Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Full length Article

The role of economic structural factors in determining pandemic mortality rates: Evidence from the COVID-19 outbreak in France

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ABSTRACT

Among the majority of research on individual factors leading to coronavirus mortality, age has been identified as a dominant factor. Health and other individual factors including gender, co-morbidity, ethnicity and obesity have also been identified by other studies. In contrast, we examine the role of economic structural factors on COVID-19 mortality rates. Particularly, focusing on a densely populated region of France, we document evidence that higher economic "precariousness indicators" such as unemployment and poverty rates, lack of formal education and housing are important factors in determining COVID-19 mortality rates. Our study will help inform policy makers regarding the role of economic factors in managing pandemics.

1. Introduction

The Director General of the World Health Organization (WHO) declared the COVID-19 epidemic as a pandemic on the 11th of March 2020. By this period, more than 110 countries were already heavily affected worldwide, with approximately 120,000 confirmed cases of the coronavirus disease (WHO, 2020a). In what follows, researchers from around the World devoted their work to the study of this new virus, by mainly using three different approaches. First, a race against the clock was launched by epidemiologists to find a vaccine (Shoenfeld, 2020; Cohen, 2020; Le et al., 2020) and reach in the earliest possible delay a satisfactory level of collective immunity (Altmann et al., 2020). Second, the medical profession devoted itself to studying the effects of the virus on the health of individuals. Lastly, the majority of researchers has attempted to identify the most effective ways to staunch this global scourge. In particular, the last group of studies aim to explore the factors behind the transmission of the coronavirus (see, e.g., Li et al., 2020) and the worsening of the health situation (see, e.g., Di Lorenzo and Di Trolio, 2020). Corresponding to this group of studies, this current study, also explores the extent of the economic consequences that the health crisis has inevitably caused (McKee and Stuckler, 2020; Yue et al., 2020).

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Fig. 1. Map of Île-de-France.

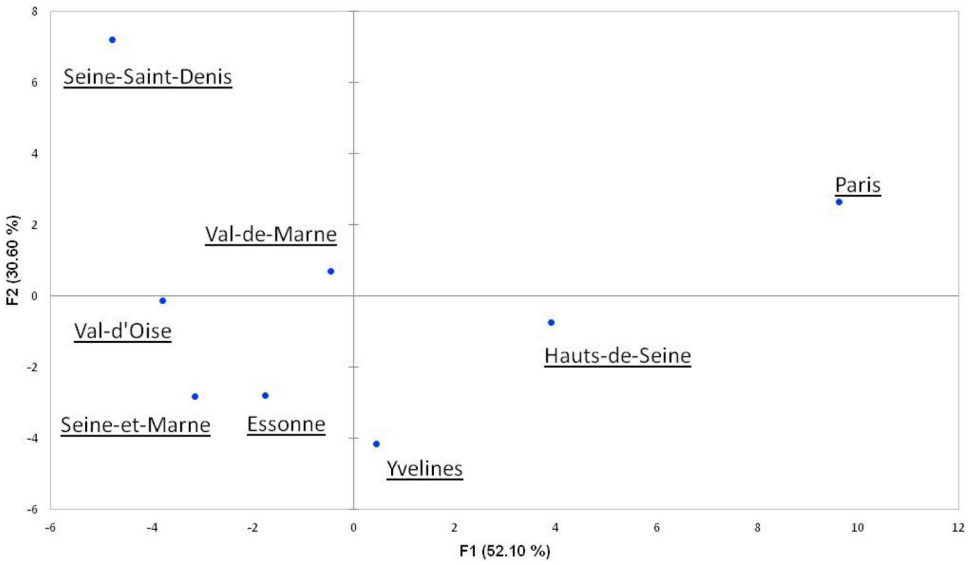

Fig. 2. Projection of IDF departments on the two main PCA axis.

