.47) | − 0.017 (− 0.24) | − 0.040 (− 1.49) | − 0.031 (− 1.04) |
| Respondent is in a couple (dummy) | 0.070 (0.86) | 0.042 (0.53) | 0.696*** (7.67) | 0.717*** (7.89) | 0.252*** (6.79) | 0.237*** (7.78) |
| Respondent is single (dummy) | − 0.076 (− 0.75) | − 0.163 (− 1.50) | 0.324*** (3.05) | 0.346*** (3.19) | 0.089 (1.23) | 0.059 (1.00) |
| Number of rooms | 0.052*** (3.81) | 0.047*** (3.18) | 0.220*** (7.83) | 0.235*** (9.60) | 0.076*** (5.64) | 0.071*** (5.19) |
| Constant | − 2.536*** (− 5.19) | − 2.347*** (− 4.45) | − 0.787 (− 1.03) | − 0.703 (− 0.91) | 4.961*** (13.73) | 5.085*** (13.71) |
| Country fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1147 | 1098 | 1147 | 1098 | 943 | 911 |
| R-square | 0.302 | 0.329 | 0.340 | 0.353 | 0.436 | 0.464 |

Source: Authors' calculation from the CSPE database

(1) Standard errors are robust to intra-group correlation. Significance levels are ***1%, **5%, *10%

(2) Wealth index is the sum of the following owned (or not) assets: former house, second house, car, air conditioner, computer, cellphone, and financial assets. Thus, the wealthiest households have a score of 7 while the most deprived household a score of 0. Incomes are in US\$ PPA

