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Residential mobility and air pollution inequalities : describing income disparities in lifelong air pollution exposure*

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Mobilité résidentielle et inégalités à la pollution de l'air : décrire les disparités d'exposition à la pollution de l'air tout au long de la vie selon le revenu

Ce document examine l'exposition différentielle des individus à la pollution en fonction de leur revenu, mesuré par le revenu disponible équivalent. Cette étude apparie des données administratives sur la localisation résidentielle et les mesures de la pollution aux particules fines (PM2.5). Les expositions sont inégales en raison d'un phénomène de localisation résidentielle endogène entre les aires urbaines et au sein de celles-ci. En nous appuyant sur méthode de décomposition d'Oaxaca-Blinder, nous montrons que les 10 % les plus pauvres sont surexposés au sein des zones urbaines, car ils résident dans les communes les plus polluées au sein de ces aires. Nous menons ensuite un exercice contrefactuel pour évaluer le rôle de la mobilité dans le maintien des inégalités. Nous mettons en évidence que les inégalités sont partiellement maintenues par la mobilité au sein des zones urbaines, par lequel les 10 % les plus riches se relocalisent vers des communes moins polluées de leurs aires urbaines. Nous montrons également que parmi les mobilités ayant lieu autour de différents événements de la vie, les mobilités liées à la naissance d'un enfant ont le plus contribué à creuser les inégalités en matière d'exposition aux PM2.5 depuis 1999.

Mots clés : Pollution atmosphérique, Inégalités, Mobilité résidentielle.

Residential mobility and air pollution inequalities : describing income disparities in lifelong air pollution exposure

This paper examines individuals' differential exposure to air pollution by income, measured as equalised disposable income. We link administrative data on residential location to fine-grained measures of ambient particulate pollution (PM2.5). Exposures are unequal due to spatial sorting between and within urban areas. Relying on the Oaxaca-Blinder decomposition method, we show that the bottom 10% of equalized disposable income is overexposed within urban areas, as they are located in the most polluted municipalities. We then conduct a counterfactual exercise to evaluate the role of mobility in sustaining inequalities of exposure. We provide evidence that inequalities are partially maintained by mobility within urban areas, whereby individuals in the top 10% move to less polluted municipalities in their urban area. We also show that among mobilities occurring around different life events, mobilities at childbirth has contributed the most to widening income inequalities of exposure to PM2.5 since 1999.

Keywords: Air pollution, Inequality, Residential mobility.

1 Introduction

In the United States, researchers have documented disproportionate exposure of low-income communities to air pollution, toxic waste or industrial emissions. Among these, exposure to fine particulate matter is a major public health concern, causing around 40,000 premature deaths per year in France (Medina et al., 2021). In 2021, the World Health Organisation (WHO) lowered its threshold for harmful annual PM2.5 pollution from 10 µg/m^3 to 5 µg/m^3.

While environmental policies tend to focus on areas with high pollution levels, the most effective policies could instead target areas where vulnerable populations are located (Deryugina et al., 2021). Identifying the locations of populations most vulnerable to air pollution and understanding some of the mechanisms underlying persistent inequalities are crucial for policy makers to design targeted policies.

However, little is known about the underlying explanations of the main drivers of environmental inequality. Previous studies identified **selective sitting** (for instance if factories and other polluting activities disproportionately choose to locate within poorer areas) and **selective migration** (meaning for instance that disadvantaged households selectively move into polluted areas, whereas advantaged groups are more likely to leave those areas) mechanisms.[1] In this study, we find some evidence of spatial sorting, namely individuals' (re)location across urban areas based on income (that may be due to one or another of these mechanisms). According to a counterfactual exercise, residential mobility leads to uneven gains in air quality across income groups.

In this paper, we first aim to assess the existing inequalities in exposure to air pollution according to equivalised disposable incomes and their evolution between 2001 and 2017 in France. We identify the role of spatial sorting within and between urban areas as an important determinant of inequality exposure. We provide some evidence that mobility contributes to the persistence of inequalities. We also analyse the gains (i.e. improvements in air quality) from residential mobility by equivalised disposable income. We examine these gains in relation to residential mobility at specific events over the lifecourse. To our knowledge, this is the first analysis of individual exposure in relation to mobility patterns in France.

To this end, we rely on a 1% sample of the French population taken from the *Echantillon Démographique Permanent*.[2] We then infer yearly residential trajectories from 1999 to 2017, at the municipality level, from multiple sources. To estimate the particulate matters exposure at the municipality level consistently over the territory and over time, we refer to yearly satellite-based PM2.5 data product (Van Donkelaar et al., 2019) in its European version, starting from 2001.

Although PM2.5 concentration has fallen sharply and consistently over time, large disparities in exposure remain. Compared to the median households, the bottom and top 10% are overexposed to particulate matter. On average, we observe a J-shaped relation-

[1]Selective migration is related to some degree of self-selection, where higher (or lower) income individuals would self-select into cleaner (or more polluted) neighbourhoods. Selective sitting refers to the fact that the exposure to air pollution in urban areas results from composition effects. For instance, poorest individuals tend to live close to hazardous facilities.

[2]We restrict it to the French metropolitan population.

ship between households income and exposure of pollution, with the top income being the most exposed. However, this relationship is reversed when considering differences within urban areas : the bottom income group lives more frequently in the most polluted municipalities.

We use the Oaxaca-Blinder decomposition method between income deciles to highlight spatial sorting, similarly to Currie et al. (2020).[3] We show that different explanations underlie the overexposure at both ends of the equivalised disposable income distribution. On the one hand, the top 10% are over-represented in the largest urban areas (those with more than 700,000 inhabitants) which, are the most polluted areas. On the other hand, the bottom 10% are more likely to live in smaller urban areas, but tend to live in municipalities in the centre of urban areas, which are also the most polluted municipalities within each area.

On average, children and young adults (aged 18-27) are overexposed to fine particulate matter because they live either in the largest urban areas and in the most polluted municipalities within urban areas. Exposure to this pollution then tends to decrease with age, as people tend to move away from large urban areas. The gap between the two ends of the income distribution tends to widen with age. The top 10% decile is particularly overexposed in later life. This is related to the over-representation of the wealthiest elderly population in the centres of large urban areas.

Throughout the course of life, individuals may relocate several times for instance due to major life events such as childbirth. This paper relies on the longitudinal dimension of the *Echantillon Démographique Permanent*, which collects the individuals' residential locations from 1999 to 2017. Individuals who moved between 1999 and 2017 would have been more exposed at the end of the period if they had stayed where they lived initially. Mobility is correlated with lower exposure in the long run, especially for the intermediate deciles.[4] The mobility of households in the median income group corresponds to the highest decrease in air pollution exposure : on average, a household in the median decile in 1999 who have moved since this date experiment a decrease in air pollution by 4% in 2017. This is due equally to the fact that they move from more to less polluted urban areas, and that within urban areas, they move from more to less polluted municipalities.

Mobility leads to a similar reduction in exposure for the bottom and top deciles of equivalised disposable income. However, the bottom 10% gains by 2.5% on average when comparing the exposure of the place of residence in 2017 with the one observed in 1999, while for the top 10% this reduction is mainly due to mobility within urban areas. This suggests that inequalities within urban areas are partly maintained by sorting by income, with the destinations of movers from the top 10% being less polluted than the destinations of movers from the bottom 10%. In addition, it may also indicate that when the top decile gains in air quality as a result of their relocation, they tend to stay in the vicinity of the largest cities.

Over the life cycle, the highest inequalities between the top and bottom groups attributable to residential mobilities are those that occur around the childbirth. Mobility around childbirth tends to involve a move away from the centres of urban areas. Mobility associated with retirement leads to larger gains in air quality for movers (compared to those who remain in the same place), but occurs to a lesser extent than mobility associated with childbirth.

[3] Currie et al. (2020) decomposes the exposure gap between the Black and White American population

[4] Analysis of mobility is carried out with the equivalised disposable income decile fixed at 2010 values.

This paper relates to three strands of literature. First, the literature on environmental justice has documented substantial disparities in exposure to environmental hazards across advantaged and disadvantaged groups. Champalaune (2020) found evidence on the overexposure to air pollution of the poorest and migrants, more particularly in urban areas in France. Padilla et al. (2014) found disparities in NO_2 exposure within four large cities in France: while it was found that disadvantaged areas were relatively more exposed in Marseilles, the relationship appeared to be reversed in the Paris city, and U-shaped in Lyons and Grenoble (Padilla et al., 2014; Morelli et al., 2016). In this paper, we focus on a specific air pollutant PM2.5 but more recently, Salesse (2022) examines the exposure to the combination of air pollutants and Godzinski and Suarez Castillo (2021) disentangle effects of multiple pollutants.

Additionally, the results of this paper are relevant for a second set of literature focused on the effects of pollution exposure according to various age scales. The effects of higher exposure to PM2.5 are particularly harmful for some segments of the population, in particular, children and elderly people. Evidence shows short and long term negative impacts on children's health, varying from increased childhood asthma rate (Currie and Walker, 2011) to an increase in infant mortality (Chay and Greenstone, 2003). Higher exposure to particulate matters in early childhood has been shown to have persistent effects across generations, impacting health status and producing large and permanent opportunity gaps early on in life (Currie et al., 2011; Colmer and Voorheis, 2020).

The effects of air pollution on elderly people are also non-negligible. A growing literature documents the effects of air pollution on cognitive skills (Chen et al., 2018), dementia (Bishop et al., 2018) and the increased risk of pulmonary and cardiovascular disease (Beelen et al., 2014), diabetes (Bishop et al., 2018) and mortality (Deryugina et al., 2019). In France, Bentayeb et al. (2012) and Larrieu et al. (2009) show that the increased average concentration of particulate matters is associated with an increase in pulmonary and cardiovascular disease in the elderly population. We contribute to the literature by documenting exposure inequalities over the course of life, focusing the analysis on vulnerable age groups.

Thirdly, we relate to a literature that describes the mechanisms of spatial sorting. The insight follows Tiebout's (1956) theory which states that households can adjust the level of public goods provision to their preferences by moving between municipalities; in other words, individuals locate relatively to spatial amenities (Kuminoff et al., 2013). This points to amenities as a potential force behind changes in location choice and, indirectly, spatial sorting. Low-income households may place a lower value on environmental improvements (willingness to pay for environmental quality) compared to their preferences for other amenities (Albouy et al., 2016) and have fewer potential resources to adapt through migration.[5] However, the literature does not provide clear evidence of induced migration by air pollution. Recent papers show that pollution reductions induced by exogenous shocks or environmental policies lead to a substantial appreciation in housing.[6]

[5] Albouy et al. (2016) estimate the willingness to pay to live in cool and hot climates and finds that college-educated households are willing to pay more than low-skilled households to avoid excessive heat.

[6] Gamper-Rabindran and Timmins (2011), Depro et al. (2015).

Our findings contribute to a better understanding of how sorting between urban areas or within urban areas shapes pollution inequalities.

The rest of the paper is organized as follows. Section 2 describes the data used for the analysis, Section 3 presents the decomposition of inequalities across and within urban areas, Section 4 details inequalities to air pollution by age, Section 5 describes the role of residential mobility and Section 6 concludes.

2 Data

In this paper, we combine two data sources (i) 1% sample of the French population issued from the *Echantillon Démographique Permanent* at the municipality-year level and (ii) PM2.5 concentrations derived from remote sensing. We use the 2017 administrative geography for *communes* and *arrondissements* (Paris, Lyons and Marseilles).

2.1 Representative sample of residents

The *Echantillon Démographique Permanent* (EDP hereafter) was historically designed to gather information on a longitudinal 1% representative sample of the population living in France. To this end, the French Statistical Institute combines information from the census and from several administrative sources for all individuals fulfilling a simple criteria: being born on one of the first four days of October. This informational system was regularly augmented by new sources. The last exhaustive census of the population from 1999 was of particular importance for our study, allowing us to identify the municipality of residence of all individuals in the scope over this year.[7] A second key almost exhaustive source is the yearly fiscal administrative data *Fidéli/Filosofi*, covering the years 2010 to 2016 for all individuals in the working sample.[8] We derive from the various EDP files sources (i) a municipality of residence from 1999 to 2017 (ii) equivalised disposable income for each individual over 2010 to 2016. We thus define our working sample as the set of all EDP individuals alive in 2010 and appearing at least once in fiscal data. We then reconstruct the residential mobility path for these 786,916 individuals as follows.

Residential trajectories

The comprehensiveness of the EDP files enables to track individual residential location over the period of analysis. Municipality of residence information exists in five sources for individuals in the scope: (i) census data for years when the individual is surveyed in a rolling census from 2004 onward (ii) nearly exhaustive fiscal data exhaustively across years and individuals from 2011 onward[9] - *Fidéli* files (iii) wage-earners' employers social declarations which contain the municipality of residence known to the employer for each year when the individuals earns wage - *DADS* files (iv) civil registry records which give the municipality of residence at birth, marriage, death and when having a child (v) voters list which contains the municipality of residence for each year when the individual newly registers on voter lists.[10]

For each individual in our working sample, the starting point of the residential trajectory which is either the municipality of residence from 1999 census or the municipality of birth for those born after 1999. We then combine from the different sources described above, and we prioritize sources in the order listed above. Figure 14 in the Appendix

[7] Since then the criteria of inclusion in the EDP sample has become larger to include 16 days of birth. However, we restrict our analysis to the sample of the historic 4 days of birth so as to take advantage of the 1999 census.

[8] In this paper, some segments of the population are prone to mismeasurement (young adults transitioning from their parents' declaration to their own, children appearing indirectly on their parents declarations, persons living in communities not liable for housing tax).

[9] The income tax declaration in year N is specific to income year $N-1$ but the tax address is that of the first of January of year N.

[10] Census data is the reference for counting the population, then tax data is considered to be reliable and comparable to census data, being almost quasi-exhaustive. The other data sources are classified according to their concordance with the annual census survey.

shows the source providing the final information in our sample after applying these priority rules. In a given year, when no information is available, we impute the municipality of residence derived from the closest year. For a majority of cases, the next identified municipality is the same as the previously identified, which suggests that under the assumption that there is no move which loops back, we impute the correct municipality. Figure 15 in the Appendix represents in each year and by age group the share of the sample which is correctly located (72% of the observations), or located with the assumption of absence of move (17%), which represents 89% of the sample. The lowest quality is found for the generations born in the 2000s. In general, we underestimate mobility across municipalities except when information is almost comprehensive (1999, 2011-2017).