The first group of studies reveals fundamental elements in understanding the COVID-19 phenomenon. These studies have demonstrated that the pandemic first started in the Chinese city of Wuhan in Hubei Province and that in the category of elderly individuals, the highest mortality rate was recorded (NHS England, 2020). These findings were quickly refined to permit a precise identification of other comorbidity factors (Bacon et al., 2020). Thus, for example, it seems very likely that patients suffering from other pathologies such as diabetes (Klonoff and Umpierrez, 2020) or asthma (Abrams and Szefler, 2020; WHO, 2020b) are more affected than healthiest patients, but also that the rhesus of the blood group and the ethnic origin of the patients (Mihm, 2020; NHS England, 2020; Hooper et al., 2020) could constitute a medical field fostering the mortality of the virus. In other words, a standard "robot portrait" of the most endangered patients of the coronavirus disease was drafted.

Furthermore, geographical studies have shown that not a single continent is sheltered[1] (Hopman et al., 2020; Gilbert et al., 2020), and that the West recorded the highest morbidity rate. The COVID-19 morbidity rate following top global ranking includes the United States of America (≥79,500 deaths), United Kingdom (≥31,900 deaths), Italy (≥30,500 deaths), Spain (≥26,600), France (≥26,300).[2] To improve the understanding of the vectors of the virus transmission as well as the morbidity factors, it seems interesting to conduct comparative studies at the three continental, regional and State levels.

However, the first observations establish that biases exist and that it therefore could be reasonable to limit comparative analyzes to territorial units with the same human and climatic characteristics (Desjardins et al., 2020; Liu et al., 2020). For example, it has

[1] It also seems that not a single country has been sheltered and that the few localities where no deaths have been recorded have chosen not to report the cases. Refer to figures from Johns Hopkins University which are widely accepted by the Global Scientific Community. Available at: https://coronavirus.jhu.edu/map.html (accessed 10 May 2020).

[2] Figures updated to May 11, 2020.

Table 1
Explication weights of each variable on the two main axis factor.

	F1	F2
Unemployment rate	0.381558	0.5903711
People 65y and more	0.700227	0.2170222
People 75y and more	0.684784	0.1869943
Aging index	0.936031	0.002343
Population density	0.697611	0.2897714
Average household size	0.959639	0.0040854
Median standard of living	0.659438	0.3188606
Share of taxed tax households	0.49332	0.488439
Share of unemployment benefits in the rev. avail.	0.24914	0.7274552
Part des prestations logement dans le rev. disp. 2016	0.343963	0.6314759
Share of social minima in rev. avail.	0.315023	0.6619699
Taux de pauvreté 2016	0.107143	0.8820404
Share of pops. with little or no diploma out of school 15 years or more	0.721121	0.2702388
Share of graduates of higher education in pop. out of school 15 years or more	0.965011	0.0075429
Share of apartments in total housing	0.556234	0.3294512
Share of houses in total housing	0.559437	0.3305705
Share of owners of their residences	0.351085	0.6040112
Share of HLM tenants in main residences	0.116735	0.518652
Share of workers in the number of jobs	0.741465	0.0183661
Activity rate by age group	0.651726	0.2236003
Public service workforce	0.670789	0.1730079
Average hourly net salary	0.85455	0.0579598
Share of admin positions, public, education, health and social action in institutions assets	0.409242	1.106E−05
General practitioner	0.780782	0.0758108
Nurses	0.564617	0.0727833
Pharmacy	0.798154	0.1077442
Elderly accommodation	0.807258	0.0102245
Nursery	0.911818	0.0793671
Pôle emploi	0.094789	0.0435737
Infant school	0.191453	0.0657052
Elementary school	0.058083	0.1342393
Middle school	0.344103	0.2657882
High school	0.662656	0.1517911
Emergency service	0.683236	0.0466165
Number of main residences overcrowded part (%)	0.017171	0.9595219
Population living in apartments part (%)	0.570496	0.3373785
People living in an apartment in a household of at least 4 people	0.141567	0.828304
Share of private park accommodation potentially unworthy (PPPI) – Source Dhrill	0.045632	0.9143809

Table 2
Projection of IDF departments on the two main PCA axis.

