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# **Title:**

The health and socioeconomic costs of exposure to soil pollution: Evidence from three polluted mining and industrial sites in Europe

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**Title:** The health and socioeconomic costs of exposure to soil pollution: Evidence from three polluted mining and industrial sites in Europe

**Abstract:**

**Aim.** *This article aims at providing a better understanding of the health and socioeconomic costs induced by soil pollution exposure.*

**Subject.** *We conduct quantitative surveys in households living near mining and/or industrial sites in France, Spain, and Portugal, as well as those located in cleaner neighboring areas.*

**Method.** *We employ a complementary estimation approach based on ordinary least square, instrumental variables, and propensity score matching.*

**Results.** *Our results confirm significant life-long health risks for residents of polluted areas compared to those in control areas. We find lower birthweight and lower childhood health status, as well as a higher risk of chronic disease in adulthood and higher premature mortality. Regarding the socioeconomic costs, we find higher rates of school absenteeism and health service demand among residents from polluted areas compared to control areas. Furthermore, we observe heterogeneous effects according to sociodemographic characteristics. As expected, children and the elderly are the most sensitive age groups; in addition, materially deprived and uneducated households are particularly vulnerable to pollution. More surprisingly, there is some evidence of higher vulnerability of educated households with regard to birth outcomes.*

**Conclusion.** *Our results have important implications for public policy: they allow alerting about actually observed health risks in the exposed areas but they also call for designing awareness campaigns and remedial strategies that are targeted towards the most vulnerable.*

**Key words:** Mining and industrial sites; pollution; reported health outcomes; absenteeism; southwestern Europe.

**JEL:** Q53; I14; J24

## 1. Introduction

Pollution threatens the environment and human health worldwide. The epidemiological literature repeatedly draws attention to this fact. Pollution exposure was responsible for 16% of all deaths worldwide in 2015 (Forouzanfar et al. 2016; Landrigan et al. 2018). It is the largest environmental cause of disease and premature death around the world—three times higher than AIDS, tuberculosis, and malaria combined.

The majority of the existing literature focuses on air and water pollution, omitting health problems generated by exposure to other types of pollution. As underlined by the *Lancet* Commission on pollution and health (Landrigan et al. 2018, p.468), soil pollution, characterized by high concentrations of metals and toxic chemicals in the soil, is “a potentially important, but not yet fully characterized or quantified source of pollution-related disease”. Hence, in this article, we focus on soil pollution, which represents around 15% of the pollution-mortality burden in rich countries (Landrigan et al. 2018).<sup>1</sup> This research topic is particularly relevant in Europe since the European Commission failed to adopt concrete policies against soil degradation in 2007.

Specifically, we base our analyses on three contaminated sites located in France, Spain, and Portugal, where the soil has been highly polluted by the *long-term* presence of mining and other industrial activities. As in other mining and industrial sites around the world, the main hazardous substances persisting in soil are metals (e.g. mercury, cadmium, lead, zinc, and arsenic) and polycyclic aromatic hydrocarbons (e.g. benzo(a)pyrene and naphthalene), producing a chemical cocktail that is potentially hazardous to human health (Vandermore 2008). According to theoretical assessment methods using geoaccumulation models (Li et al. 2014),

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<sup>1</sup> It is worth noting that the estimated number of deaths by risk factor varies according to national GDP. In high-income countries, air pollution is the primary cause of death (60%), followed by occupational pollutants (20%), soil pollution, including heavy-metal residues and toxic chemicals (15%), and finally water pollution (5%).

1 long-term exposure to metals and toxic chemicals is assumed to increase health risks through  
2 several vectors of transmission: repeated and prolonged contact with residuals in the ground  
3  
4 (e.g. agricultural activity), air (e.g. breathing dust), water (e.g. swimming and drinking), and  
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6 local food (e.g. homegrown fruits and vegetables, wild food, and farm produce). However, few  
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8 studies analyze the cumulative effects of soil pollution exposure using empirical data and tools.  
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12 The health effects of soil pollution are of interest to social scientists in terms of both the overall  
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14 negative effect of illness on public welfare and the cost of pollution to society. First, soil  
15  
16 pollution exposure has a potential impact on medical and pharmaceutical expenditures by  
17  
18 increasing health service demand, including hospitalizations, physician visits, medication,  
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20 follow-up treatments, and other related services (see Deschênes et al. 2017; Moretti and Neidell  
21  
22 2011; Schlenker and Walker 2016 for results relying on air pollution exposure). Second,  
23  
24 pollution-related illness and mortality have potentially significant impacts on productivity,  
25  
26 lowering national aggregated income by reducing labor force participation and labor market  
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28 productivity. Soil pollution exposure may lead to individuals being too sick to work regularly  
29  
30 (absenteeism) or dying prematurely and no longer contributing to economic production  
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32 (Landrigan et al. 2018). Soil pollution exposure have also potential impacts on human capital  
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34 (Hunt et al. 2016). Indeed, since children are particularly sensitive to pollution-related disease,  
35  
36 even at extremely low doses of exposure, it is safe to assume that pollution exposure affects  
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38 productivity at school, not only in attendance rates, but through a loss of concentration during  
39  
40 the school day. There is convincing evidence that early-life exposure to neurotoxic pollutants  
41  
42 concentrated in soils, such as lead and mercury, has a significant effect on cognitive  
43  
44 development and the ability to focus (Landrigan et al. 2018). In short, any cause of productivity-  
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46 loss at school can affect academic outcomes and subsequent life opportunities. Hence, soil  
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48 pollution-related disease and morbidity that contribute to academic failure can perpetuate  
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50 intergenerational poverty (Hunt et al. 2016).  
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Our contribution to the literature is to provide empirical evidence about the health and socioeconomic costs of soil pollution exposure, through the construction of an original comparative database and the use of statistical models that limit bias induced by endogeneity problems. Concretely, we conducted standardized quantitative surveys in households living near mining and/or industrial sites known as pollution hot-spots in France, Spain, and Portugal, as well as those located in ‘clean’ neighboring areas. The compilation of individuals from polluted municipalities and clean municipalities nearby allows understanding health-related outcomes of very specifically defined groups of individuals. In contrast, the use of administrative health records would usually not allow matching individuals on such a small scale to their place of residence. Also, the survey allows a large set of pollution-specific variables to be collected such as original information about pollution perceptions. To identify a non-biased effect of residential location (i.e. polluted vs. clean areas) and health outcomes, we combine ordinary least square (OLS) estimations with two complementary endogeneity-correcting estimators: instrumental variables (IV) and propensity score matching (PSM) procedures. In addition, we investigate the potential presence of age-specific and socioeconomic-specific heterogeneity in the relationship.