Key life events

We consider various life events that may trigger residential relocation. We detail below how childbirth, retirement or transition to nursing homes are defined.

Childbirth: Data from civil registers enable us to identify the descent of each EDP individuals and provide information on year of birth. Mobility around childbirth are derived based on surrounding year of childbirth, one year before, during and two years after childbirth were considered in the analysis.[11]

Transition to retirement: Fresh retirees are defined as individuals who do not declare any pension benefit at a given year $t-1$ but receive some pension at year t regardless of their current professional status.[12] New retirees are identified using detailed income data from fiscal sources available for the 2010-2016 period where retirement pension information is available.[13] We define a mover retiree as one who changed residence surrounding the year of retirement (one year before and two years after). Furthermore, transitions to retirement are only observed for individuals who retire on the period 2010 to 2016. Figure 17 in the Appendix represents the proportion of identified transition to retirement. The majority of our sample i.e. 60 % of population aged over 55 years old, retired at 61 years old which is expected given the legal claim age of retirement in France.[14]

Transition to nursing homes: To identify transitions to nursing homes, we use information from housing taxes. That information includes residential location and type of accommodation (private or community accommodation like sheltered or nursing homes).[15] Transition to nursing homes is identified from the classification community directory that includes all type of nursing homes (private and public nursing homes). Transitions to nursing homes are identified when nursing home is registered as residential accommodation at year t and private home at year $t-1$.

[11] Propensity to move around childbirth is notably high one year and two years after childbirth.

[12] Some individuals may still work while receiving their first pension scheme.

[13] All regimes of retirement pension are considered, including specific regimes which permit some earlier retirement age (French national railway company, army). Our sample is restricted to people older than 55 to exclude disability pensions but include earlier retirement from public civil scheme.

[14] The French pension system is a mandatory pay-as-you-go pension scheme, pension benefits depend on the working time span and a legal claim age of retirement (pensions cannot be claimed before that age) set at 62.

[15] The sampling design of the accommodation community directory is based on a comprehensive census of the population residing in communities over a cycle of 5 years. 20% of the population living in communities are surveyed every year. Once individuals have been surveyed, information related to their community accommodation has been registered in fiscal files.

Equivalised disposable income

Our measure of equivalised income is the disposable household income (sum of earnings, self-employment, capital income, and social transfers minus direct taxes, divided by the number of consumption unit).[16] When dividing the disposable income by household units of consumption, we take into account differences in household size and composition. An individual equivalised income is assigned based on that of its household.

For individuals included in the Filosofi database, we have a direct measure of the disposable income.[17] As the Filosofi sample does not cover people living in collective housing (nursing homes, student residences...) or homeless, young adults aged 18-30 and elderly over 80 are under-represented compared to the Fideli sample. This is especially detrimental to our analysis, as for instance the elderly are particularly vulnerable to air pollution. Following Blanpain (2019), we impute disposable income for these individuals to obtain a sample representative of the entire French population.

Disposable income are available since 2010. We computed deciles of equivalised disposable income for this year, separately by age groups (10 years old and less, 11 to 20, 21 to 30, $\cdots$, over 80 years old).

2.2 Exposure to Air Pollution

In France and many Western countries, the network of air quality monitors is spatially sparse. However, recent advances in air quality estimation have led to spatially complete and time consistent estimates of air pollutant concentrations over long periods through various techniques. In this work, we first rely on satellite-derived data products which have received increasing attention in recent years (*WIP*).

PM2.5

Particulate matter pollution poses serious health risks—notably for children, the elderly, and vulnerable populations. Air pollution regulations have increasingly focused on small particles, such as those less than 2.5 micrometers (PM2.5).

Van Donkelaar et al. (2019) produce global and regional PM2.5 yearly datasets disseminated openly at fine spatial scale in raster format in grids ($0.01° \times 0.01°$, about 1 square kilometer). The scale of dissemination corresponds to the most precise satellite observations of aerosol optical depth (AOD) measures which are the inputs to the estimations.[18] AOD corresponds to the measure of aerosols (e.g., urban haze, smoke particles, desert dust, sea salt) distributed within a column of air from the surface to the top of the atmosphere. These satellite-derived measures are transformed to a first set of PM2.5 surface concentrations, the mapping being simulated with a chemical-transport model (specifically GEOS-chem). These estimates are subsequently calibrated by incorporating ground-based observations and using a geographically weighted regression. [19] Economists,

[16] The consumer units are calculated using the modified OECD scale which allocates 1 consumer unit to the first adult in the household, 0.5 to the persons of 14 years or older and 0.3 to children under the age of 14 years.

[17] Individuals in the Fideli sample are identified either based on income tax **or** residence tax files, while individuals in the Filosofi database have filed at least income tax file **and** are taxable on residence tax.

[18] In practice, these fine scale measures are combined with coarser resolution AOD measures.

[19] From 2010, ground station data are included to calibrate the estimates on PM2.5 concentration level that are derived from satellite observations. It relies on the assumption that when incorporating ground-based observations into purely satellite-derived (i.e. geophysical) values, the ground-based observations are more certain, and differences between geophysical values and the monitors represent uncertainties in

social scientists and epidemiologists are increasingly using these satellite-based estimates of PM2.5 concentrations to analyze the health and economic impacts of ambient pollution exposure (Fowlie et al., 2019; Colmer et al., 2020; Currie et al., 2020; Di et al., 2017).

In this study, we use the European regional estimates (V4.EU.03) version of the datasets (Hammer et al., 2020). Exposure data thus covers the French metropolitan territory from 2001 to 2017. We derive PM2.5 concentration at the municipality level by computing the weighted average of the level of pollution associated with each raster grid that overlaps with each municipality (using official zoning of municipalities in French territory in 2017). Then, we spatially intersect this gridded, raster data with residential municipality files from EDP source data, in order to assign to each individual their level of exposure given their municipality of residence.

Exposure by Urban Area

To investigate the heterogeneity of exposure to air pollution across French cities, we exploit a geographical classification based on Functional Urban Areas (FUA). Based on population density and travel-to-work flows as key information, a functional urban area consists of a densely inhabited city and of a surrounding area (commuting zone) whose labour market is highly integrated with the city (Dijkstra et al., 2019). Once the urban centre is segmented, commuting flows are used to identify which of the surrounding, less densely populated local units were part of the city's labour market (commuting zone). Urban areas are segmented according to five classes (Paris; area with 700,000 inhabitants or more (excluding Paris); area with 200,000 to less than 700,000 inhabitants; area with 50,000 to less than 200,000 inhabitants; area with less than 50,000 inhabitants). Figure 16 in the Appendix represents the spatial extent of these categories.

From 2006 to 2009, the concentration in PM2.5 has greatly increased notably in the urban area of Paris, according to ACAG data.[20] This evolution is in line with the increase in the concentration of NO_2 observed in the urban area of Paris.[21] The NO_2 pollutant is usually produced in conjunction with PMs by traffic (Godzinski and Suarez Castillo, 2021) : and increase in PMs is thus expected to occur simultaneously with an increase in NO_2.

Overall, we find that average exposure for all urban areas decreases from 2010 to 2017. The declining trend in PM2.5 concentration is likely due to investments in cleaner production by industries and implementation of Atmosphere Protection Plan since 2010 (Champalaune, 2020). On average, individuals living in the largest urban areas (notably, Paris urban area) are the most exposed to PM2.5 over the whole period. Interestingly, exposure to air pollution is trending downward over time. The level of exposure to PM2.5 is tied to population density, but the interquartile range of exposure remains rather wide for inhabitants located within the largest urban areas. The Paris urban area exhibits the highest level of exposure over time, followed by urban areas with 700,000 inhabitants or more, while outskirts areas display the lowest levels of exposure to PM2.5. Spatial sorting is therefore expected to play a key role in exposure to PM2.5.

the geophysical values.

[20]No evidence exists on a change in the collection of these data: while the technology of the ground monitors for the measurement of PM have changed over the period, ACAG data collection are homogeneous over the whole period of analysis 2000-2017.

[21]refer to official data on NO_2 from the Observatory on air quality in the urban area of Paris, `http://www.advocnar.fr/wp-content/uploads/2016/04/bilan_2010.pdf$`

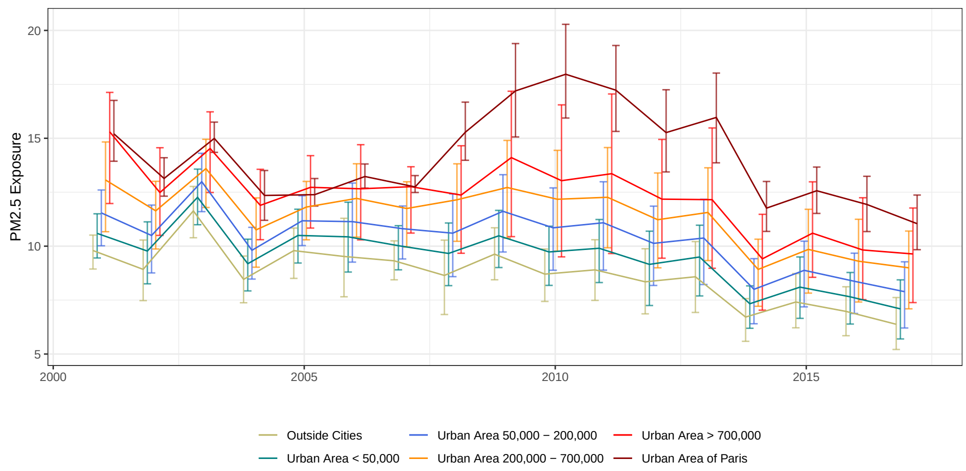


Figure 1: PM2.5 Exposure (Mean, Q1, Q3) by urban Area type.
Source: ACAG (Atmospheric Composition Analysis Group).

Evolution of air pollution 2001-17

How evolve the exposure inequality over time? Figure 2 shows the change in relative exposure of three groups of income (compared in pairs, and by type of urban area) from 2001 to 2017. At the national level, we first observe a sharp increase from 2007 to 2010 in the exposure of the top 10% of income relative to respectively the first decile (by 5%) and to the median one (by 10%). These two relative exposures have on the contrary decreased since 2010. The patterns are very different at the urban areas: since the mid 2000s, the relative exposure of the bottom 10% compared to the median households have worsened in all type of urban areas (by approximately 5% from 2005 to 2017). Within one urban areas, the relative exposure of top and median households are rather stable over the period.

These patterns are consistent with a composition effect, related to a spatial sorting of households over type. For instance, one may related the increase in over-exposure of the top deciles at the end of the 2000s with their over-representation in the Urban area of Paris, where the PM exposure increased rapidly at this time (see Figure 1). These mechanisms are analysed in details below.

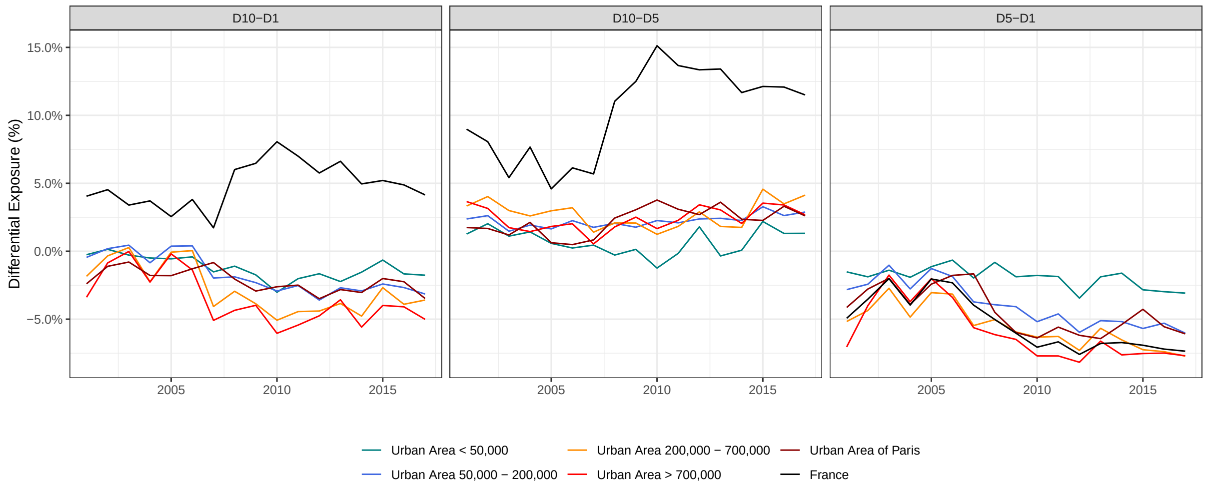


Figure 2: Evolution of differential exposure between decile groups. *Note: D1, D5, D10 refer respectively to the bottom 10%, median group and the top 10%. Differential of mean exposure between income groups are expressed in percentage. The black line illustrates the differential of exposure between two income groups in France, the other colored lines give differentials between two income groups by type of urban area. For example, in the left panel, the red line depicts the differential exposure in PM2.5 between the top 10% and the bottom 10% living in urban areas with more 700,000 inhabitants.*
Source: ACAG (Atmospheric Composition Analysis Group) and EDP (Echantillon Démographique Permanent).