Fig. 9 Length of residence and height in polluted and control areas

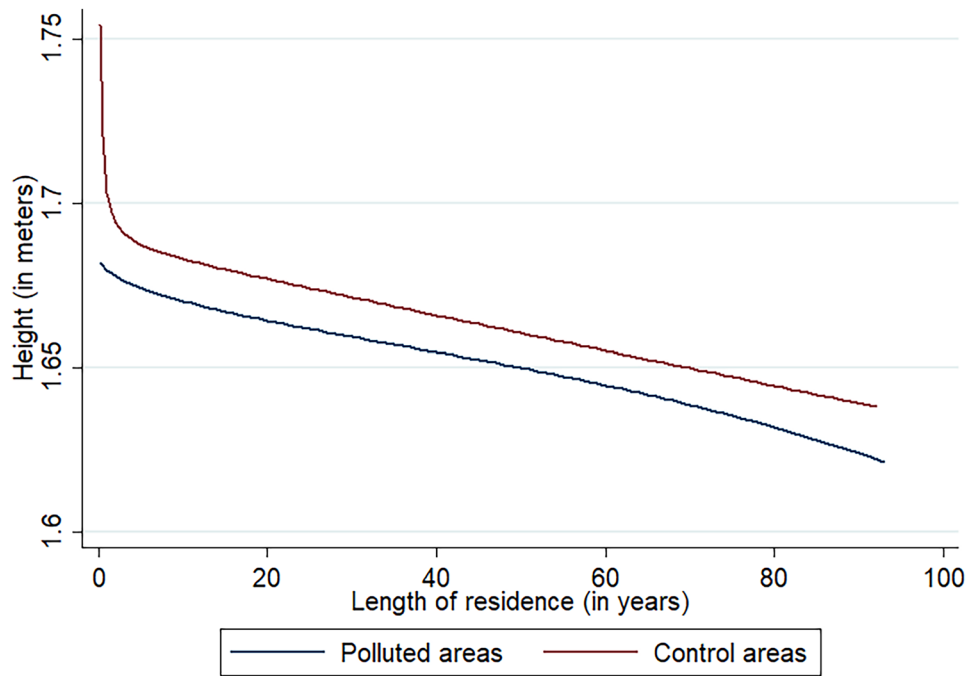


Table 9 Reduced-form regression of the dependent variable on the instruments

| | Prob(LivingPollutedAreas) |
|---|---------------------------|
| Height of the respondent (in meters) | - 0.548*** (- 3.02) |
| Parental education of the respondent (at least a high-school level) | - 0.075* (- 1.80) |
| Number of children (lower than 17 years old) | - 0.003 (- 0.10) |
| Number of young adults (18–29 years old) | 0.019 (0.56) |
| Number of lower-middle age adults (30–44 years old) | - 0.003 (- 0.07) |
| Number of higher middle age adults (45–64 years old) | - 0.061* (- 1.84) |
| Number of old adults (higher than 65 years old) | - 0.037 (- 1.04) |
| Number of male members | - 0.018 (- 0.59) |
| Respondent is in a couple (dummy) | 0.049 (1.08) |
| Respondent is single (dummy) | 0.085 (1.64) |
| Number of rooms | 0.045*** (4.51) |
| Country fixed effects | Yes |
| Observations | 1098 |
| R-square | 0.0295 |

Source: Authors' calculation from the CSPE database

Table 10 Factors correlated to the intention to move out in the next 5 years, OLS estimates (full table of Eq. 3)

| | (1) | (2) | (3) | (4) | (5) |
|---|------------------------|------------------------|------------------------|------------------------|------------------------|
| Average age of adults (in years) | - 0.002** (- 2.47) | - 0.003** (- 2.55) | - 0.002** (- 2.56) | - 0.000 (- 0.35) | - 0.000 (- 0.43) |
| Number of male members | - 0.010 (- 0.78) | - 0.011 (- 0.90) | - 0.001 (- 0.06) | - 0.001 (- 0.06) | 0.001 (0.07) |
| Respondent is in a couple (dummy) | - 0.004 (- 0.30) | - 0.003 (- 0.18) | 0.002 (0.09) | 0.002 (0.10) | 0.001 (0.04) |
| Respondent is single (dummy) | 0.056** (2.25) | 0.056** (2.34) | 0.067** (2.48) | 0.067** (2.45) | 0.068** (2.57) |
| Number of members with foreign parents | 0.027 (0.99) | 0.026 (0.96) | 0.036 (0.84) | 0.039 (0.93) | 0.036 (0.88) |
| Number of rooms | - 0.004 (- 0.59) | - 0.003 (- 0.61) | - 0.006 (- 0.83) | - 0.006 (- 0.79) | - 0.006 (- 0.76) |
| Having a garden (dummy) | - 0.040 (- 1.12) | - 0.037 (- 1.03) | - 0.023 (- 0.76) | - 0.024 (- 0.81) | - 0.022 (- 0.81) |
| Presence of family members around | - 0.043* (- 2.06) | - 0.045** (- 2.14) | - 0.037 (- 1.32) | - 0.037 (- 1.34) | - 0.038 (- 1.44) |
| Lifetime in the area (in year) | - 0.001** (- 2.67) | - 0.001*** (- 2.84) | - 0.001*** (- 3.44) | - 0.001*** (- 3.27) | - 0.001*** (- 3.10) |
| Willingness to live in a polluted land that decreases life expectancy by 5yo (1-to-5 scale) | 0.007 (0.62) | 0.007 (0.55) | 0.001 (0.15) | 0.001 (0.12) | - 0.002 (- 0.17) |
| Area attractiveness index (3-to-15 scale) | - 0.010*** (- 3.68) | - 0.009*** (- 3.45) | - 0.010*** (- 3.55) | - 0.010*** (- 3.39) | - 0.009*** (- 3.07) |
| Perceived knowledge about anti-pollution protection methods (1-to-5 scale) | - 0.012* (- 1.90) | - 0.011 (- 1.63) | - 0.011 (- 1.60) | - 0.011 (- 1.58) | - 0.011 (- 1.64) |
| Associative involvement (dummy) | 0.031 (1.04) | 0.033 (1.16) | 0.028 (0.97) | 0.025 (0.85) | - 0.036 (- 0.74) |
| Social cohesion perception (1-to-5 scale) | - 0.022** (- 2.34) | - 0.024** (- 2.51) | - 0.022* (- 1.79) | - 0.024* (- 1.92) | - 0.026** (- 2.18) |
| Regular participation in community parties (dummy) | - 0.022 (- 0.99) | - 0.022 (- 0.97) | - 0.013 (- 0.54) | - 0.016 (- 0.64) | - 0.057** (- 2.59) |
| Number of members who obtained a high school grade | - 0.006 (- 0.75) | - 0.002 (- 0.26) | - 0.016 (- 1.64) | - 0.014 (- 1.43) | - 0.015 (- 1.70) |
| Wealth index (0-to-7 score) | | - 0.019** (- 2.35) | | | |
| Income Quintile 1 | | | 0.025 (0.47) | - 0.002 (- 0.05) | - 0.022 (- 0.44) |
| Income Quintile 2 | | | 0.007 (0.13) | - 0.005 (- 0.11) | - 0.016 (- 0.30) |
| Income Quintile 3 | | | 0.020 (0.28) | 0.022 (0.33) | 0.017 (0.25) |
| Income Quintile 4 | | | - 0.004 (- 0.11) | - 0.009 (- 0.26) | - 0.019 (- 0.55) |
| Polluted area (dummy) | 0.034* (1.90) | - 0.045 (- 1.09) | 0.139** (2.13) | 0.292*** (3.18) | 0.229** (2.47) |
| Wealth*PollutedArea | | 0.022* (1.93) | | | |
| IncomeQ1*PollutedArea | | | - 0.105 (- 1.67) | - 0.058 (- 1.03) | - 0.039 (- 0.68) |
| IncomeQ2*PollutedArea | | | - 0.078 (- 1.18) | - 0.053 (- 0.85) | - 0.044 (- 0.70) |