We find that living near mining or industrial sites has negative externalities on human health, school absenteeism, and health service demand. While birthweight tends to be lower in polluted areas, children growing up in control areas have a better health status and are less often absent at school. We also find that adult residents of polluted areas have a higher risk of suffering from chronic disease than control adults. Further, there is clear evidence that exposure to soil pollution increases health service demand and premature mortality. Finally, we observe heterogeneous effects according to demographic and socioeconomic factors. As expected, health hazards tend to be greater for children and the elderly. Likewise, materially deprived and uneducated households disproportionately report premature death in the immediate family when

they live in polluted areas. Conversely, we observe the impact on birthweight of living in a polluted area to be greater among households where the respondent is educated. This unexpected result might be explained by the higher consumption of local (but contaminated) food products by relatively educated mothers than by uneducated mothers.

The structure of the article is as follows. We first describe the database and explain the empirical strategy. We then present our results. Finally, we conclude and provide recommendations for public policy.

## 2. Materials and methods

### *2.1. An original comparative database*

Three cross-sectional standardized household surveys were conducted from October 2018 to January 2019 among 1,194 families in France, Portugal, and Spain. These surveys resulted in an original comparative database about the socioeconomic and health issues of soil pollution exposure, called Comparative Survey on Pollution Exposure (CSPE). To collect representative information for each study area, we employed a random selection of housings based on cadastral geo-localized data (using a GIS software). The random selection of housings was established at the town-level in France and Spain, and municipality-level in Portugal, using the most recent census data provided by national institutes of statistics.<sup>2</sup> Consequently, the CSPE database is representative of three polluted European areas (in rural and peri-urban settings): the town of 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). Then, to construct a counterfactual group, we further collected representative data in similar neighboring but cleaner areas as benchmarks for the

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<sup>2</sup> The response rate of selected and visited housings was between 20% and 25% depending on the survey area.

1 effects related to pollution exposure. The control areas are the town of Montbazens in France  
2 (138 households and 309 individuals); the municipality of Vagos in Portugal (200 households  
3 and 437 individuals); and a group of villages (Portus, Galifa, Perin, La Corona, Cantera, and  
4 Molinos Marfagones) located to the west of Cartagena in Spain (172 households and 452  
5 individuals).<sup>3</sup> While the three polluted areas are hotspots of soil pollution in Europe, as  
6 evidenced in geochemistry and mineralogy (Patinha et al. 2015; Pérez-Sirvent et al. 2016; Sivry  
7 et al. 2010), the selection of control areas relied on the region-specific literature. In Portugal for  
8 instance, Guihard-Costa et al. (2012) and Inácio et al (2014) explain that Estarreja and Vagos  
9 had the same natural amenities before the installation of the chemical complex in Estarreja.  
10 Similarly, in a health report, the French institute of public health considered Montbazens as  
11 control area to infer the effects of pollution exposure in Viviez (Durand et al. 2011). As shown  
12 in Figure 1, polluted and control areas are close enough to allow a certain comparability, but  
13 far enough to not have the same concentrations of pollutants in soils.  
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31 In short, our southwestern European sample makes it possible to observe three types of polluted  
32 areas around the world: (i) ex-mining towns (Portman and Estrecho de San Ginès), (ii) former  
33 metal industry undergoing technological reconversion (Viviez), and (iii) active (petro-)  
34 chemical complexes (Estarreja and Alumbres). Not surprisingly, socioeconomic indicators of  
35 the polluted locations tend to be worse in the two first groups and better in the third compared  
36 to the controls. Further contextual information about our sample of study areas is available in  
37 Appendix A.  
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50 [insert Figure 1]  
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55 <sup>3</sup> For example, Guihard-Costa et al. (2012) and Inácio, Neves, and Pereira (2014) explain that Estarreja and Vagos  
56 had the same natural amenities before the installation of the chemical complex in Estarreja. Similarly, the French  
57 Institute of Public Health uses Montbazens as a control area to establish the health effects of pollution exposure in  
58 Viviez (Durand et al. 2011). We failed to find equivalent publications for the Spanish Sierra Minera. Hence, we  
59 selected a group of control areas to the west of Cartagena, where the natural features would resemble the Sierra  
60 Minera if the latter did not host large mining and petrochemical sites (Banos-Gonzales and Baños Paez 2013).  
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## 2.2. Outcome indicators

To measure the health and socioeconomic costs of exposure to soil pollution, several outcome indicators are computed for households and individuals. At the household level, we asked the respondent to report the birthweight in kg of the last child, and the number of family members (living the same community) to have died before the age of 65 years. Measuring early mortality by asking for familial premature death is an approach commonly used in epidemiological studies (Gami et al. 2007; Hendryx et al. 2010). Birthweight is a proxy for neonatal health, since maternal exposure to pollution may lead to lower birthweight, namely due to intrauterine growth retardation and/or prematurity (Bobak 2000). For each surveyed household, we also collected individual information on childhood health and healthcare demand (from 0 to 15 years old). More precisely, we asked the respondent to: (i) assess the health status of each child on a 5-point Likert scale (varying from very bad to very good health status), (ii) report whether a child needs frequent medical treatment (binary-response variable), (iii) report whether a child has been diagnosed with allergies by a doctor (binary-response variable). We also asked the respondent to report the occurrence of school absences during the last semester as a proxy for school productivity. Finally, we asked respondents to provide information on themselves, as well as other adult household members, in order to identify: (i) who has been diagnosed with a chronic disease (dummy), (ii) the number of work absences during the last semester (a proxy for labor productivity), (iii) the number of medical visits during the last semester (a proxy for health service demand and medical expenditure).