3 Inequalities of exposure to air pollution

Geographic location is a major determinant in explaining mean gaps as air pollution is positively associated with cities density. Moreover, household location choices are endogenous dynamic decisions, that may vary along household preferences and throughout the life cycle. The following descriptive statistics show different patterns of inequality between and within urban areas. To compare the unconditional and conditional mean difference in pollution exposure across income groups, we use the following linear regression model on our sample of residents over 2001-2017:

$$PM_{it} = \alpha + \sum_{k=1}^{k=10} \beta_k \mathbb{1}decile_{ik} + \lambda_t + \underbrace{UA_c}_{\text{Spatial Effects}} + \epsilon_{it} \tag{1}$$

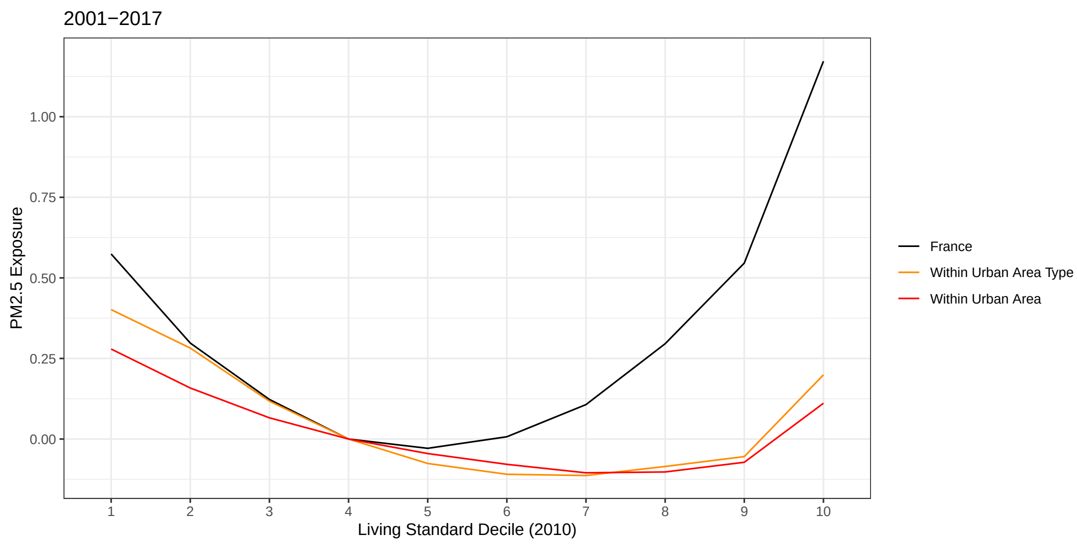
where PM_{it} is the average concentration individual i is exposed to in year t, $\mathbb{1}decile_{ik}$ is a dummy equal to 1 when individual i belongs to decile k of disposable income in 2010 (decile 4 being normalized to 0) and λ_t is a year fixed effect capturing the overall trend in PM2.5 concentrations. UA_c is some component that is either (i) not included, (ii) conditional on the urban area type (5-valued typology), or (iii) or on the specific urban area (700-valued areas). The $\hat{\beta}_k$ in these three specifications respectively represent the average exposure by decile (i) nationally, (ii) within the type of urban area and (iii) within the urban area. The type of urban area alone explains more than 30% of the variability in exposure over time and across individuals. The urban area itself (about 700 different urban areas) explains more than 70% of the variability.

We examine whether the differences in exposure can be explained by differences in residential location. Figure 3, top panel compares the average exposure (Equation 1) unconditional and conditional to urban area. On average and unconditionally to urban area, we find a J-shaped relationship between income and exposure in France: low and high income groups are disproportionately exposed to high levels of PM2.5 pollution compared to middle income individuals (black line in top panel), and the top 10% are twice more exposed than the bottom 10%. However, conditioning pollution exposure to urban areas (red and orange lines in top panel), we observe on the contrary a almost linear decreasing relationship between the income and exposure to PM, from the first to the ninth decile. If within areas, the top 10% appears more exposed than the ninth one, it is twice less exposed than the bottom one. When considering the gradients of exposure by income separately by type of urban areas, we observe a similar profile : a decreasing pattern from the bottom to the median decile, and a increase from the ninth to the top decile. Within all type of urban areas, the top income are less exposed than the bottom one. When considering small urban areas (less than 200 000 inhabitants), the profile is flatter (bottom panel of Figure 3). The relationship between disposable income and exposure within urban areas differs significantly from the national pattern. Champalaune (2020) found similar results using neighbourhood level analysis in France.[22]

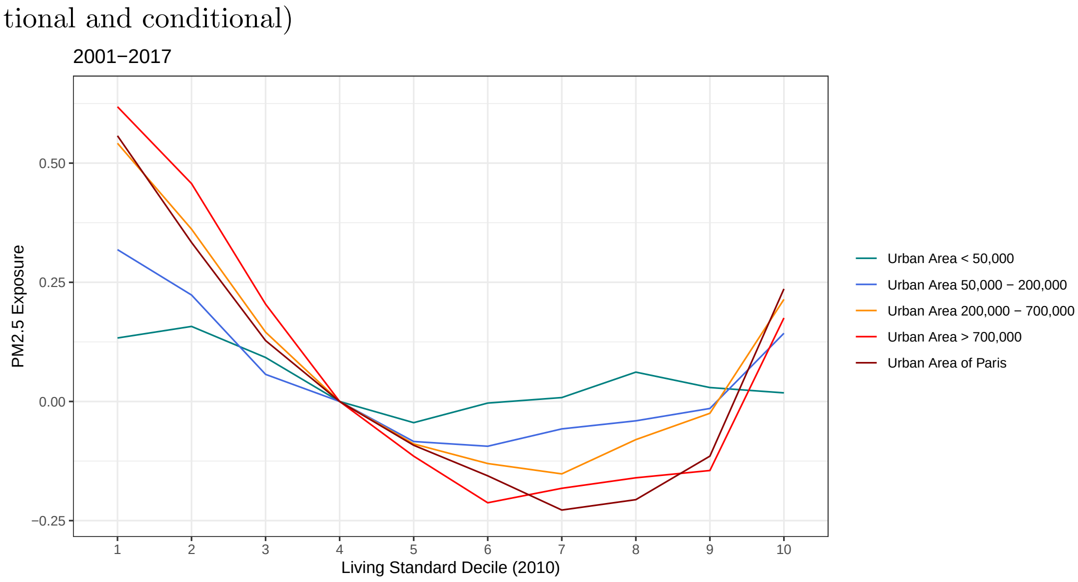
These differentials in pollution exposure might reflect differences in where income groups live, in other words their spatial distribution across urban areas. For instance, more than half of the top 10% live in very large urban areas, while only about 30 % live

[22] National exposure by decile differs at the top of the distribution: Champalaune (2020) finds that neighbourhoods above the ninth decile of the local income distribution are as exposed as those in the bottom 10%. The differences with our results may be due to the individual level measure, to the concept of income (here equivalised disposable income) and probably to a lesser extent to the different spatial scale.

in very large urban areas.



(a) Average exposure to PM2.5 in relation to equivalised disposable income (unconditional and conditional)



(b) Conditional on urban area

Figure 3: Exposure to air pollution by income. *Note: The gradients are estimated from regressions of exposure on decile. Black line in Figure (a) displays the regression of pollution unconditional to urban area. Orange and red lines display "within urban area type" resp. conditional on the urban area type (5-valued typology) or on the specific urban area (700-valued areas). Figure (b) display the gradients conditional on specific urban area type. All regressions controls for year fixed effects (reference group: 4th decile in 2001).* Source: ACAG (Atmospheric Composition Analysis Group) and EDP database, 2017.

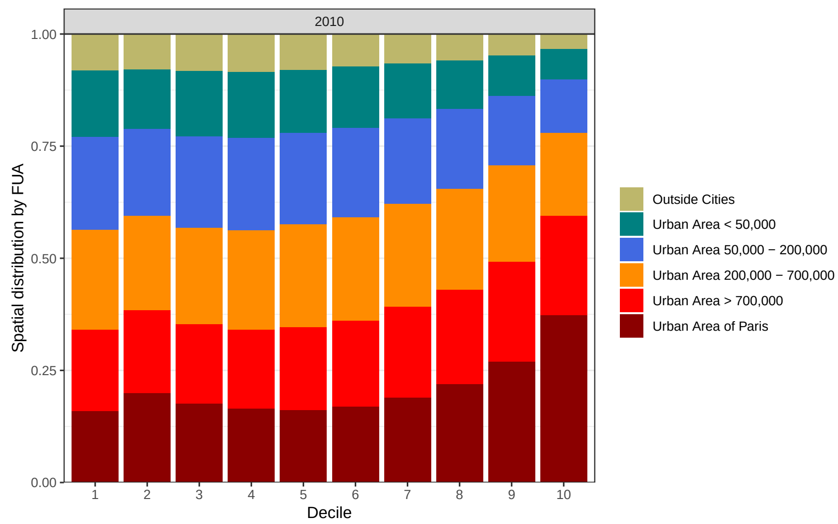


Figure 4: Distribution of the income groups across type of urban area.
Note : 18% of the first decile of income leave in the urban area of Paris, while it is the case of 37% of the top decile of income.

3.1 Decomposing inequalities in exposure across and within urban areas

To examine inequalities between deciles, we decompose the mean exposure to PM2.5 between income groups using an Oaxaca-Blinder decomposition (Blinder, 1973; Oaxaca, 1973).[23] We decompose mean gap exposure and disentangle whether it is related to decile (of income) composition across urban areas or within urban areas. In this analysis we consider the gaps between the top 10% (labelled D10 in the Figures) and the bottom 10% (labelled D1), D5 versus bottom 10% and D5 versus top 10% by the type of urban areas.

The Oaxaca Blinder method decomposes the gap between two income groups into an explained and an unexplained component, after estimating Equation (1). The explained component is the difference in outcome attributable to observed characteristics, here the type of urban areas. Therefore, it represents the amount of PM2.5 by which the gap in exposure would be reduced if two income groups were identically distributed across urban area types. The unexplained component reflects differences between income groups in PM2.5 exposure within urban area types. Formally, the decomposition of the gap between, two income groups, D_1 and D_2 can be written as

$$\bar{P_{D_1}} - \bar{P_{D_2}} = \underbrace{\sum_u (p_{u,D_1} - p_{u,D_2})\hat{\beta}_{u,D_2}}_{\text{Explained By Sorting Across } u} + \underbrace{\sum_u p_{u,D_1}(\hat{\beta}_{u,D_1} - \hat{\beta}_{u,D_2})}_{\text{Distinct Exposure Within u}}$$

where u is urban area type, p_{u,D_1} (resp. p_{u,D_2}) is the proportion of the D_1 (resp. D_2) living in u type, $\hat{\beta}_{u,D_1}$ (resp. $\hat{\beta}_{u,D_2}$) is the average exposure of the D_1 (resp. D_2) when living in u type, estimated by linear regression in each group, refer to Appendix A.1.

The decomposition suggests that the over-exposition to exposure of the top 10% is mainly driven by their location between areas : for instance, in 2017 on average we observe a difference of 1 $\mu g/m^3$ between the top 10% and the median, and 80% is explained by the between component, meaning that the most privilegied are over-represented in the

[23]The Oaxaca-Blinder technique was originally used in labour economics to decompose earnings differentials and to estimate the extent of discrimination (Blinder, 1973; Oaxaca, 1973).

most polluted areas. The location within these areas may reinforce (in the case of the gap between median and top 10%) or on the contrary mitigate (in the case of the gap between median and the top) these differences. This suggest that within areas, the top 10% locate in more polluted municipalities than the median income households (the within component is $-0.2\,\mu g/m^3$ while they live in less polluted municipalities than the bottom ones (the difference is $0.3\,\mu g/m^3$. Again, we observe that the median group is the least exposed group, as these households are under-represented in both the most polluted areas, and in the most polluted municipalities within areas. This is consistent with the profile of the exposure observed in Figure 3, once the location in areas is controlled for. These patterns appear stable over time.

Table 1: Share of the exposure gap explained with spatial sorting across urban area types (Oaxaca Blinder Decomposition)

	Exposure			(i) D1 - D10			(ii) D1 - D5			(iii) D5 - D10		
Year	D1	D5	D10	Gap	Between	Within	Gap	Between	Within	Gap	Between	Within
2001	13.4	12.7	13.9	−0.6	−0.8	0.2	0.6	0.1	0.5	−1.2	−0.9	−0.3
2010	13.0	12.1	14.1	−1.1	−1.5	0.4	0.9	0.2	0.7	−2.0	−1.8	−0.2
2017	9.2	8.5	9.6	−0.4	−0.7	0.3	0.7	0.1	0.5	−1.0	−0.8	−0.2

Note: The within and between components are obtained using an Oaxaca-Blinder decomposition (see Appendix A for details). The between component corresponds to the so-called "explained gap". It corresponds to the difference in exposure that is explained by the spatial sorting across urban area types (6 modalities) of the two income groups, and taking the average exposure of the highest decile in each urban areas as a reference group. The within component corresponds to the so-called "unexplained gap" of the Oaxaca-Blinder decomposition. It corresponds to the difference, within each area, between the average exposure of the two groups, taking the proportion of the lowest income group as a reference group. Source: EDP database and author's calculations.

However, when comparing the bottom 10% and the top 10%, the within gap is positive while the between gap is negative. Those opposite signs suggest that individuals in the bottom 10% are more likely to live in more polluted municipalities than individuals in the top 10%, but that individuals in the bottom 10% are under-represented in the most polluted urban areas in comparison with the top 10 %.

Finally, the median group is the least exposed group: it is under-represented in polluted urban areas and polluted municipalities. Overall, Table 1 shows that inequalities in exposure between income groups persists over time and that the gaps associated to between and within components are quite stable.

These general pattern masks a great diversity of situations depending on urban areas, as described in Figure 5. In most urban areas the bottom 10% is over-exposed (the red dots located below the bisecting lines in the two top panels in Figure 5), and this overexposure occurs mostly in the largest urban areas (depicted with the largest dots in the Figure). This result is consistent with the conclusion of Padilla et al. (2014), who found that patterns of inequality may be heterogeneous across French cities: high income individuals tend to be more exposed to NO_2 in Paris and Lille, but not in Lyons and Grenoble (Padilla et al. (2014)).