	F1	F2
Paris	9.605195	2.654331
Seine-et-Marne	−3.14978	−2.797914
Yvelines	0.442294	−4.153429
Essonne	−1.7583	−2.790276
Hauts-de-Seine	3.911152	−0.734134
Seine-Saint-Denis	−4.79127	7.2151162
Val-de-Marne	−0.45865	0.7085487
Val-d'Oise	−3.80063	−0.102243

been observed that in Sub-Saharan Africa, the contamination and transmission rates are extremely lower relative to countries in the North and West of the Globe (Martinez-Alvarez et al., 2020; Nuwagira and Muzoora, 2020). The positive effects of various factors including the protective role of previous injections of Malaria vaccine on populations exposed to COVID-19 have been explored (Sargin and Yavasoglu, 2020). Moreover, the global death reports indicate that the number of national deaths appears to vary largely. Some countries report exclusively deaths in hospitals (like France at the early stage of the pandemic) while others merge deaths in hospital, domestic and nursing homes (like Germany). Accordingly, an international study seems to be unrealistic at the moment.

Unlike previous papers focusing on human factors, our study proposes an approach to explore the structural factors of contamination, contagion and mortality of COVID-19. Indeed, in addition to genetics and geography, we aim to explore new elements that may be put forward to explain the excess mortality in certain populations. To do this, we limit our study to Île-de-France. As shown in Fig. 1, the Île-de-France is a French region which includes eight departments,[3] which has the unique characteristic of not constituting a cluster of contamination due to an identifiable and outstanding event.

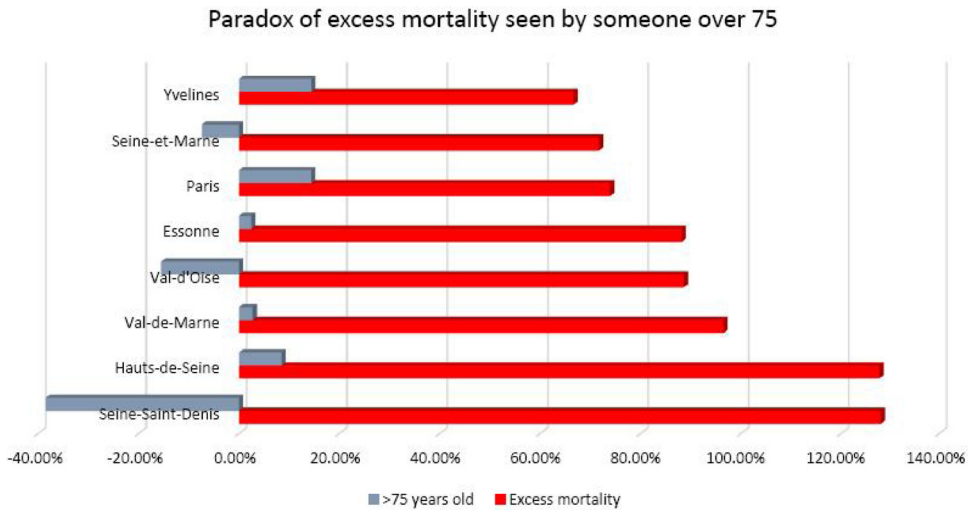

Fig. 3. Link between age and excess mortality.

Table 3
Economic, social and financial variables.

	Unemployment benefit in income	Poverty rate	Social minima in income	Little or no graduate in the workforce
Seine-Saint-Denis	39.13%	84.07%	118.18%	46.12%
Paris	−5.14%	1.69%	−27.27%	−30.97%
Seine-et-Marne	−5.14%	−25.34%	−7.44%	5.85%
Yvelines	−14.62%	−37.57%	−47.11%	−15.24%
Essonne	−8.30%	−16.98%	−14.05%	−0.29%
Hauts-de-Seine	−11.46%	−21.48%	−33.88%	−21.76%
Val-de-Marne	−1.98%	7.48%	5.79%	4.70%
Val-d'Oise	7.51%	8.13%	5.79%	11.60%