Epidemiologists are often concerned by reported health outcomes as recall bias can disproportionally affect respondent declarations between case and control areas (Coughlin 1990). This may lead to an overestimation of health externalities if respondents from polluted areas are better able to recall certain events (e.g. birthweight, death, absenteeism, medical visits) and illnesses (e.g. medical treatments, allergies, chronic diseases) compared to respondents

from control areas.<sup>4</sup> However, Table 1 shows that there is no within-group correlation between the respondents' perception of local pollution (on a 5-point Likert scale) and health-related outcomes, except for reported child allergies, adulthood medical visits, and school absences in control areas where positive correlations stand out. Hence, for most health indicators, we can be confident that non-random recall errors are absent in our samples. If the reporting of health outcomes was influenced by the respondents' perception of pollution, then an over-declaration of health penalties and diseases would have been found among pollution-sensitive respondents. We are also confident of the accuracy of declarations of birthweights, absences, and chronic diseases. Moreover, we assume that having household members who die prematurely or suffer from chronic disease is information that a respondent would be unlikely to forget—and epidemiological studies support this.<sup>5</sup>

[insert here Table 1]

### 2.3. A linear model

Because mining and industry might also directly pollute air and water, or affect health through exposure when working, we specify a reduced-form model of health effects from polluting industries. In other words, we analyze the cocktail effect of soil pollution. Equation 1 mathematically poses the baseline multivariate regression model:

$$\text{Eq.1: } Y_i = \beta_0 + \beta_1 T_i + \beta_2 X_i + \varepsilon_i$$

<sup>4</sup> The risk of recall bias is especially high when the issue is commonly established in social media and popular knowledge. For example, it is often the case with regard to the link between pollution and allergies.

<sup>5</sup> For instance, O'Sullivan et al. (2000) found that 75% of declared birthweights were within 50 grams of the hospital record. Moreover, the birthweight gap (recalled birthweight vs. hospital record) correlates with neither the sociodemographic indicators nor the time interval between childbirth and data collection. Similarly, a case-control study assessing the effects of professional chemical exposure on cancer risk found that 82% of reported work histories agreed with the records, with no statistical difference between cases and controls or according to age, education level, or social class. Furthermore, comparing patients' self-reports to general practitioners' information, Kriegsman et al. (1996) observed that the accuracy of reported chronic disease is generally satisfactory.

$Y_i$  refers to the outcome indicators that we previously described for statistical unit  $i$ . Depending on the outcome variable,  $i$  refers to an individual or a household. For the sake of clarity, we use an OLS estimator to run linear estimations when  $Y$  is continuous (e.g. birthweight, child health status, occurrence of premature death, medical visits, and school and work absenteeism),<sup>6</sup> but run linear probability estimations when  $Y$  is binary (e.g. risk of child medical assistance, risk of suffering from allergies for children and chronic diseases for adults). We also tested a Probit binomial estimator for binary-outcome variables, but, as the results were similar, we chose only to report OLS estimates.

$X_i$  is a vector of control factors. First, we control for potentially important demographic and socioeconomic confounders to the pollution-health relationship (Sheppard et al. 2012). More specifically, we control for age, gender, marital status, household composition, ethnicity, completed education level, a wealth index, and housing size. We also include a general measurement of the respondent's risk attitude—another potential confounder between pollution exposure and health outcomes. Indeed, risk lovers may take concomitant risks regarding pollution exposure and health-related behaviors. In the survey, we measured risk aversion by a 5-point Likert scale, varying from having a very low to a very high willingness to take risks in general. As suggested by Dohmen et al. (2011), measurements of general risk aversion generate the best all-round predictor of risk behaviors. We then control for general health status by integrating measurements of body mass index (BMI) and height. BMI is considered in the literature as a *short-term* indicator of health status, since weight strongly depends on current consumption and lifestyle. By contrast, height is considered a pre-existing *long-term* indicator of health status, as it strongly reflects nutritional status and maternal risk behaviors occurring from gestation to early childhood (Thomas et al. 1991). Finally, we control for the length of

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<sup>6</sup> We also ran regressions using logged values of birthweight rather than real birthweight values in order to limit the influence of potential non-linearities in birthweight declarations. The results were similar.

residence in the area to fix the duration of pollution exposure across households, and we include country fixed-effects.<sup>7</sup> Obviously, the way in which we introduce control factors into the model varies according to the targeted subject (i.e. the household-based, child-based, and adult-based outcomes). Table B1 in Appendix B clarifies this matter by describing the way in which each variable is included in the model.

$T_i$  is a proxy for soil pollution exposure. To approximate this exposure we use a binary-treatment variable that identifies whether the household lives in a polluted area or in a control area. In addition to obvious measurement errors (due to possible individual heterogeneity in soil pollution exposure), there is a potential selection bias due to an overrepresentation of economically and socially deprived households in polluted areas (Banzhaf and Walsh 2008; Levasseur et al. 2021). Yet the poorest tend to have lower health status, as well as riskier health behaviors and lower interest in their children's education (Zuidema and Nentjes 1997). Although we control for socioeconomic and demographic factors, as well as *long-term* and *short-term* health status, unobserved factors  $\varepsilon_i$  may still bias OLS estimates (i.e. when  $\varepsilon_i$  is correlated to  $T_i$ ). For instance, those living in polluted areas could be less sensitive to environmental health hazards, which may lead to risky health behaviors. In contrast, not controlling for potential avoidance behaviors may understate the estimated effect of soil pollution exposure on health outcomes (Moretti and Neidell 2011). To limit such selection bias and subsequent endogeneity problems, we perform an IV strategy using the best available instruments of our dataset. As the complete exogeneity of selected instruments is always debatable in applied economics, we complete OLS and IV estimates with PSM estimates. Both IV and PSM methodologies are described in Appendix C.