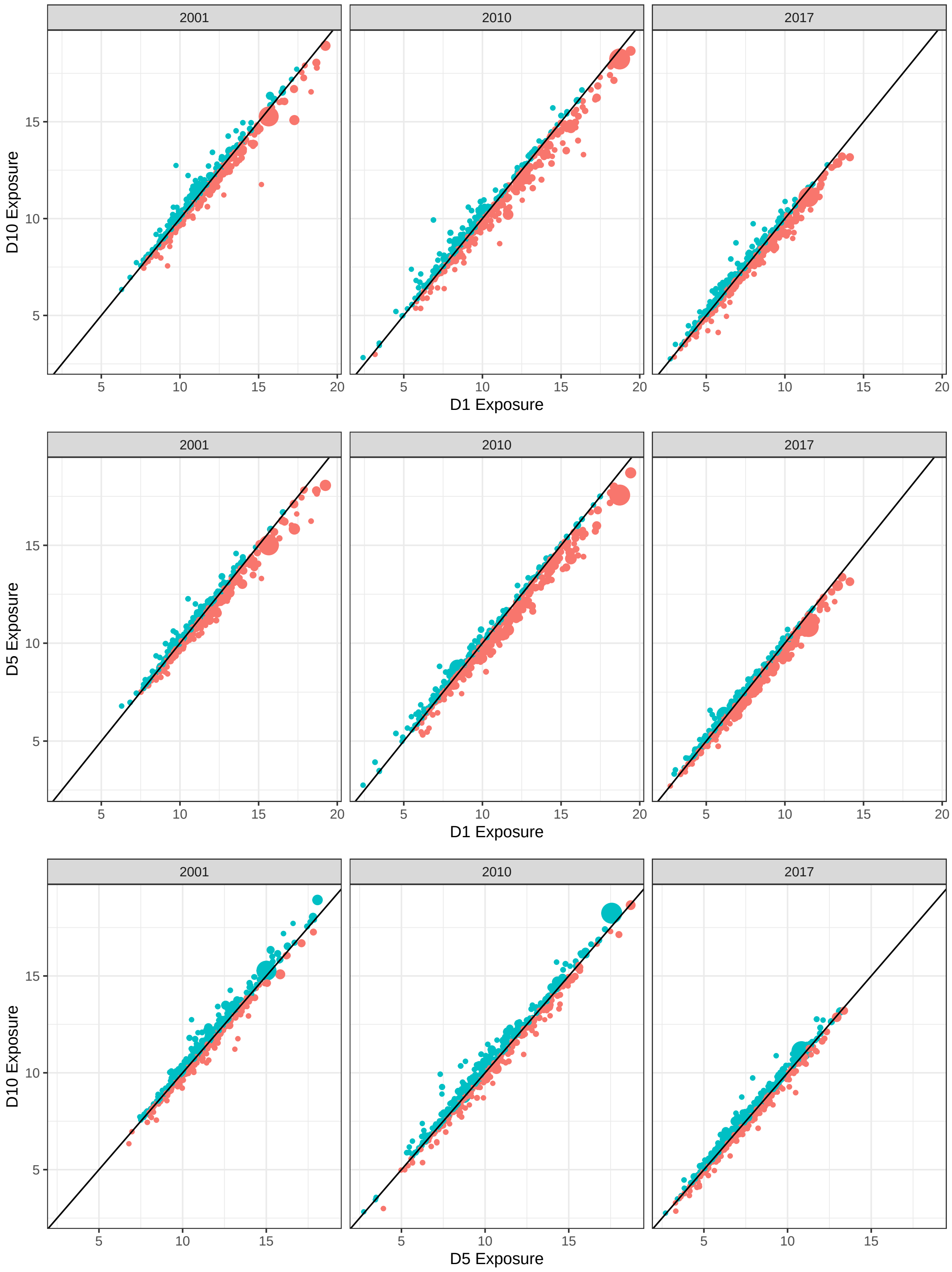


Figure 5: Comparison of Exposure within Urban Areas by Decile (bottom 10%, D5, top 10%). *Each point represents one urban areas, with a size proportional to the number of individuals in both decile. Below the bisecting line, the point colored in red when the exposure is higher for the lowest of both decile.*
Source: EDP database, 2017 and author's calculations.

3.2 Exposure inequalities by age

Air pollution has larger health consequences on infants and elderly people than on the rest of age groups, Currie and Walker (2011) and Deryugina et al. (2019). Do the most vulnerable age groups experience a disproportionate exposure to air pollution? To address this question, we first compare the average levels of pollution experienced by generational groups. Exposure to PM2.5 is observed for each individual over the period of analysis. The average exposure of an individual is observed for a maximum of 17 years, that does not correspond to the whole individual life course. The analysis overlaps individuals longitudinal exposure from distinct generations.

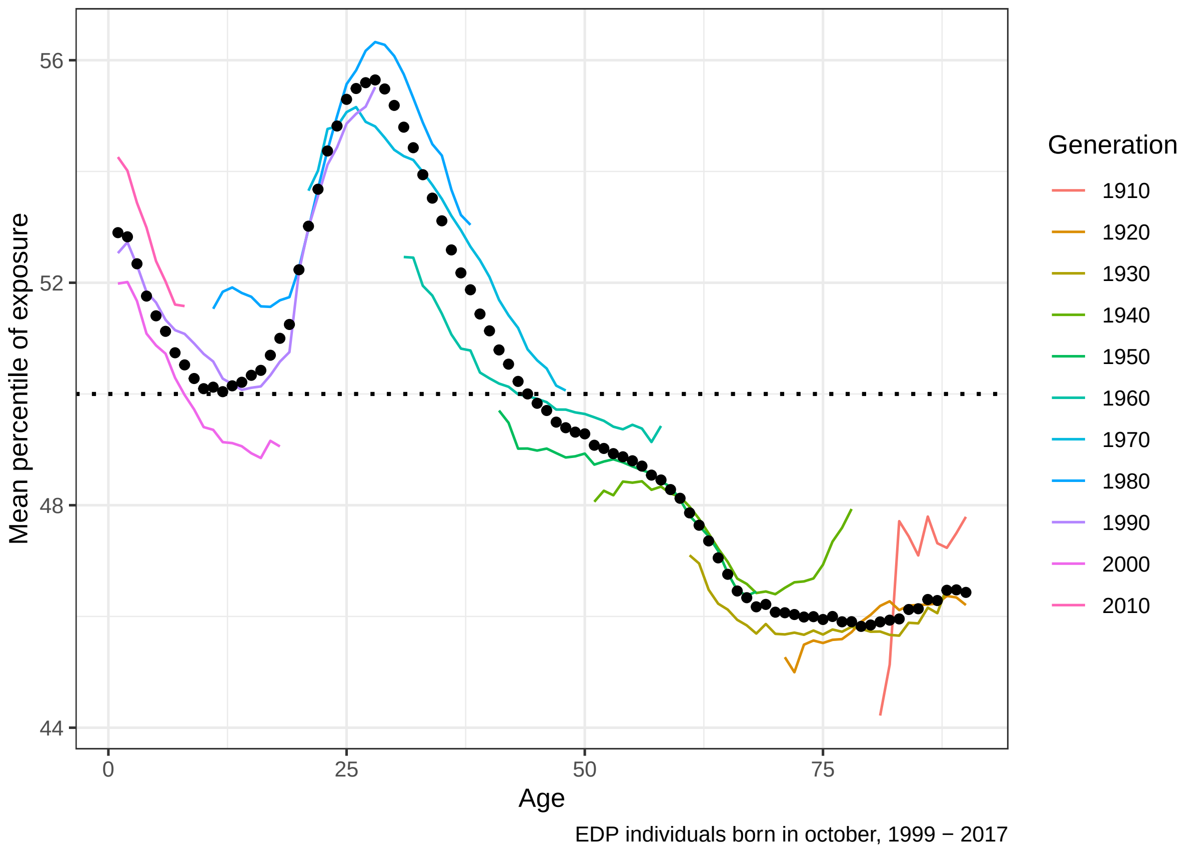
The top panel of Figure 6 shows how inequality in residential exposure to PM2.5 varies by age. Babies and infants are overexposed, i.e. above median level. This inequality declines with age with small difference in exposure for teenagers (compared to infants) but then the mean exposure increases sharply from 18 years old to 27 years old. From 27 years old, the mean exposure decreases steadily. However, we show an increase after 75 years old: elderly population experiences an increase of exposure in a later stage of life. However, this result needs be interpreted with caution due to survival bias and differential mortality. Survival bias is in relation with the fact that we observe only elderly individuals that are still alive and have survived regardless of income group they belong to. Average exposure on elderly group is observed based on survivors, this group may have "survived" as for instance, they may experience less pollution and were less exposed before 1999 (before our period of analysis). On the other hand, differential mortality is related to individuals with a higher level of vulnerability (Deguen and Zmirou-Navier, 2010).[24]

We then explore whether inequalities in exposure across income groups persist over the lifespan. The bottom panel of Figure 6 shows that until 60 years old, the poorest and highest income groups are the most exposed groups (bottom panel). In late adulthood, the top 10% is more exposed than the bottom 10%. The gap between both groups is widening with age, as the exposure of the bottom 10% decreases more rapidly from 50 onwards.

From 75 years old, the bottom 10% is the least exposed across income groups. At 75 years old, the top 10% is ranked 10 percentile higher (i.e. 54th mean percentile of exposure) than the bottom 10% (i.e. 43th percentile of exposure). This shows that the bottom 10% of the elderly group live in areas where air pollution is below median, and all the more so as they age.[25] This may indicate that the bottom 10% of the elderly group live in areas where air pollution is falling faster than elsewhere, or that the mobility of the elderly population tends to reduce inequalities in later life.

[24] Poorer individuals incur a higher mortality risk (Blanpain, 2019), they are more likely to experience more detrimental effects of air pollution since they have more fragile health due to social determinants.

[25] However, this result needs to be interpreted in light of survival biais.



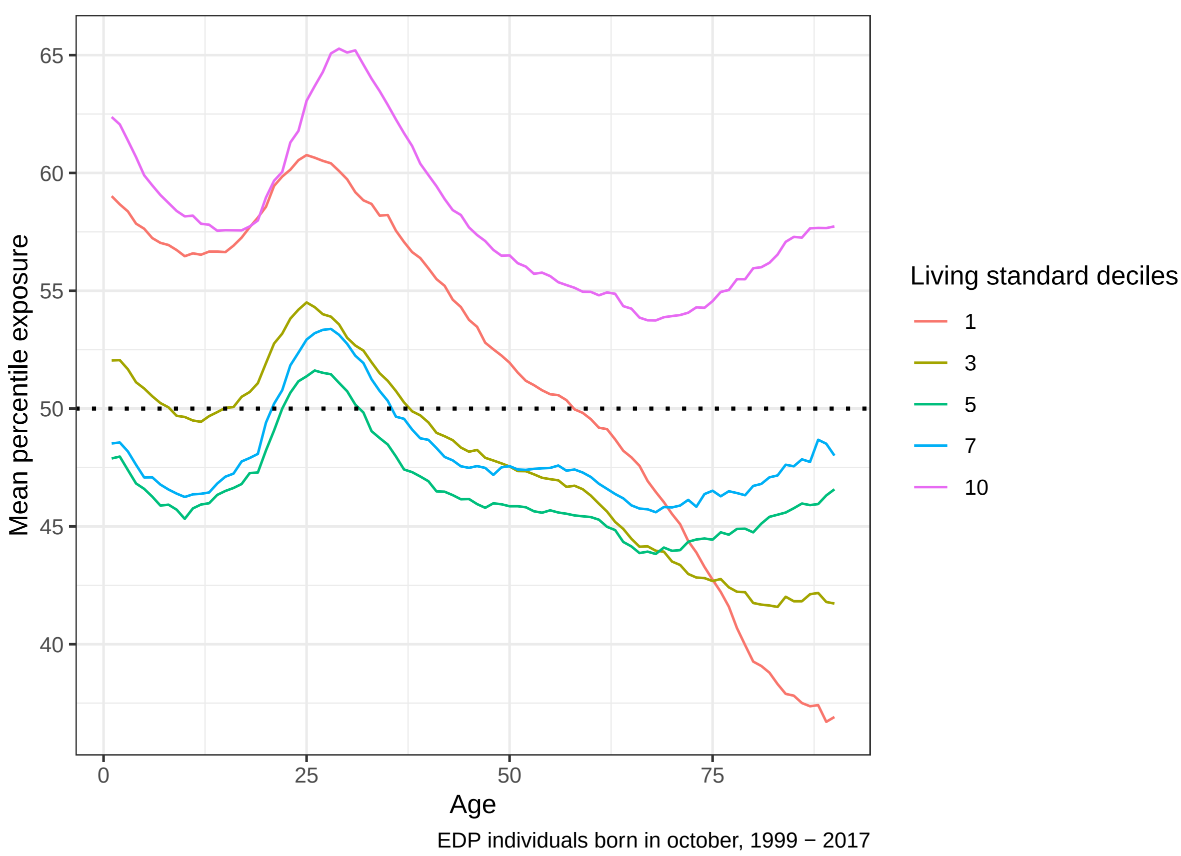


Figure 6: Exposure to fines particles over life cycle. *The dotted horizontal line represents the median value of exposure to PM 2.5. The curve with black dots represents the mean across age top figure. The colored lines represent the mean exposure for individuals born in a decade i.e. the pink line (2000) depicts the mean exposure of individuals born between 2000 and 2009.*
Source: EDP database, 2017.

We then examine the extent to which spatial sorting throughout the life course could explain persistent inequalities. Figure 20 in the Appendix shows that ends of income distribution are overexposed regardless of urban area for population aged from 0 to 55 years old. However, the relationship between income and exposure to PM2.5 tends to weaken between 70 and 80. Does this evidence hold for all age groups?

Figure 7 shows the location of individuals by type of urban area and by age group. Throughout the life course, the top 10% tend to live predominantly in large urban areas. Looking more closely at the location of individuals as they age, the top 10% tend to move from large urban areas to small urban areas, while the bottom 10% tend to move away from city centres. Specifically, before the age of 55, almost 60% of the top 10% live in large urban areas, i.e. urban areas with more than 700 000 inhabitants, while after the age of 55 this proportion falls to 48%. In contrast, about a quarter of the young population (up to 20 years old) from the bottom 10% live in Paris. Only 10% of the bottom 10% live in the Paris region when they are old (from 70 years old).

These results suggest significant residential moves of the bottom and top 10% population throughout the life course.