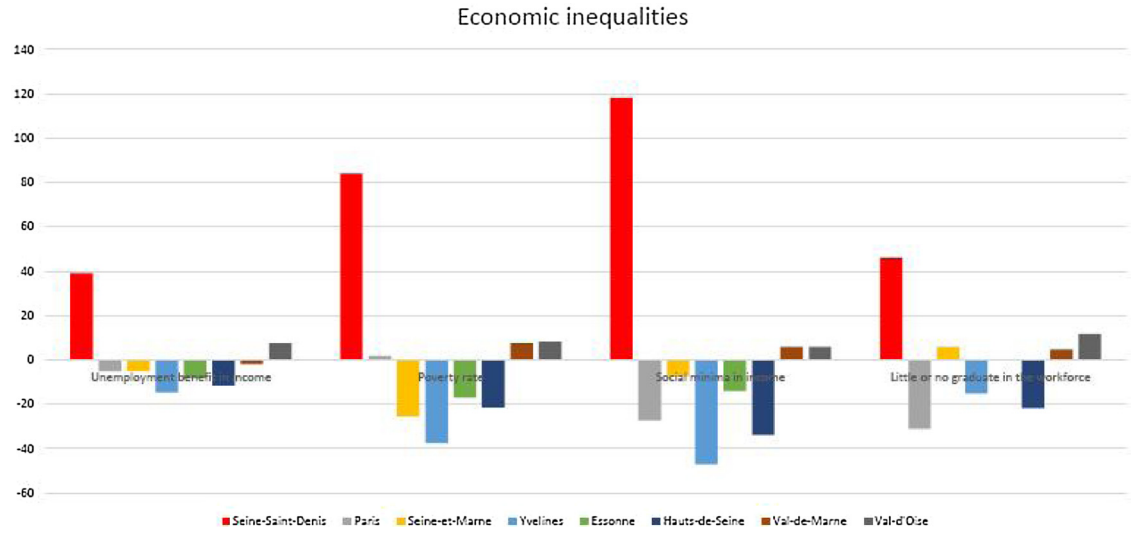

Fig. 4. Economic inequalities.

Indeed, certain territorial units have formed clusters of contamination largely responsible for the degree of contamination at the National level. For example, in the French city of Mulhouse belonging to the Grand Est region, a major gathering of faithful

[3] In France, administrative levels in order of importance (ascending order) are municipalities/agglomerations (35,357 units), departments (101 units) and regions (18 units).

Table 4
Housing variables.

	Potentially unworthy housing	Household size	Overcrowded housing
Seine-Saint-Denis	104.78%	9.47%	68.16%
Paris	77.47%	−20.00%	29.80%
Seine-et-Marne	−37.20%	5.26%	−38.78%
Yvelines	−64.51%	1.05%	−40.41%
Essonne	−72.70%	5.26%	−28.98%
Hauts-de-Seine	−4.44%	−7.37%	6.12%
Val-de-Marne	−1.71%	−3.16%	11.84%
Val-d'Oise	−1.71%	9.47%	−7.76%