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<sup>7</sup> We tested for various model specifications, by integrating covariates one by one, as well as analyzing more careful specifications that exclude confounding factors for which the causality in the Eq.1 is less clear (e.g. excluding height, BMI, housing size and length of residence). For each specification, the results were similar (results available upon request).

### 3. Results

#### 3.1. Descriptive statistics

Figures 2(a) and 2(b) show polynomial fractional estimates of the relationship between residential location (polluted vs. clean areas) and health outcomes. More precisely, we model soil pollution exposure by comparing lifetime in a polluted area (positive values on the right side) versus a control area (negative values on the left side). For household-based outcome indicators reported in Figure 2(a), we use the length of residence as lifetime indicator. Figure 2(a) clearly suggests that soil pollution exposure might reduce birthweight and increase the occurrence of premature death. For instance, while the number of early deaths in the family remains around 0.3-0.4 in control areas, this number significantly increases along with the length of residence in a polluted area. After 30 years of residence in a polluted area, the number of early deaths exceeds 0.6 local family members. Regarding individual-based health outcomes (children and adults), in Figure 2(b) we use individual age as lifetime indicator. Figure 2(b) shows increased health disadvantages for individuals aging in polluted areas. We find that the perceived health status of children decreases with the child's age in polluted areas, whereas this indicator increases with the child's age in control areas. Similarly, we observe that the likelihood of requiring medical assistance increases with the child's age in polluted areas, but decreases in clean areas. Interestingly, the likelihood of being diagnosed with allergies is low (around 10%) and is uncorrelated with the child's age in control areas. By contrast, this significantly increases with the child's age in polluted areas. By the age of 15, the risk reaches almost 40%.

[Insert Figures 2(a) and 2(b)]

Mean-comparison tests are consistent with Figures 2(a) and 2(b). Table 2 exhibits significant correlations between residential location (polluted vs. clean areas) and health problems. While

Figures 2(a-b) and Table 2 present a link between soil pollution exposure and health status, these results may be biased because of endogeneity issues. Hence, we implement multivariate regressions and endogeneity-corrector procedures to mitigate this.

[Insert Table 2]

### **3.2. Health costs of living in areas with soil pollution**

Table 3 summarizes OLS, IV, and PSM estimates by only reporting the fitted coefficients of interest for all outcome indicators (i.e. the average treatment effect). Tables B2 to B6 in Appendix B exhibit full OLS and IV estimates for household-based outcome indicators (i.e. birthweight and premature deaths), for child-based outcome indicators (i.e. health status, medical assistance, allergies, and school absenteeism), and for adult-based outcome indicators (i.e. chronic disease, work absenteeism, and medical visits). In just-identified IV estimates, we use the respondent's local pollution perception (on a 5-point Likert scale) as a primary instrument. In over-identified IV estimates, we add the housing rent as a second instrument to test for the validity of the former.

Regarding the first IV requirement, first-stage IV estimates show that both instruments are strong predictors of the probability of living in polluted areas versus control areas (available in Table B7 of Appendix B).<sup>8</sup> In addition, as illustrated at the bottom of Tables B2 to B6, F-statistics on the excluded instruments are systematically high. Another evidence of the strength of instruments is visible when we run reduced-form regressions, which regress outcome indicators on the instruments and covariates (available in Table B8 of Appendix B). As Angrist and Pischke (2008) argue, it is reassuring to note that the sign, the magnitude, and the

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<sup>8</sup> As expected, we observe a positive and significant correlation between the respondents' local pollution perception and the fact of living in a polluted area. Regarding housing cost, the sign of the correlation is also consistent: monthly rent is significantly and negatively correlated to the probability of living in polluted areas.

significance of the fitted coefficients of instruments are consistent and proportional to the effect of treatment variables (polluted vs. clean areas) on health outcomes.

As evidenced in Tables B2 to B6, Hansen over-identification tests suggest that our instruments meet the exogeneity requirement. The null-hypothesis of exogeneity can never be rejected (i.e. no correlation between residuals and excluded instruments), except for the regression of birthweight on residential location (Column 3, Table B2). Furthermore, restricting the sample to control areas, there does not appear to be any correlation between the respondent's pollution perception and family health outcomes that could skew our IV identification, except for the reported occurrence of medical visits among the elderly (Table B9 in Appendix B). In other words, the correlation between the respondent's pollution perception and health outcomes is not due to omitted factors or reverse causality, at least for children and working-age adults.<sup>9</sup>

The third step of our empirical strategy is based on a PSM approach, comparing treated units (i.e. individuals or households living in polluted areas) to analogous control units weighted by observed characteristics. To verify the quality of the matching procedure, Figures B1(a) to B1(m) in Appendix B report the standardized percentage bias for each covariate before and after matching. Overall, the levels of standardized bias are relatively low after matching. In addition, for each covariate, there are no significant mean differences after matching between polluted and control areas (available upon request). Thus, we assume that, after matching, polluted and control areas are statistically comparable, conditional upon the set of factors included.

[Insert Table 3]

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<sup>9</sup> Among the elderly, one may suppose the presence of reverse causality. Indeed, older people tend to make more interactive attributions in negative situations than younger adults, for example, attributing their health problems to pollution exposure (Blanchard-Fields 1994).

Overall, we can observe the following facts. As evidenced in Table 3, OLS, IV, and PSM estimates are consistent and reveal similar results.<sup>10</sup> By fixing several important confounders,<sup>11</sup> OLS estimates show that living in a polluted area decreases the birthweight of the last child by 85 grams. Regarding PSM estimates, Table 3 exhibits a similar amplitude, with an average treatment effect on the treated (ATT) of -82 grams. In contrast, just-identified IV estimates show roughly twice the impact (-173 grams), suggesting potential estimation bias (recall that we fail to accept the Hansen over-identification test in Table B2, Column 3). Table 3 also shows a higher occurrence of premature family death (before the age of 65) in polluted areas compared to cleaner areas. As suggested by IV and PSM procedures, this finding is robust to the potential presence of unobserved heterogeneity and reverse causality, the effect varying from 0.16 to 0.26 extra deaths, depending on the estimator. Table 4 explores potential heterogeneous effects by crossing residential location (i.e. polluted vs. clean areas) with household socioeconomic status indicators (i.e. education and wealth).<sup>12</sup> As predicted, premature deaths due to exposure to soil pollution are more frequent when the household is materially deprived (according to the wealth index) and the respondent is not educated beyond primary level. More unexpectedly, Table 4 presents a negative correlation between soil pollution exposure and birthweight that is significantly higher for households with educated respondents compared to those with non-educated respondents. We provide an interpretation for this result in the discussion.