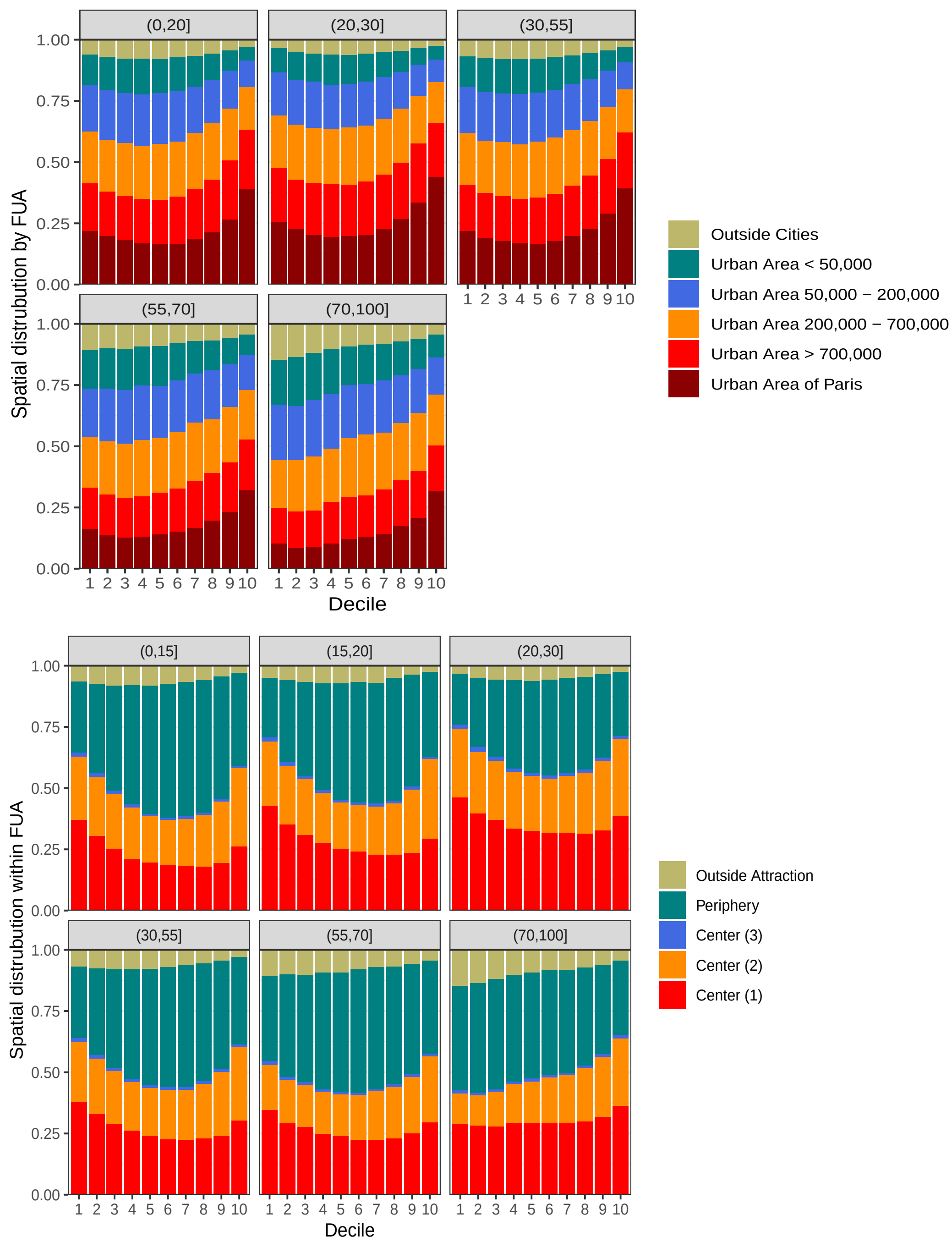


Figure 7: Spatial sorting of disposable income within urban area by age in 2017.
Source: EDP database, 2017.

4 The role of residential mobility in exposure inequality

In this section, we test whether sorting by income is a possible mechanism underlying unequal exposure to air pollution. To gauge the role played by residential mobility, we conduct a counterfactual exercise which aims at evaluating the level of exposure that would have prevailed if individuals in our sample would have remained in the municipality where they lived in 1999.[26] By freezing observed mobility, we obtain an alternative exposure for each individual, which we compare to its actual exposure throughout the period. The gain of air quality associated to mobility is derived as follows for specific k decile of income:

$Gain_{k,t}$= $\overline{Y}_{actual_{k,m,t}}$- $\overline{Y}_{counterfactual_{k,m1999,t}}$, for t=years from 1999 to 2017 and k decile of income (bottom 10%, D5 and top 10%)

where $\overline{Y}_{actual_{k,m,t}}$ is the actual average exposure, based on k decile of income, t year and m actual municipality of residence, whereas $\overline{Y}_{counterfactual_{k,m1999,t}}$ is the counterfactual average exposure based on municipality of residence in 1999. This counterfactual corresponds to the average exposure that would have been measured if individuals live in the same place over the analysis period as they live in 1999.[27]

In the absence of residential mobility since 1999, exposure to PM2.5 would have been higher, regardless of the location in the income distribution (see figure 8).[28] Individuals in the middle of that distribution have benefited more from mobility than the other deciles. These individuals benefit, thanks to mobility, of 3.8% to 4.5% air quality from 2010 onward while the other deciles display smaller gains around 2% over the same period (left panel in Figure 8). Residential mobilities between 1999 and 2017 thus tend to lower exposure to air pollution.

Focusing now on mobility within urban areas as opposed to mobility between urban areas, the gain (lower exposure) for the lowest decile stems primarily from mobility between urban areas (middle and right panels in Figure 8). By contrast, within urban areas inequalities between income groups are partially maintained by sorting by income, whereby individuals in the highest decile move to less polluted municipalities within urban areas, which is less often for individuals in the bottom 10%. In addition, it may suggest that the top 10% gains in air quality when they relocate, by living in proximity of the largest cities. Finally, when moving either to another urban area or within urban areas, the median income group benefits from the largest gains in air quality.

[26]For individuals born after 1999, their municipality of birth.

[27]In practice, for each year t and individual i, we consider the pollution level measured in year t, in the municipality where the individual resides in 1999.

[28]The residential location are comprehensively identified in 1999 and from 2010 to 2016, but are only reconstituted from 2000 to 2009 (see section 2.1). The patterns on mobility from 2000 to 2009 should thus be analyzed with caution, and we turn closer attention on the changes comparing 2010-2020 with 1999.

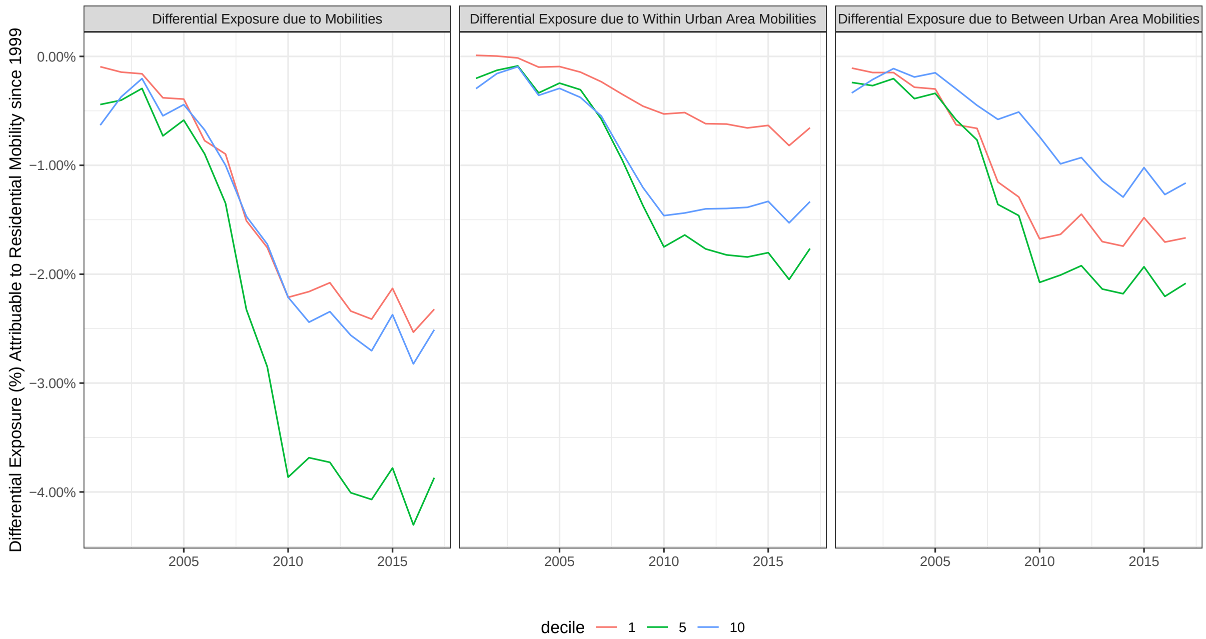


Figure 8: Differential with counterfactual exposure and attributable to residential mobilities since 1999, by decile. *Note: Differential exposure are calculated by subtracting the actual exposure with counterfactual exposure : where the observed exposure is compared to the exposure which would have prevailed if each individual had remained in its municipality of residence in 1999. Differentials exposure due to within urban area/ between urban area are calculated for individuals who move to another municipality but respectively within the same urban area or towards another urban area.*
Source: ACAG (Atmospheric Composition Analysis Group) and EDP database, 2017.

The mobility of the different income groups may be related to changes in air quality over this time period. The results in Figure 8 need to be interpreted independently of new standards on air quality.[29] It is possible that for instance the bottom 10 % moved to municipalities where the implementation of new standards was the most effective, resulting in larger decreases of air pollution. For instance, we could consider an individual who moved from a city in the first periphery to the relatively less polluted city center, that exhibits less air pollution due to new standards. In the next section, we do not examine mobility in response to change in air quality but mobility triggered by life events.

[29] Champalaune (2020) examines the effect of Plan de Protection de l'Atmosphère, that was gradually implemented in different urban areas from 2010.

While previous analysis suggests that mobility plays a role in reducing exposure to air pollution, we now focus on mobility around key life events. Residential mobility is tied to events such as childbirth, children leaving the parental home, or divorce and career-related events e.g first job or retirement. Figure 9 shows that residential mobility varies much by age.[30] It increases in young adulthood, then decreases later until retirement and finally increases in late old age (over 80). The mobility rate of the youngest age group (0-20 years) is close to the mobility rate of adults aged 35-50, which is to be expected if children and young adults follow the spatial mobility of their parents. The high mobility rate of the young adult population (18-30 years old) is related to leaving the parental home. During adulthood, adults move moderately after settling down.[31]

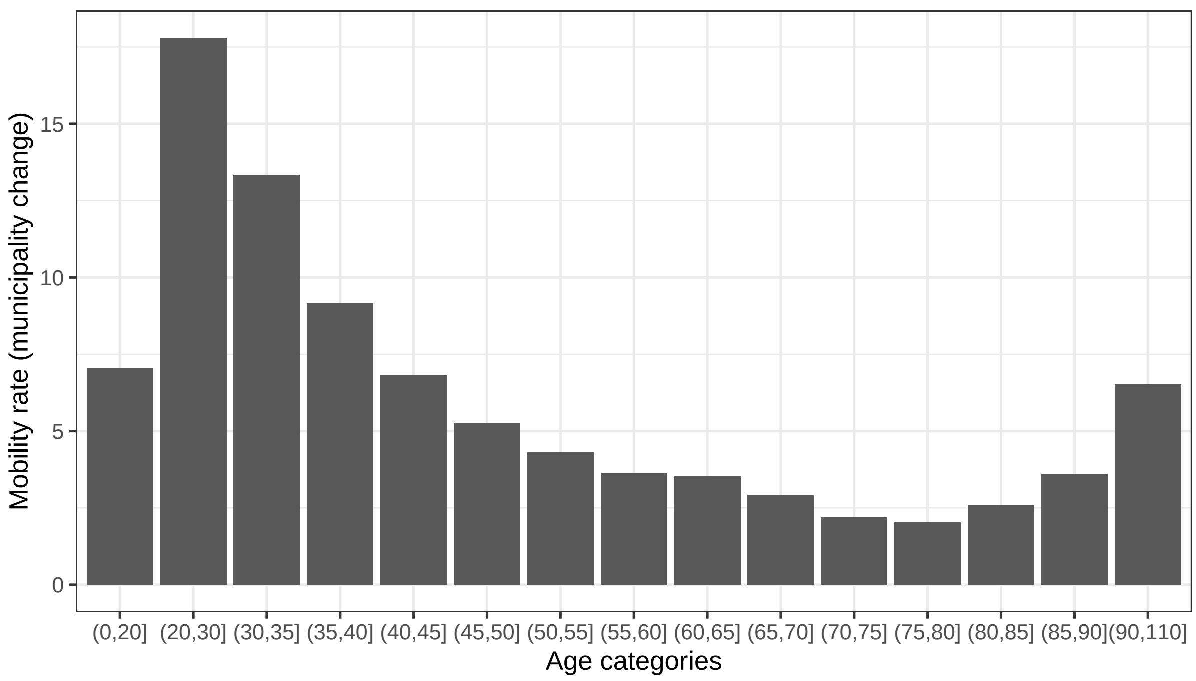


Figure 9: Mobility rate by age categories. *Mobility rates are derived from the analytic sample based on yearly municipality mobility in 2017.*
Source: EDP (Echantillon Démographique Permanent).

Figure 10 displays the average gains in air quality when individuals move either around the birth of a child or around retirement. Among the different types of mobility that could occur over a lifecourse, those that occur around retirement lead to higher air quality, as mobility around retirement is mostly from large urban areas towards smaller and less polluted urban areas. Although less than 5% of the population aged 60 to 65 years old move around retirement, these movers benefit from a 10% reduction in PM2.5 pollution. In contrast, the 30-35 years old are more likely to move, but they benefit from a smaller reduction when they move. On average, 13% of people aged 30 to 35 move, and they benefit from a 3% reduction in pollution due to a type of mobility, residential move around childbirth.

[30] The chart displays mobility rate including only mobility between municipalities. Mobility within municipalities is not taken into account. Before 2011, mobility rates are available over a 5-year period.

[31] 40% of elderly migrants move to nursing homes.

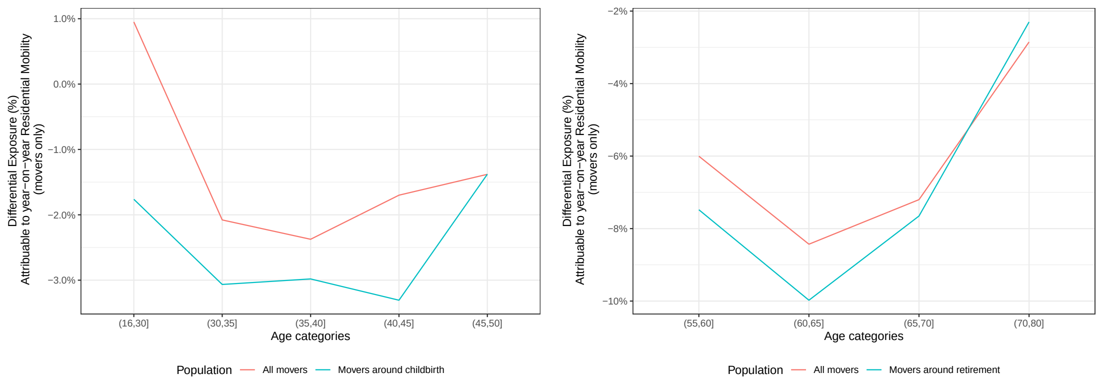


Figure 10: Differential with counterfactual exposure and attributable to residential mobility (by type of life event). *Note: Differential exposure is measured as the difference between the actual mean level of pollution and the counterfactual mean level of pollution. The counterfactual level of pollution refers to level of pollution in municipality where individuals reside in 1999. For each individual, the counterfactual time series is filled with time series of the residence municipality in 1999.*
Source: ACAG (Atmospheric Composition Analysis Group) and EDP database, 2017.