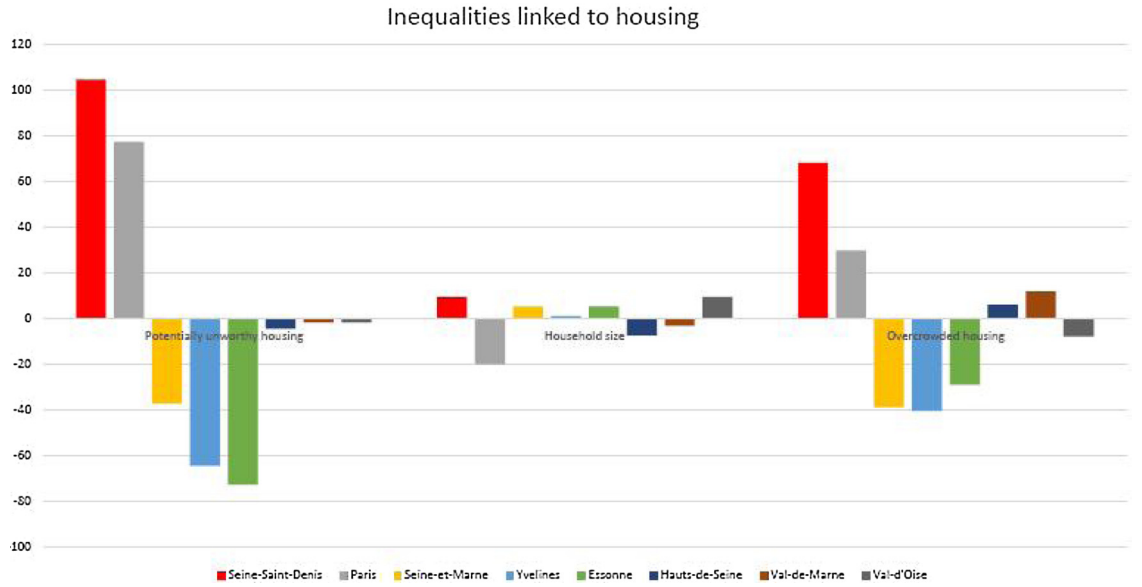

Fig. 5. Inequalities linked to housing.

Table 5
Values of the delta percentage of our panel of data for each department – Part I.

Departments	Excess mortality	0 → 19yrs	20 → 39yrs	40 → 59yrs	60 → 74yrs	≥75yrs
Paris	73.90%	−37.41%	18.28%	−4.97%	7.17%	14.38%
Seine-et-Marne	71.70%	5.55%	−8,82%	2,29%	3.93%	−7.41%
Yvelines	66.60%	2.34%	−15.93%	3.63%	6.78%	14.38%
Essonne	88.20%	4.76%	−6.47%	0.98%	−0.54%	2.45%
Hauts-de-Seine	127.80%	−6.54%	3.56%	1.31%	−3.09%	8.48%
Seine-Saint-Denis	128.10%	10.44%	4.51%	−2.28%	−15.50%	−38.51%
Val-de-Marne	96.50%	−1.70%	1.44%	−0.13%	−0.93%	2.71%
Val-d'Oise	88.60%	9.18%	−4.52%	−1.36%	−1.22%	−15.54%

evangelists is considered to be responsible for a non-negligible part of the whole excess mortality linked to COVID-19 among the State. In addition, the Île-de-France region is highly populated with 12,174,880 million inhabitants (19% of the whole French population) and is socially heterogeneous in terms of ethnicity, professional qualification of workers, graduate of higher education and quality of the health system, etc. However, its boarders stand inside a small geographic area with no climatic ecosystems effects. Under these conditions, Île-de-France constitutes a relevant field of study for the various structural factors other than individual ones like age or comorbidities promoting the contamination, contagion and mortality rates of COVID-19.

2. Data and approach

The INSEE collects, analyses and disseminates information on the French economy and society. We start with a large panel of 66 variables,[4] which are representative of the economic, financial or structural factors relating to housing in Île-de-France and its population. Then, using the principal component analysis (PCA), we select a closer panel of 30 variables which appear to be very

Table 6
Values of the delta percentage of our panel of data for each department – Part II.

	2019-Q4 quarterly unemployment rate	Population density	Average household size	Median of standard of living	Share of taxable households	Share of unemployment benefits in disposable income
Paris	−14.04%	270.31%	−20.00%	15.85%	8.98%	−5.14%
Seine-et-Marne	−7.11%	−95.79%	5.26%	−2.43%	−1.78%	−5.14%
Yvelines	−14.04%	−88.83%	1.05%	11.60%	10.40%	−14.62%
Essonne	−9.88%	−87.29%	5.26%	−0.06%	2.81%	−8.30%
Hauts-de-Seine	−12.65%	62.69%	−7.37%	14.83%	10.72%	−11.46%
Seine-Saint-Denis	44.19%	21.21%	9.47%	−26.55%	−24.40%	39.13%
Val-de-Marne	−0.17%	0.22%	−3.16%	−5.11%	−1.46%	−1.98%
Val-d'Oise	13.69%	−82.52%	9.47%	−8.13%	−5.26%	7.51%

significant in terms of segmentation of the departments in Île-de-France, and particularly Seine-Saint-Denis.