In individual-based regressions, we observe that living in polluted areas also affects child health during his/her growth and development. Table 3 shows that living in polluted areas decreases

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<sup>10</sup> In line with Angrist and Pischke (2008), we prefer fitted coefficients from just-identified estimates as they are median-unbiased and therefore less likely to be subject to a weak-instruments critique than over-identified estimates.

<sup>11</sup> Excluding residential location, the most important predictors of birthweight are respondents' BMI, height, and origins, as well as accommodation size (Table B2 in Appendix B). These results highlight the importance of parental anthropometric factors and sociodemographic factors regarding neonatal health.

<sup>12</sup> Obviously, we also checked for potential heterogeneous effects nationally. However, we do not detect heterogeneous effects across different cases, apart from in Alumbres, where respondents declare lower levels of health status for their children compared to other polluted areas (results available upon request).



the 5-point perception score of child's health status by around 0.28-0.39 points, depending on estimators. Moreover, there is convincing evidence that children living in polluted areas are more likely to suffer from diagnosed allergies compared to those living in cleaner areas. For instance, just-identified IV estimates indicate that living in a polluted area increases the risk of a child suffering from allergies by 17.8 percentage points. Likewise, we find negative health externalities for working-age and active adults, as well as for the elderly. For example, just-identified IV estimates show that living in polluted areas increases the risk of suffering from any chronic disease for working-age and active adults by 7.7 and 10.4 percentage points respectively (Table 3). Note that, as expected, this risk is higher for the elderly (+16.9 percentage points, if we refer to just-identified IV). Using PSM, the estimates are only significant for active workers and the elderly.

### ***3.3. Socioeconomic costs of soil pollution exposure***

To explore the socioeconomic consequences of health problems imputable to soil pollution exposure, we estimate the effects of residential location (polluted vs. clean areas) on school/work absenteeism, as well as potential impacts on healthcare demand. According to Table 3, OLS, IV, and PSM estimates suggest a slight impact of soil pollution exposure on school absenteeism (significant at the 15% level). Indeed, living in polluted areas increases by 1.5/1.6 days the occurrence of school absences over the last semester. However, we fail to find an effect on work absences. Finally, Table 3 shows that working-age adults and active workers who live in polluted areas visit medical practitioners significantly more frequently than their counterparts in cleaner areas (between 0.3 and 0.8 extra visits, dependent on estimators and samples). Surprisingly, this effect is more systematically significant for working-age adults and active workers than for the elderly. One can for instance assume that this latter age group is more likely to be hospitalized than to visit a physician. Similarly, OLS, IV, and PSM estimates

suggest that living in polluted areas significantly increases the risk of a child requiring regular medical treatment (i.e. by around 8-15 extra percentage points, depending on estimators).

#### 4. Discussion and conclusion

This article identifies the health and socioeconomic costs of exposure to soil pollution by focusing on three polluted mining and industrial sites in France, Spain, and Portugal. We employ an empirical approach by first collecting original household data in polluted and nearby cleaner areas, and then analyzing this data using an empirical strategy that combines three complementary estimators (i.e. OLS, IV, and PSM). In addition, we control for rarely observed confounders influencing the link between residential location and health outcomes, such as height and nutritional status. Even if the identification strategy performed does not rely on perfect instruments, namely because the chronicity of soil pollution impedes the use of episodic exogenous instruments, the convergence of findings across the three complementary approaches is comforting.

Our results suggest that living near polluted sites not only may significantly affect human health but also might impair the chance of socioeconomic success. With regard to health, we observe negative effects of exposure to soil pollution throughout the whole lifecycle, from birthweight and childhood health status to chronic diseases in adulthood and premature mortality. In addition, we find some evidence that living in polluted areas may negatively influence school attendance, probably due to illness. This result highlights the expected impact of soil pollution exposure in terms of a loss of academic productivity, with the potential to impede human capital accumulation during childhood and a subsequent professional career (Hunt et al. 2016). For adults, we fail to identify an effect on work absenteeism, but we show that working-age individuals and active workers living in polluted areas have higher occurrence of medical visits than their counterparts who live in control areas. Similarly, children who live on polluted soil are more likely to require regular medical treatment than control children. These latter findings

1 suggest that soil pollution exposure increases the demand for healthcare services and thus  
2 contributes to increased public health expenditure.  
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5 Another contribution of this study is to explore potential heterogeneous effects across age and  
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7 socioeconomic status. In line with the existing literature, we find that the health effects of soil  
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9 pollution exposure are particularly salient for children (Landrigan et al. 2018; Makri and  
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11 Stilianakis 2008) and the elderly (Geller and Zenick 2005). In terms of socioeconomic  
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13 heterogeneity, the results are more ambiguous and call for further studies. Focusing on  
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15 premature mortality, we observed stronger effects for uneducated and materially deprived  
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17 households. This is in line with the findings of Morelli et al. (2016), who show a higher impact  
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19 of fine particulate matter (air pollution) on mortality in areas with a moderate to high social  
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21 deprivation index compared to areas with low deprivations. In contrast, the negative correlation  
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23 between soil pollution exposure and birthweight tends to be higher for households with a  
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25 minimum level of education (i.e. higher than primary) compared to uneducated households (i.e.  
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27 lower than primary education). A similarly surprising result is found in recent work by  
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29 Montazeri et al. (2019), who note that wealthier and more educated mothers and their children  
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31 are more exposed to certain toxic chemicals and metal residues (e.g. arsenic, mercury) than  
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33 their poorer counterparts in Europe. The authors speculate that there could be more regular  
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35 consumption of local food products containing high levels of heavy and chemicals (e.g. seafood,  
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37 organic food, homegrown fruits and vegetables, goods from short distribution channels, and  
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39 wild food) among higher social groups.<sup>13</sup> Conversely, uneducated (and poorer) mothers are less  
40  
41 willing to pay for expensive (potentially contaminated) local products and more likely to buy  
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43 affordable processed and imported food products (Darmon and Drewnowski 2008; Dowler  
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59 <sup>13</sup> See also Schupp and Sharp (2012) for more explanations about why the poor are less concerned by (risky) self-  
60 provisioning activities.  
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2001).<sup>14</sup> Differences in in-utero survival rates according to parental education could also explain why educated parents reported lower birthweights. One could speculate that in-utero survival is lower among less-educated parents than among more educated parents. If this assumption is correct, the probability of preterm birth should be higher among educated parents. However, there is no correlation between the risk of preterm birth and parental education (p-value=0.732). Similarly, there is no bivariate correlation between birthweight and parental education (p-value=0.148). Hence, this second possible explanation can be rejected.