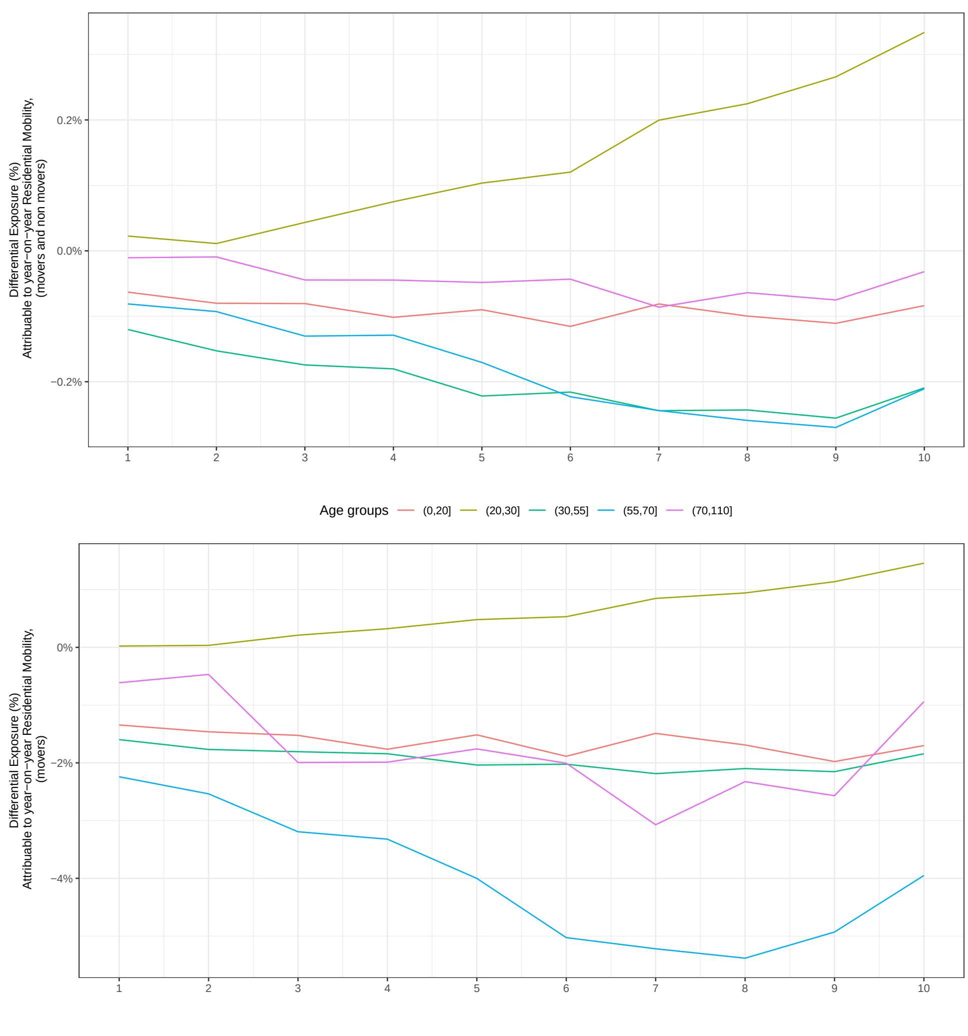
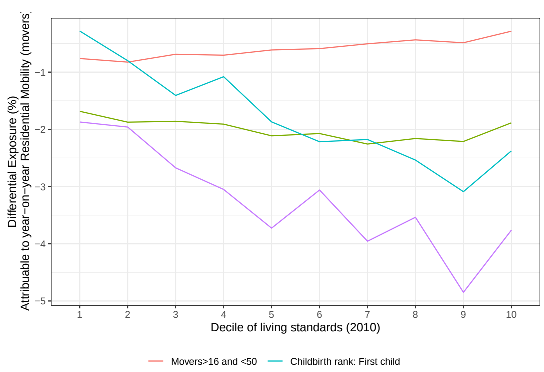


Figure 11: Differential with counterfactual exposure and attributable to residential mobility, by age and decile of income. *Note: Observed exposure is compared to the counterfactual exposure that individuals would have experienced if they had stayed in their municipality. Top figure of the panel displays differential exposure for the whole population only while the bottom figure displays differential exposure for movers population.*
Source: ACAG (Atmospheric Composition Analysis Group) and EDP database, 2017.

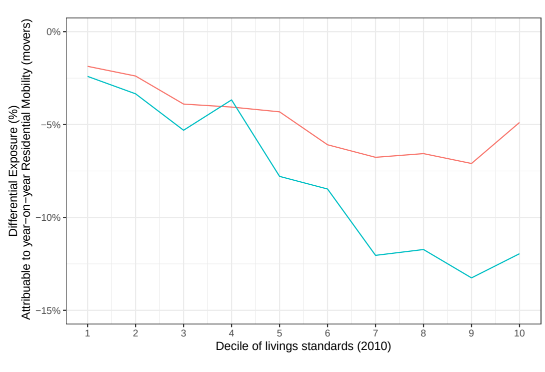
Mobility consecutive to demographic events: around childbirth and retirement

We examine the extent to which mobility induced by major life events further decrease or increase exposure to fine particulates. To understand the role of mobility around a childbirth or retirement events, we need to distinguish between the individual benefits that people derive from their mobility (Figure 12) and the role of mobility in widening inequalities in the population as a whole (Figure 13).[32] In both cases, the exposure gain (or reduction) is unevenly distributed across the movers population and across income groups. Relying on the same counterfactual approach, we assign to each individual their location before childbirth event (resp. before retirement event) and then we derive differential exposure by comparing the observed exposure with the counterfactual exposure.[33] Restricting the population to the movers only, households with children in the bottom 10% experience a smaller reduction than those in the top 10%, irrespective of the number of children. For example, the poorest households with at least two children experience a decrease by 1.5%, while the reduction in exposure for the similar families of top 10% households is reported to be 4% (Figure 12, a).

Around childbirth, households may have to adjust the housing situation to this change which implies residential relocation. Regardless of the number of children, exposure to PM2.5 tends to decrease when moving. Gains due to mobility around childbirth grows with the number of children, suggesting that households relocate in either smaller urban areas or further from urban area centers, see Figure 12, b. This is explained by sorting mechanisms, where households who need to increase the size of their dwelling, tend to relocate in more affordable areas further away from urban area centres. Here, results could be interpreted in light of the housing market forces rather than households' preferences for higher air quality among other amenities.



(a) Gains for movers around childbirth



(b) Gains for movers around retirement

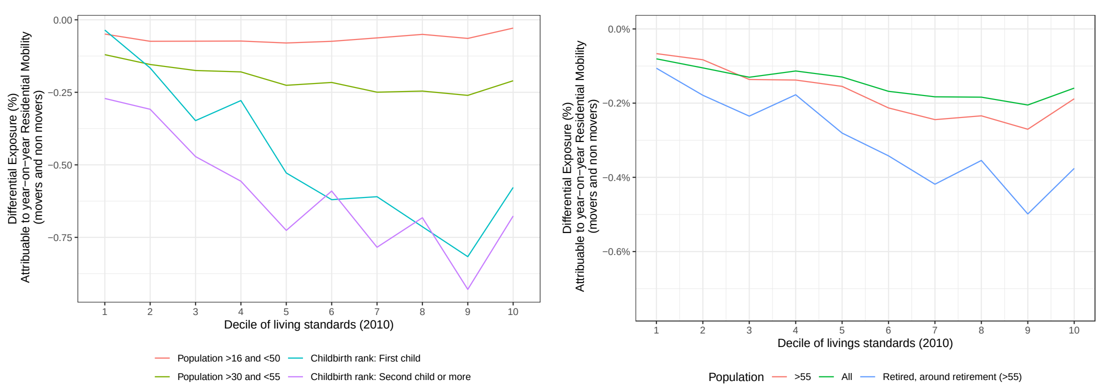
Figure 12: Differential exposure due to mobility around a childbirth or retirement event.
Note: Differential exposure are calculated on the population of movers only. Left chart (a) refer to data on households with at least one child.
Source: ACAG (Atmospheric Composition Analysis Group) and EDP (Echantillon Démographique Permanent).

Turning to the older population, the gains for retired movers are reported respectively to an exposure decrease of respectively 2.5 % for the bottom 10% and 12 % for the top 10%. Thus, mobility gains around retirement provide an additional 9.5% gain to the wealthiest. The differences in gains can be explained by the direction of migration.

[32]The former corresponds to the gains in exposure for the movers only, while the latter correspond to the change in exposure on the entire population.
[33]Gains of air quality are derived from households with at least one child.

Mobility around retirement is characterised by migration towards smaller urban areas in other words, by sorting between urban areas, Figure 21 in the Appendix. In contrast, children overexposure is tied to within sorting: parents are constrained to reside within urban areas as they trade off proximity to jobs opportunities and expanding housing size. This constraint is relaxed at retirement.

Nevertheless, when it comes to explaining inequalities for the population as a whole, mobility occurring around childbirth contributes the most to widening inequalities. The charts (a) in Figure 13 show that individuals who move around childbirth experiment higher gains, specifically the top 10% whose gain amounts to 0.7 % on a yearly basis, whereas the gain associated to retirement is equivalent to almost 0.4%. Despite higher individual gains around retirement, the change in overall inequalities attributable to mobility around childbirth is higher, as the mobility rate at retirement age is much lower than the mobility rate around childbirth, Figure 9.



(a) Gains around childbirth (b) Gains around retirement

Figure 13: Differential exposure due to residential relocation induced by retirement transition. *Note: Differential exposure are calculated on the whole population. Observed exposure is compared to the exposure that individuals would have experienced if they stay in their municipality before mobility.*
Source: ACAG (Atmospheric Composition Analysis Group) and EDP (Echantillon Démographique Permanent).

These results provide a basis for the concern that the correlation between environmental risk and vulnerable groups can be driven partially by sorting, and, in particular, the flight from the nuisance by less vulnerable groups (Depro et al., 2015). While we provide evidence that income is an important underlying driver of heterogeneity in pollution exposure, it is unlikely to be the main explanation. There could be various factors correlated with income that contribute to sorting, which we cannot disentangle, including differential amenities preferences (Banzhaf et al., 2019), or housing market (Christensen and Timmins, 2022). Individuals may combine preferences to avoid risk with changes in the implicit prices of air quality among other amenities.

5 Conclusion

Previous studies in France have mostly shown disproportionate exposure to air pollution along deprivation variables. In this analysis, we focus on the relationship between income and exposure to air pollution. We found that on average individuals experience 9.1 µg/m^3 of PM2.5 exposure in 2017, which is above the recommended threshold of 5 µg/m^3 by WHO. However, this average hides heterogeneous levels of exposure depending on income and place of residence. At the national level, the top 10% are over-exposed, because they live more frequently in the largest urban areas. But within every urban areas, the bottom 10% are exposed to a much higher exposure, as they live in the most polluted municipalities within the urban areas.

We also provide evidence on the role of selective mobility in reinforcing income inequalities in air pollution exposure over the life cycle. In general, households gain on average in terms of air pollution when they move. But the top 10% of income benefits of higher gains of air quality than the bottom 10% when moving within urban areas.

On average, the higher gain in air pollution occurs when households relocate after a childbirth. To our knowledge, this is the first paper to examine the inequalities in exposure throughout the life course focusing on the children and the elderly (i.e. the groups the most vulnerable to air pollution exposure).

These results on inequalities throughout the lifecourse can inform the literature on the human capital impacts of pollution exposure (Bentayeb et al., 2012). This literature has suggested that pollution exposure, especially in early childhood, can have large and negative impacts on vulnerable groups' health (Currie et al., 2014). In light of this literature, the overexposure of children suggests that this would increase gaps in health status, educational attainment and ultimately income inequality between bottom and top deciles.

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A Appendix A

A.1 Oaxaca-Blinder decomposition of income pollution gaps

We examine the difference between the averages of Y in two groups, in light of differences on residential location. For instance, we consider mean difference of exposure between bottom 10% and top 10% income groups. A linear relationship is modeled separately between variable P and its determinants:

$$P_i^{D1} = \sum_{u=1}^{U} \beta_u^{D1} X_{iu} + \epsilon_i^{D1}, \quad \forall i \in D_1$$

$$P_i^{D10} = \sum_{u=1}^{U} \beta_u^{D10} X_{iu} + \epsilon_i^{D10}, \quad \forall i \in D_{10}$$

where X are variables on urban area types. Based on this specification, the difference in expected pollution exposure for the bottom 10% and the top 10% can be written as:

$$\overline{P}_{D1} = \sum_{u=1}^{U} \beta_u \overline{X}_u^{D1}, \quad \overline{P}_{D10} = \sum_{u=1}^{U} \beta_u \overline{X}_u^{D10}$$

where $\overline{X}_u^{D1}$ (resp. $\overline{X}_u^{D2}$) equals p_{u,D_1} (resp. p_{u,D_2}) the proportion of individuals from the bottom 10% (resp. top 10%) who live in urban area u and β_u^{D1} (resp. β_u^{D2}) the average pollution exposure of $D1$ (resp. $D2$) in the urban area u. The mean difference in exposure between the bottom 10% and the top 10% can be decomposed into two parts, the explained part and unexplained part.

$$\bar{P}_{D_1} - \bar{P}_{D_{10}} = \underbrace{\sum_u (p_{u,D_1} - p_{u,D_{10}})\hat{\beta}_{u,D_{10}}}_{\text{Explained By Sorting Across } u} + \underbrace{\sum_u p_{u,D_1}(\hat{\beta}_{u,D_1} - \hat{\beta}_{u,D_{10}})}_{\text{Distinct Exposure Within u}}$$

B Additional Figures

Figure 14: Proportion of the sample located with each sources by year and age group (age in 2017). Source: EDP (Echantillon Démographique Permanent).