2.1. Principal components analysis

Thus, in order to characterize the best set of discriminant variables, we proceed with a principal component analysis. This approach allows us to best capture the explanatory and segmenting power of the available variables. Fig. 2 shows the best representation (projection) in two dimensions of the 8 departments regarding the set of available variables. We see clearly that the department of Seine-Saint-Denis is far away from the others (in the upper left position), which argues in favor of a significant difference in terms of values of the variables from other departments in Île-de-France. Consequently, this proves that an examination of the specificities of these departments is useful and relevant in understanding and explaining the reasons and factors which brought to the excess COVID-19 mortality in Seine-Saint-Denis. More so, we can see that the most distant and therefore different departments with respect to Seine-Saint-Denis are Paris and Hauts-de-Seine.

To offer a deeper analysis of this segmentation, we take a look on the weight of each variable as represented by each of the two axis. These results are provided in Table 1. We can see that a positive value on the first axis (i.e. horizontal) characterizes the following:

- A high share of graduates of higher education in population out of school 15 years or more at a level of 96.50%;
- Average household size at a level of 95.96%;
- A high value of the aging index at a level of 93.60%;
- A high average hourly net salary at a level of 85.45%.

This suggests that a department with a high coordinate in Factor 1 exhibits all these points and that higher is its coordinate in these factors. The projection of IDF departments on these two main PCA axis are presented in Table 2.

The departments of Paris and Hauts-de-Seine which take a high value in this axis projection are so fundamentally and intrinsically characterized and determined by a population with a high level of education, with a higher salary than the other departments and also an older population. This last factor is, of course, the main reason why the mortality rates are important in both departments.

Conversely, the Seine-Saint-Denis department which takes the most negative value in this projection is largely characterized by a younger population with a lower level of education and a medium value of salary at the end. But, as we showed previously, its mortality rate due to COVID-19 is the highest. Furthermore, we consider the second axis (i.e. vertical) given that the Seine-Saint-Denis appears to be also isolated from other departments in the upper region (i.e. positive values).

Here, we can see that a positive value in this factor characterizes the following:

- A high number of main residences overcrowded at a level of 96.00%;
- A high share of private park accommodation potentially unworthy (PPPI) at a level of 91.44%;
- A high number of people living in an apartment as a household of at least 4 people at a level of 88.83%;
- A high poverty rate at a level of 88.20%;
- A high value of share of unemployment benefits in the revenue available at a level of 72.74%.

This implies that Seine-Saint-Denis is highlighted by very difficult economic and health conditions, overcrowded housing potentially unworthy, a low-income population, and mostly from income linked to unemployment benefits. Hence, these socio-economic conditions cause a higher mortality rate in the period of COVID-19 pandemic.

[4] Taken from the French statistical database of The National Institute of Statistics and Economic Studies (INSEE).

Table 7
Values of the delta percentage of our panel of data for each department – Part III.

	Share of social minima in disposable income	Poverty rate	Share of those with little or no education in the out-of-school population aged 15 and over	Share of higher education graduates in the out-of-school population of 15 years or more	Share of apartments in total housing	Share of houses in total housing
Paris	−27.27%	1.69%	−30.97%	52.54%	44.56%	−97.14%
Seine-et-Marne	−7.44%	−25.34%	5.85%	−25.87%	−39.52%	84.59%
Yvelines	−47.11%	−37.57%	−15.24%	10.18%	−16.22%	35.35%
Essonne	−14.05%	−16.98%	−0.29%	−10.75%	−22.49%	49.01%
Hauts-de-Seine	−33.88%	−21.48%	−21.76%	31.61%	29.62%	−63.15%
Seine-Saint-Denis	118.18%	84.07%	46.12%	−33.69%	10.51%	−22.48%
Val-de-Marne	5.79%	7.48%	4.70%	−2.43%	13.50%	−29.47%
Val-d'Oise	5.79%	8.13%	11.60%	−21.59%	−19.96%	43.29%

Table 8
Values of the delta percentage of our panel of data for each department – Part IV.