The identification of heterogeneous effects in the soil pollution-health relationship is highly informative for public policy. First, it seems obvious for public policy providers to target the most vulnerable demographic groups regarding anti-pollution interventions (i.e. children and the elderly). Regarding social vulnerability to soil pollution exposure, targeting the poor only could be a first strategy. However, more attention should be paid to higher social categories too, who might disproportionally consume local (but contaminated) food products. It is noticeable that the rapid succession of land uses and the reconversion of wasteland into urbanized land can attract young households attracted by the wider environmental amenities of the territory, exposing their children to risks they do not have to memory of (Levasseur et al. 2021). In villages and cities located near mining or industrial sites, these changes should be accompanied by awareness campaigns on the avoidance of exposure to soil pollution (e.g. washing hands, floors and toys frequently, avoiding that younger children play on the ground outside, and not eating locally produced food or drink well water) and, more importantly, remedial strategies (e.g. the storing/treatment of contaminant residues, ground covering in schools, and the renovation of dwellings).

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<sup>14</sup> Obviously, we do not exclude the possibility that the regular consumption of cheaper imported processed food (often rich in sugar, refined fat, and carbohydrates) generates further health issues, such as obesity and related chronic diseases.

From a scientific perspective, this article helps to fill the literature gap by providing key insights into the consequences of exposure to soil pollution, which still remains an underexplored issue in the pollution-health literature. We provide clear evidence that metals and chemicals in European soil may significantly affect human health when exposure is repeated over the long term. Finally, this study makes a methodological contribution by demonstrating that comparative study design (polluted vs. clean areas) through area-specific household surveys is a powerful tool for environmental assessment analyses, especially when incorporating endogeneity-corrector estimators.

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FIGURES AND TABLES

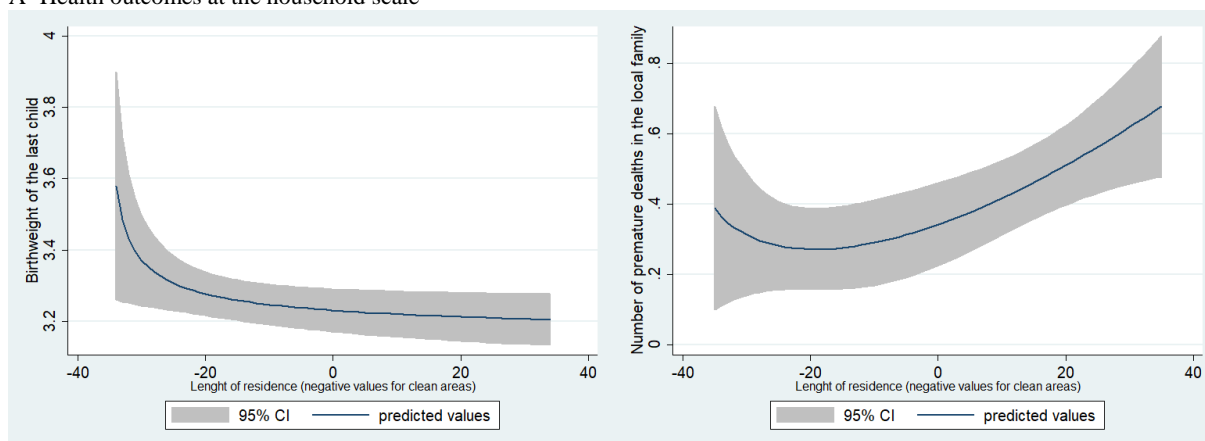
Figure 1: Mapping of polluted and control areas