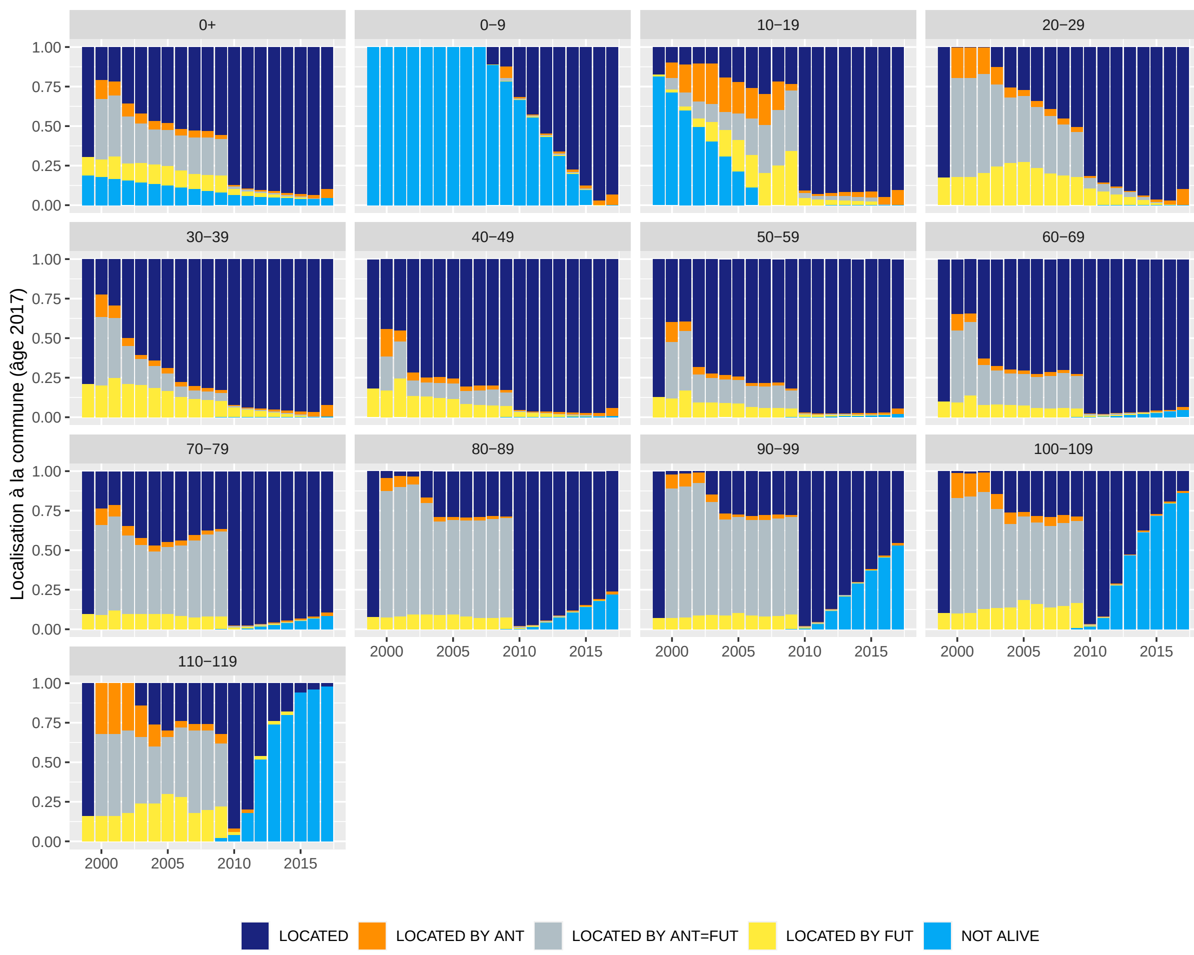

Figure 15: Proportion of the sample with known or imputed municipality of residence by year and age group (age in 2017). *Note:"LOCATED" means that the municipality is known from at least one source, "LOCATED BY ANT=FUT" means that while no sources give the municipality of residence that year, past and future municipalities are the same and we hypothesize that the individual did not move. "LOCATED BY ANT" or "BY FUT" means that the municipality of residence is imputed from the closest information, in the past or the future.*
Source: EDP (Echantillon Démographique Permanent).

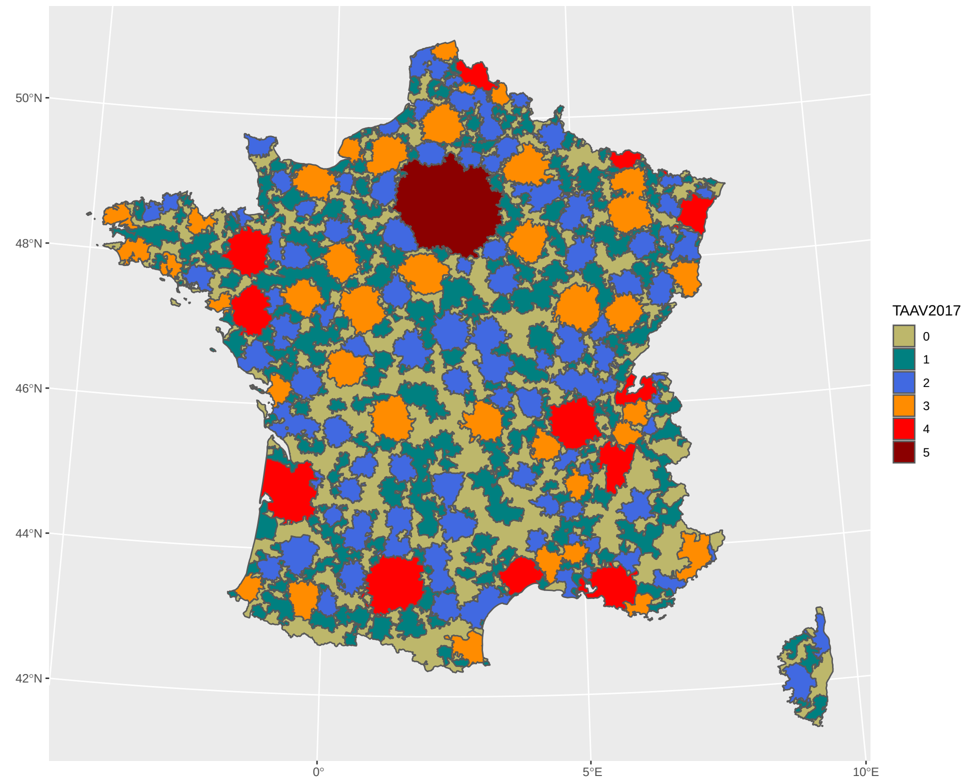

Figure 16: Urban Area Types Modalities
Source: Functional urban areas, INSEE 2020

Table 2: Share of the Exposure Gap explained with Spatial Sorting across Urban Area Types (Oaxaca Blinder Decomposition-People aged between 25 and 50 years old)

	Exposure			(i) bottom 10% - top 10%			(ii) bottom 10% - D5			(iii) D5 - top 10%		
Year	bottom 10%	D5	bottom 10%0	Gap	Exp.	Unexp.	Gap	Exp.	Unexp.	Gap	Exp.	Unexp.
2001	13.7	12.7	14.0	−0.3	−0.7	0.4	0.9	0.2	0.8	−1.2	−0.9	−0.3
2010	13.8	12.4	14.7	−0.9	−1.5	0.6	1.4	0.4	1.0	−2.3	−2.0	−0.3
2017	9.7	8.8	9.9	−0.2	−0.7	0.5	0.9	0.2	0.7	−1.1	−0.9	−0.2

Table 3: Exposure Gap explained with Spatial Sorting across Urban Area Types

	Exposure			(i) bottom 10% - top 10%			(ii) bottom 10% - D5			(iii) D5 - top 10%		
Year	bottom 10%	D5	top 10%	Gap	Exp.	Unexp.	Gap	Exp.	Unexp.	Gap	Exp.	Unexp.
Age group: 0-16 years old												
2001	14.0	12.8	14.0	0.1	−0.6	0.7	1.3	0.3	1.0	−1.2	−0.9	−0.3
2010	13.7	12.0	14.2	−0.5	−1.5	1.0	1.7	0.4	1.4	−2.2	−1.8	−0.4
2017	9.7	8.5	9.8	−0.1	−0.7	0.6	1.2	0.2	1.0	−1.3	−0.9	−0.3
Age group: between 56 and 74 years old												
2001	12.6	12.5	13.7	−1.1	−1.1	−0.01	0.03	−0.2	0.2	−1.1	−0.9	−0.3
2010	12.3	11.8	13.5	−1.1	−1.5	0.3	0.5	0.1	0.4	−1.6	−1.6	−0.1
2017	8.9	8.4	9.2	−0.3	−0.6	0.3	0.5	0.1	0.5	−0.8	−0.7	−0.1
Age group: over 75 years old												
2001	11.9	12.8	14.1	−2.2	−1.5	−0.7	−0.9	−0.6	−0.3	−1.3	−0.8	−0.5
2010	10.9	11.9	13.8	−2.8	−2.3	−0.5	−1.0	−0.6	−0.4	−1.8	−1.6	−0.2
2017	8.3	8.4	9.4	−1.1	−0.9	−0.2	−0.2	−0.2	0.01	−1.0	−0.7	−0.2

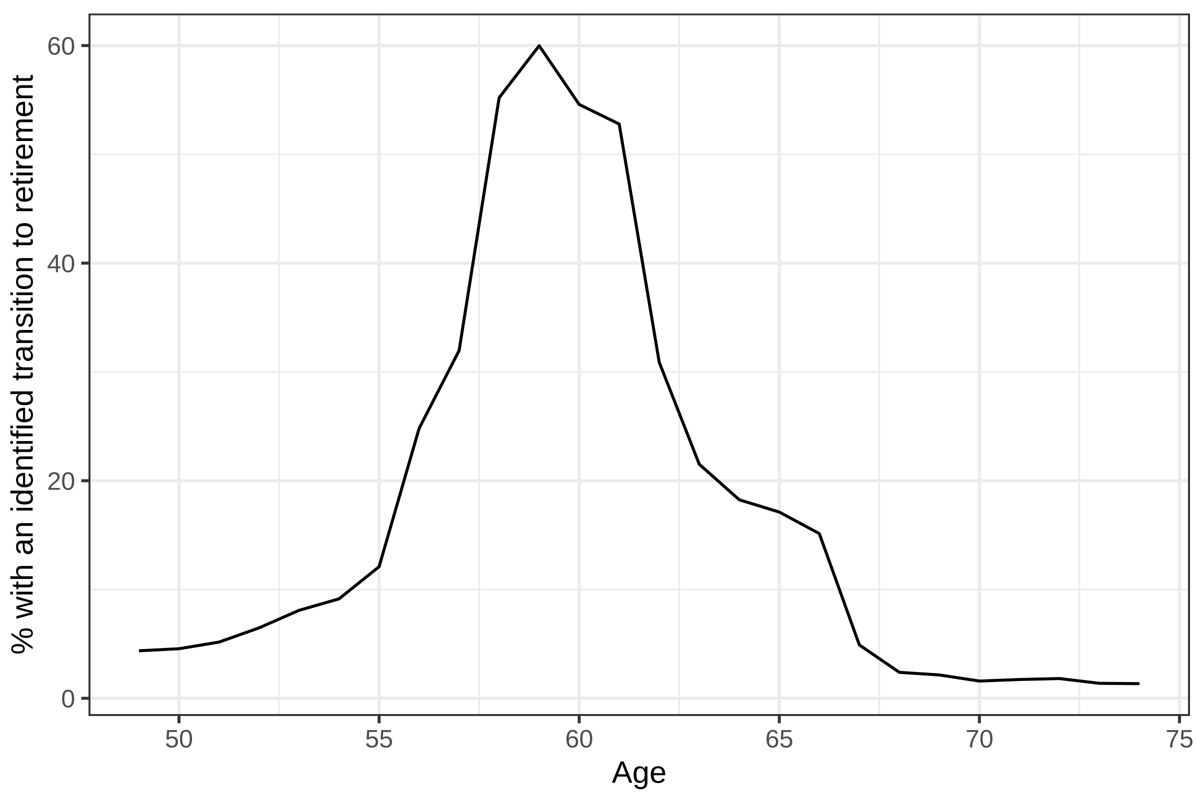

Figure 17: Proportion of the analytic sample with an identified transition to retirement from 2012 to 2017 (age in 2011).
Source: EDP (Echantillon Démographique Permanent).

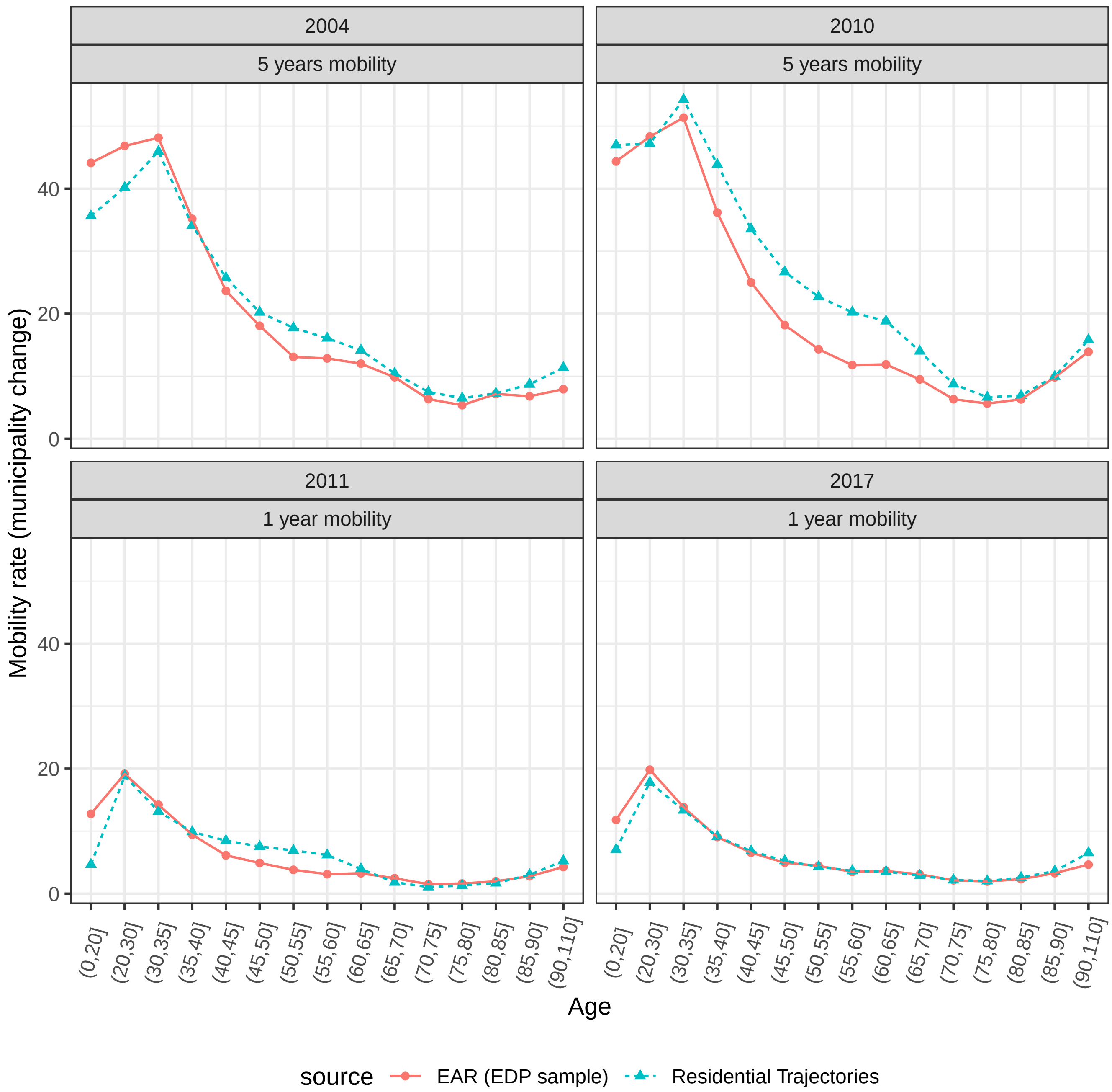

Figure 18: Comparison of mobility rates estimated from the analytic sample with those obtained from the EAR source.
Source: EDP (Echantillon Démographique Permanent).