	Share of workers in the number of jobs	Average hourly net wages	Share of public administration, education, health and social work	General practitioner 2018	Nurse	Pharmacy
Paris	−37.74%	28.90%	−9.94%	116.64%	126.70%	114.95%
Seine-et-Marne	39.25%	−14.55%	6.47%	−15.67%	−1.90%	−23.91%
Yvelines	−4.27%	14.69%	−0.09%	−9,61%	−24.89%	−15.39%
Essonne	11.80%	−8.35%	8.30%	−26.61%	−12.76%	−27.05%
Hauts-de-Seine	−47.11%	24.93%	−38.38%	1.67%	−24.71%	4.98%
Seine-Saint-Denis	12.47%	−25.12%	4.65%	−16.09%	−17.10%	−14.28%
Val-de-Marne	1.76%	−6.78%	12.31%	−21.39%	−28.24%	−12.43%
Val-d'Oise	23.85%	−13.71%	16.68%	−28.96%	−17.10%	−26.87%

3. Results

The list of these variables is presented in Tables 5–9 in the Appendix part. To compare the values of these set of variables we decided to evaluate the variation in percentage of each value for each department with respect to the average of the Île-de-France region. This implies that a value of 10% in a Table suggests that a department has a value 10 % higher than the average of all departments in the Ile de France region.

Our study provides interesting results. First, we note in Fig. 3 that the link between the population over age of 75 and excess mortality is not absolute. Two departments with the highest population deltas over age of 75, Paris (+14.38%) and Yvelines (+14.38%), are among the departments with the lowest excess mortality (respectively +73,90% and +66.60%). Conversely, while Seine-Saint-Denis department displays the lowest delta on the population over 75 (−38.51%), it shows the highest excess mortality (+128.10%). Theoretically, the standard observation would have been the opposite. The high mortality rate observed among people over 75 years in France, representing 78.3% of deaths with an average age of 81.2 (Santé Publique France, 2020), should have led to a negative ranking on such departments. The Val-d'Oise is also a department with a negative delta regarding the population over 75 years old (−15.54%) but with the fourth excess mortality in Île-de-France (+88.6%). Seine-et-Marne department has also a smaller population of over 75 (−7.41%) associated to an excess mortality rate of +71.70%.

Furthermore, our study allows us to identify a broader number of factors. Firstly, we analyze the specificity of each department with a significant excess mortality despite its more advantageous demography compared to others. Secondly, using economic, social and financial variables that can reveal the insecurity of department populations, such as unemployment benefits, poverty rate, minimum social benefits or level of education, and other variables specific to the structure of housing, we offer a chance to implement tailor-made structural policies. For instance, in regard to unemployment benefit income, we observe that Seine-Saint-Denis and Val-d'Oise are the only departments to have a positive delta with +39.13% and +7.51% respectively, as presented in Table 3, with a very clear demarcation for Seine-Saint-Denis (see Fig. 4). Among the cluster, all the other departments have negative deltas (see unemployment benefit income in Fig. 4).

With respect to the poverty rate using the same observation, four departments have positive deltas with a clear demarcation of the Seine-Saint-Denis (+84.07%), Val-d'Oise (+8.12%) and Val-de-Marne (+7.48%) (see poverty rate in Fig. 4). We find similar result at the observation of social minima where three departments including Seine-Saint-Denis, Val-d'Oise and Val-de-Marne have positive deltas with a clear demarcation for Seine-Saint-Denis (+118.20%), Val-d'Oise and Val-de-Marne tied (+5.79%) (see Social minima in income in Fig. 4). Finally, in regard to the share of individuals without diploma into the workforce, Seine-Saint-Denis still occupies the first place with a delta of +46.12% compared to the average of the cohort. It is followed by Val-d'Oise (+11.60%), Seine-et-Marne (5.84%) and Val-de-Marne (+4.69%) (see the "little or no graduate in the workforce" item in Fig. 4).