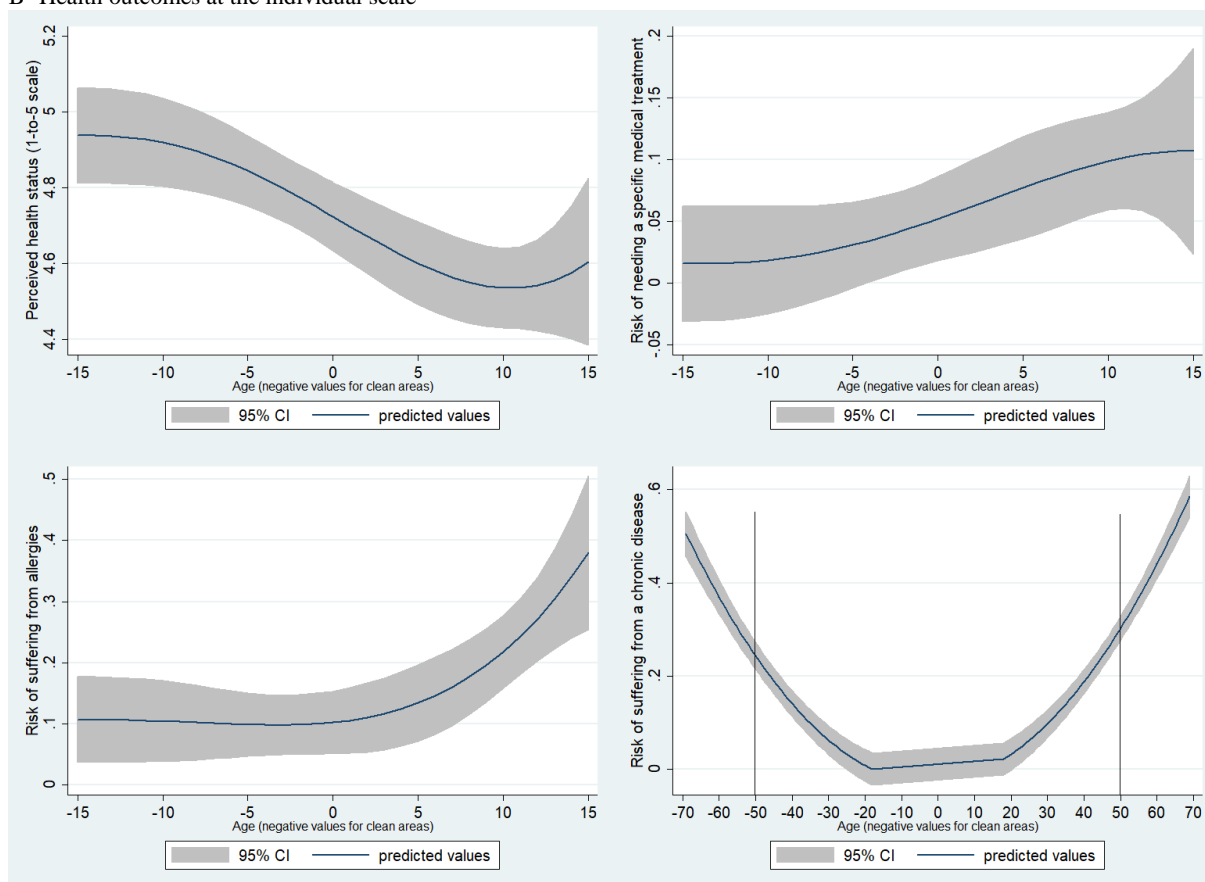
Source: OSM, authors' computations. This map has already been published in Levasseur et al. (2021).

**Figure 2: Bivariate polynomial plots between soil pollution exposure and health outcomes**

A- Health outcomes at the household scale



B- Health outcomes at the individual scale



Note: Fractional polynomial estimates are used. On the x-axis, negative values refer to control areas and positive values to polluted areas.

Source: Authors' calculations from the CSPE database.

**Table 1: Within-group (polluted vs. clean areas) OLS regressions of the respondent's perception of area pollution on health outcomes**

DEPENDENT VARIABLE: Level of area pollution perception by the respondent		
	Sample of polluted areas	Sample of control areas
Birthweight of the last child (in kg) during the last semester	-0.045 (-0.46) <i>N</i> =479	-0.133 (-1.30) <i>N</i> =342
Premature death	-0.001 (-0.02) <i>N</i> =595	0.050 (0.76) <i>N</i> =425
Health status perception (0-15yo)	-0.098 (-0.84) <i>N</i> =189	-0.489 (-1.63) <i>N</i> =137
Requiring medical treatment (0-15yo)	-0.056 (-0.14) <i>N</i> =189	0.129 (0.43) <i>N</i> =140
Suffering from allergies (0-15yo)	-0.182 (-0.77) <i>N</i> =189	0.563* (1.74) <i>N</i> =140
Suffering from a chronic disease (all adults)	-0.016 (-0.22) <i>N</i> =1,372	0.008 (0.11) <i>N</i> =1,035
School absences during the last semester	-0.007 (-0.24) <i>N</i> =102	0.055*** (4.90) <i>N</i> =80
Work absences during the last semester	0.001 (0.45) <i>N</i> =632	0.004 (1.36) <i>N</i> =485
Medical visits during the last semester (all adults)	-0.008 (-0.78) <i>N</i> =1,373	0.023** (2.33) <i>N</i> =1,034

Note: Significance levels: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$  (t-statistics in parenthesis).

Source: CSPE database (2019).

**Table 2: Mean-comparison tests between polluted and control areas across health outcomes**

	Polluted areas		Control areas		Mean-difference test (p-value)
	Mean	S.E.	Mean	S.E.	
Birthweight of the last child (in kg) during the last semester	3.253	0.024	3.318	0.029	<b>-0.065*</b> (0.089)
Premature deaths in family living locally	0.579	0.042	0.333	0.0368	<b>0.245***</b> (0.000)
Child health status assessed by the respondent (on a 5-point scale) (0-15yo)	4.587	0.055	4.883	0.033	<b>-0.296***</b> (0.000)
Probability that a child requires medical treatment (0-15yo)	0.089	0.021	0.021	0.012	<b>0.069***</b> (0.010)
Probability that a child suffers from allergies (0-15yo)	0.201	0.029	0.100	0.025	<b>0.101**</b> (0.013)
Probability that an adult suffers from a chronic disease (all adults)	0.355	0.013	0.288	0.014	<b>0.067***</b> (0.001)

Note: Significance levels: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$  (p-value in parenthesis).

Source: CSPE database (2019).