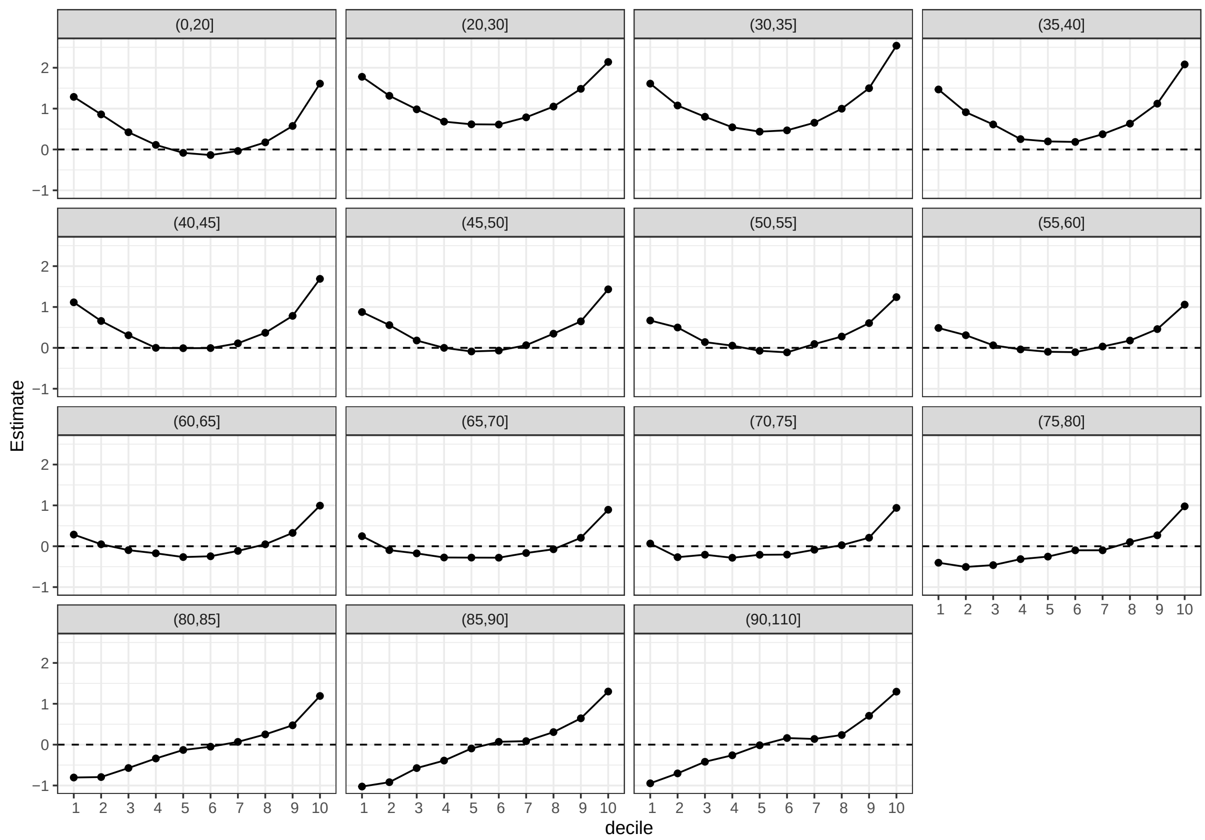

Figure 19: Exposure to PM 2.5 by age and decile groups of disposable incomes
Source: ACAG (Atmospheric Composition Analysis Group) and EDP (Echantillon Démographique Permanent).

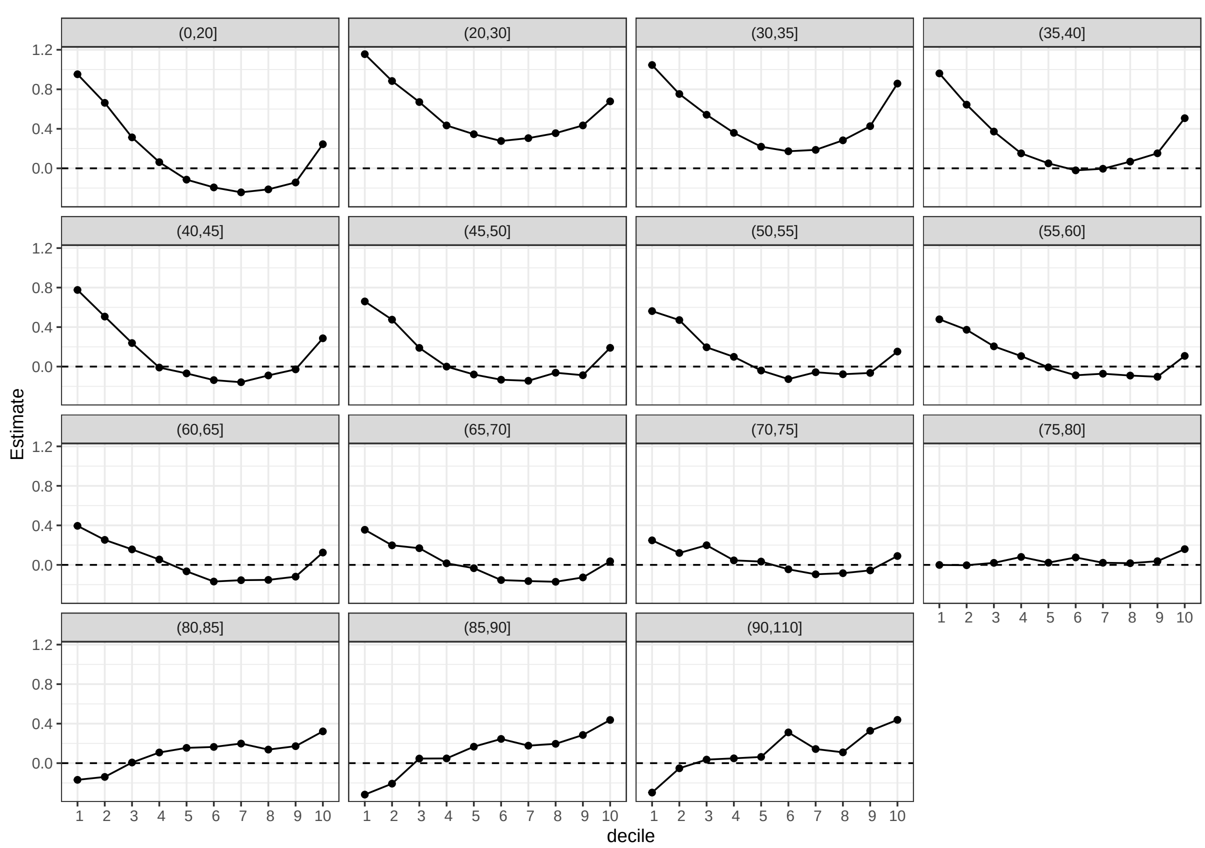

Figure 20: Exposure to PM 2.5 by age and decile groups of disposable incomes, controlling urban area types.
Source: ACAG (Atmospheric Composition Analysis Group) and EDP (Echantillon Démographique Permanent).

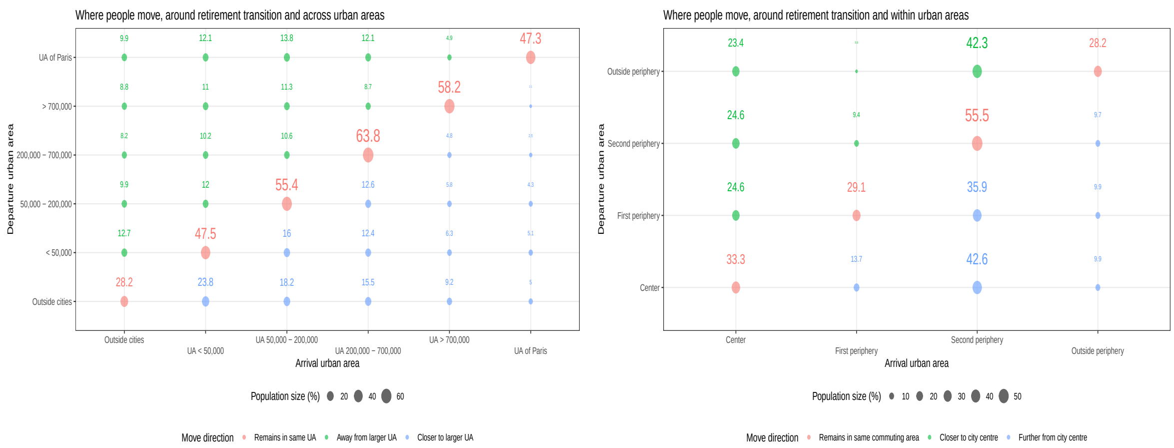

Figure 21: Matrix of departure and arrival urban areas of movers around retirement transition
Source: EDP (Echantillon Démographique Permanent)

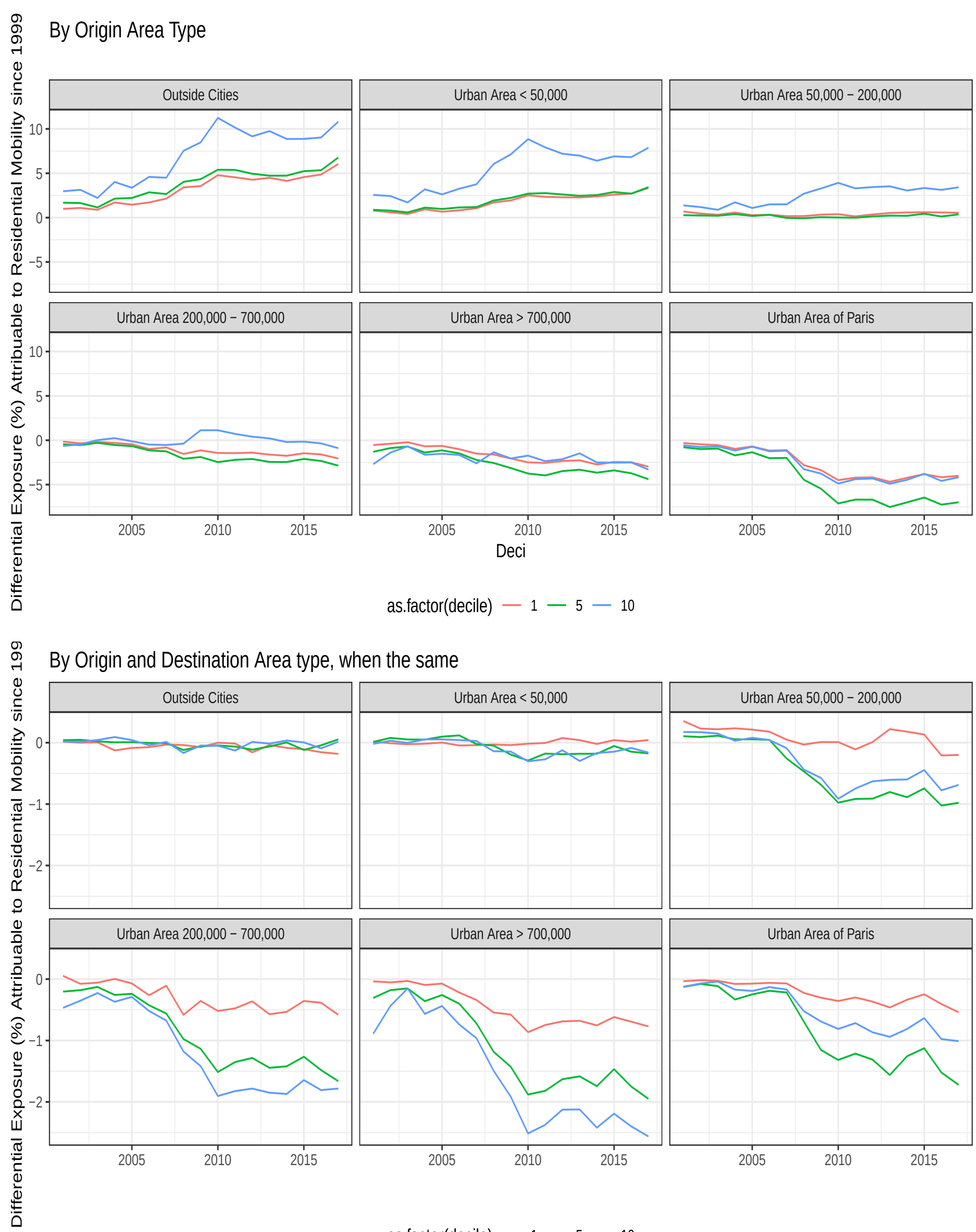

Figure 22: Differential exposure due to residential relocation by type of mobilities. *Note: Observed exposure is compared to the exposure that individuals would have experienced if they stay in their municipality before mobility.*
Source: EDP (Echantillon Démographique Permanent)

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