Table 10 (continued)

| | (1) | (2) | (3) | (4) | (5) |
|-------------------------------|----------|----------|-----------|------------|------------|
| IncomeQ3*PollutedArea | | | - 0.166* | - 0.165** | - 0.166** |
| | | | (- 2.02) | (- 2.09) | (- 2.12) |
| IncomeQ4*PollutedArea | | | - 0.136** | - 0.130** | - 0.124** |
| | | | (- 2.40) | (- 2.44) | (- 2.43) |
| AverageAge*PollutedArea | | | | - 0.003*** | - 0.003*** |
| | | | | (- 3.55) | (- 3.50) |
| Association*PollutedArea | | | | | 0.073* |
| | | | | | (1.65) |
| CommunityParties*PollutedArea | | | | | 0.113** |
| | | | | | (2.29) |
| Constant | 0.514*** | 0.585*** | 0.499*** | 0.411*** | 0.449*** |
| | (5.37) | (5.31) | (5.11) | (4.16) | (4.70) |
| Country fixed-effect | Yes | Yes | Yes | Yes | Yes |
| Observations | 1099 | 1099 | 900 | 900 | 900 |
| R-square | 0.110 | 0.114 | 0.133 | 0.139 | 0.150 |

Source: Authors' calculation from the CSPE database

(1) Standard errors are robust to intra-group correlation. Significance levels are ***1%, **5%, *10%

(2) Wealth index is the sum of the following owned (or not) assets: former house, second house, car, air conditioner, computer, cellphone, and financial assets. Thus, the wealthiest households have a score of 7 while the most deprived household a score of 0

(3) Area attractiveness index is the sum of the following 1-to-5 perception scores: global attractiveness, availability of public services and availability of shops and retailers. Thus, areas perceived as the most attractive have a score equal to 15, while areas perceived as the most deprived have a score of 3

Author Contribution All authors contributed to the study conception and design. The main data analysis and the first draft of the article were made by the first author. All authors contributed to the writing of the final version of the article.

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Declarations

Competing Interests The authors declare that they have no conflicts of interest.

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