**Table 3: Health effects of living in polluted areas versus control areas (summary results)**

ESTIMATOR	OLS	Just-identified IV	Over-identified IV	PSM
<i>Household-based outcome indicators</i>				
Birthweight of the last child (in kg)	-0.085** (-2.08) N=729	-0.173** (-2.19) N=727	-0.225** (-2.43) N=555	-0.082* (-1.75) N=729
Premature death in the family living locally	0.177*** (2.96) N=914	0.255** (2.32) N=911	0.188 <sup>b</sup> (1.49) N=688	0.161** (2.51) N=914
<i>Child-based outcome indicators</i>				
Child's health status assessed on a 5-point Likert scale (0-15yo)	-0.369*** (-3.46) N=228	-0.386** (-2.23) N=228	-0.465** (-2.13) N=196	-0.283*** (-2.57) N=224
Probability that a child requires medical treatment (0-15yo)	0.077* (1.84) N=231	0.113 <sup>b</sup> (1.58) N=231	0.147* (1.82) N=197	0.085* (1.83) N=227
Probability that a child suffers from allergies (0-15yo)	0.154*** (2.75) N=231	0.178** (2.17) N=231	0.196** (2.19) N=197	0.118* (1.73) N=227
School absences during the last semester (kindergarten and primary)	1.036 <sup>b</sup> (1.55) N=135	1.561 <sup>b</sup> (1.55) N=135	2.005* (1.88) N=114	1.489 <sup>b</sup> (1.57) N=111
<i>Adult-based outcome indicators</i>				
Probability that a working-age adult (18-70yo) suffers from a chronic disease	0.044** (1.98) N=1,642	0.077** (1.99) N=1,637	0.061 (1.37) N=1,284	0.030 (1.21) N=1,635
Probability that an active worker suffers from a chronic disease	0.056** (2.30) N=955	0.104*** (2.59) N=953	0.110** (2.24) N=765	0.052* (1.84) N=951
Probability that an elderly person (>70yo) suffers from a chronic disease	0.098* (1.92) N=417	0.169* (1.66) N=417	0.370*** (3.18) N=236	0.118** (2.04) N=395
Medical visits during the last semester for working-age adults (18-70yo)	0.551*** (2.98) N=1,644	0.848** (2.51) N=1,639	0.755* (1.82) N=1,284	0.504*** (2.75) N=1,637
Medical visits during the last semester for active workers	0.389** (2.23) N=957	0.678** (2.08) N=955	0.747** (1.99) N=765	0.309* (1.74) N=953
Medical visits during the last semester for the elderly (>70yo)	1.087*** (2.67) N=415	1.176 (1.22) N=415	1.597 (1.36) N=235	1.310*** (2.88) N=392
Work absences during the last semester (active adults 18-70yo)	0.746 (0.88) N=954	1.294 (1.05) N=952	2.082 (1.18) N=762	1.947 (0.86) N=950

Note: Significance levels: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1, <sup>b</sup> p<0.15 (t-statistics are in parenthesis). T-statistics are cluster robust at the household level in OLS and IV estimates. All control variables are included. Country-fixed effects are included. Please refer to the Appendix for complete tables of OLS and IV estimates.

Source: CSPE database (2019).

**Table 4: Heterogeneous birthweight and mortality effects across wealth and education (OLS estimates)**

DEPENDENT OUTCOME	Birthweight of the last child (in kg)		Number of premature deaths in the local family	
	Linear	Linear	Linear	Linear
<i>Estimator</i>	(1)	(2)	(3)	(4)
<b>Living in a polluted area</b>	<b>-0.057</b>	<b>-0.129***</b>	<b>0.524***</b>	<b>0.057</b>
	(-0.44)	(-2.73)	(2.80)	(0.80)
<b>LivingPollutedArea*WealthIndex</b>	<b>-0.007</b>		<b>-0.097**</b>	
	(-0.24)		(-2.19)	
<b>LivingPollutedArea*LowEducation</b>		<b>0.161*</b>		<b>0.340**</b>
		(1.79)		(2.45)
Length of residence (in years)	0.001	0.001	0.003	0.002
	(0.61)	(0.62)	(1.57)	(1.50)
Age of the respondent (in years)	0.001	0.001	-0.000	-0.000
	(0.55)	(0.57)	(-0.09)	(-0.12)
Gender of the respondent (male)	-0.077	-0.076	-0.018	-0.019
	(-1.32)	(-1.31)	(-0.26)	(-0.26)
Body-mass index of the respondent (in kg/m <sup>2</sup> )	0.025***	0.025***	0.008	0.007
	(5.10)	(5.06)	(0.95)	(0.85)
Height of the respondent (in meters)	0.872***	0.880***	-0.279	-0.257
	(2.97)	(3.00)	(-0.66)	(-0.61)
Respondent has foreign origins (dummy)	0.200**	0.202**	-0.064	-0.069
	(2.39)	(2.43)	(-0.69)	(-0.72)
Respondent is in a couple (dummy)	-0.023	-0.023	-0.089	-0.093
	(-0.49)	(-0.49)	(-1.26)	(-1.32)
Respondent's attitude to risk (a 5-point Likert scale)	-0.002	-0.001	0.085***	0.084***
	(-0.08)	(-0.05)	(2.68)	(2.67)
Respondent has a low level of education (dummy)	-0.025	-0.116	0.278***	0.077
	(-0.37)	(-1.39)	(2.90)	(0.80)
Respondent has an intermediate level of education (dummy)	-0.051	-0.043	0.188***	0.194***
	(-1.02)	(-0.86)	(2.75)	(2.83)
Parental education of the respondent (at least high-school level)	-0.032	-0.036	-0.021	-0.037
	(-0.59)	(-0.67)	(-0.28)	(-0.48)
Wealth index (0-to-7 score)	0.003	-0.002	0.018	-0.039
	(0.11)	(-0.09)	(0.62)	(-1.39)
Number of children in household	-0.034	-0.034	-0.013	-0.012
	(-1.13)	(-1.14)	(-0.30)	(-0.28)
Size of dwelling (number of rooms)	0.029*	0.029*	0.082*	0.082*
	(1.76)	(1.76)	(1.77)	(1.77)
Constant	1.065*	1.090**	-0.294	-0.024
	(1.95)	(2.01)	(-0.36)	(-0.03)
Country-fixed effect	Yes	Yes	Yes	Yes
Observations	729	729	914	914
R-squared	0.083	0.087	0.078	0.079

Note: Cluster robust t-statistics in parenthesis at the household level. Country-fixed effects are included. Significance levels: \*\*\* p<0.01,

\*\* p<0.05, \* p<0.1.

Source: CSPE database (2019).



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**Supplementary Material**

APPENDIX\_revisedversion\_clean.docx