Based on the analysis of economic and financial variables, the first conclusion that can be drawn is that there are several common points between Seine-Saint-Denis and Val-d'Oise. These are two departments with a smaller population of 75+ but with significant excess mortality, despite social distancing measures implemented by the French Government. Indeed, following the promulgation of the Law 2020-290 of March 23, 2020 code-named "Emergency to face the epidemic of COVID-19", extended by the Law 2020-546 of May 11, 2020,[5] the French Government is authorized to rule into legislative matters by decree when it concerns the fight against COVID-19 epidemic in France.

In addition, regarding inequalities relating to the structure of housing, with particular reference to unworthy housing, the two departments with positive deltas are Seine-Saint-Denis (+104.77%) and Paris (+77.47%) (see "Potentially unworthy housing" in Fig. 5). For the average size of households, five departments have a positive delta: Seine-Saint-Denis (+9.47%), Seine-et-Marne (+5.26%), Yvelines (+1.05%), Essonne (+5.26%) and Val-d'Oise (+9.47%) (see "Household size" in Fig. 5). Finally, regarding the variable "overcrowded main residences", four departments have positive deltas including Seine-Saint-Denis (+68.16%), Paris (+29.79%), Hauts-de-Seine (+6.12%) and Val-de-Marne (+11.83%), with a delta far above that of Seine-Saint-Denis (see "Overcrowded housing" in Fig. 5).

[5] Refer to https://www.legifrance.gouv.fr/.

Table 9
Values of the delta percentage of our panel of data for each department – Part V.

	Elderly accommodation	Emergency service	No. of overcrowded main residences	Population living in apartment	People living in apartments in a household of at least 4 people	Share of housing in the potentially unworthy private housing stock (PPPI) – Source Dhrill
Paris	52.58%	34.74%	29.80%	53.73%	60.00%	77.47%
Seine-et-Marne	2.41%	−7.37%	−38.78%	−44.59%	−25.33%	−37.20%
Yvelines	−6.53%	1.05%	−40.41%	−20.36%	−49.71%	−64.51%
Essonne	4.47%	1.05%	−28.98%	−25.11%	−29.90%	−72.70%
Hauts-de-Seine	10.65%	9.47%	6.12%	32.52%	0.57%	−4.44%
Seine-Saint-Denis	−27.15%	1.05%	68.16%	11.78%	53.90%	104.78%
Val-de-Marne	−14.78%	−15.79%	11.84%	14.47%	8.19%	−1.71%
Val-d'Oise	−21.65%	−24.21%	−7.76%	−22.42%	−17.71%	−1.71%

4. Conclusion and opening to future work

Seine-Saint-Denis differs from other departments in Île-de-France when grouped according to a number of important variables. On one hand, these variables relate to the main field of financial economic poverty while on the other, there are structural factors relating to housing. These variables shed light on the excess mortality during social distancing and lockdown policies implemented by the French Government. Six of these seven variables are also significant in Val-d'Oise, another department which, like Seine-Saint-Denis, has a significant excess mortality with a lower proportion of people over the age of 75. Thus, our study provides political leaders with a number of inputs which allows them to better implement effective measures in the event of a second wave of COVID-19 or new pandemics due to viruses within the COVID-19 family.

Territorial units with higher precariousness indicators (unemployment benefit income, poverty rate, social minima in income, little or no graduate in the workforce) and less suitable housing (unworthy housing, household size, overcrowded housing) are more at risk, including when their population is younger. Therefore, it is a requirement to set up new health policies facilitating an accurate monitoring of the inhabitants and their environment in these departments or agglomerations, with the main objective of breaking human-to-human transmission chains more quickly and efficiently. Regarding future studies, it would be interesting to corroborate the results obtained from this study with evidences from other countries and other continents regarding the analysis of structural factors and mortality rates during pandemics.

Conflict of interest

The authors declare that there is no conflict of interest.

Appendix

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