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Estimating the association between social frontiers and neighbourhood depression rates in England

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Abstract

Social frontiers – abrupt borders between communities – may heighten territorial and defensive behaviour, reduce opportunities for positive contact between groups, and exacerbate the sense of outgroup threat, resulting in a negative impact on mental health for residents living in neighbourhoods bounded by social frontiers. Previous research on the links between residential segregation and mental health has largely ignored the effect of social frontiers. To study the association between social frontiers and mental health we link Place Based Longitudinal Data Resource data on the numbers of depression diagnoses and antidepressant drugs prescribed by GPs with estimates of ethnic and religious social frontiers produced from the 2011 and 2021 Census for all Lower Super Output Areas in England. These estimates are produced from spatial binomial / Poisson models that allow for spatial autocorrelation via a simultaneous autoregressive (SAR) type structure. We find strong and consistent evidence of an association between the prevalence of mental health problems at the neighbourhood level (Lower Super Output Areas) in England and the intensity of social frontiers for particular ethnic (Chinese, Indian, Pakistani, White British) and religious (Hindu, Jewish, Muslim) groups. For example, in 2021 depression rates were between 1% and 67% higher for every 10% point increase in the intensity of social frontiers between Pakistani and non-Pakistani residents. Living in an area segregated by social frontiers is potentially detrimental to mental health. These results demonstrate the importance of understanding the role of community boundaries when considering the links between segregation and wellbeing.

Introduction

Social frontiers – abrupt transitions between neighbourhoods in social, ethnic or religious mix – have emerged as a previously overlooked but important aspect of residential segregation (Dean et al. 2019; Piekut et al. 2019; Pryce 2021; Křížková et al. 2021). The lack of residential mixing along the boundaries between residential groups has been shown to affect crime rates (Legewie and Schaeffer 2016; Dean et al. 2019), residential mobility (Olner et al. 2024), and housing discrimination (Binner et al. 2024).

Despite these findings, the potential mental health consequences of living near social frontiers remain largely overlooked in empirical research. The only study we are aware of focuses on Peace Walls in Northern Ireland (Maguire et al. 2016). It finds large and statistically significant negative associations with the take-up of anti-anxiety and antidepressant medications. However, it is unclear whether these findings can be generalised beyond the unique context of Northern Ireland to 'invisible' frontiers – unfortified neighbourhood boundaries prevalent in UK, European and North American cities (Dean et al. 2019; Křížková et al. 2021; Legewie and Schaeffer 2016; Legewie 2018).

The broader literature exploring the link between residential segregation and mental health has yielded somewhat ambiguous results (Mair et al. 2008). This may be because of the focus on the overall distribution of ethnic groups (typically measured using the index of dissimilarity, D) and the failure to control for the potentially important effects of social frontiers. Kramer (2017, p.2), for example, lamented how 'empirical research on neighbourhood boundary making is practically non-existent'. This omission is important because measures such as D do not capture the prevalence of social frontiers (see Supplementary Material). By examining what happens where neighbourhoods border, we aim to shed new light on the association between segregation and mental health.

The link between social frontiers and mental health

In the present study, we hypothesise that social frontiers will have a negative association with mental health. Various theoretical perspectives support this. Social frontiers represent a lack of residential mixing at the interface of contrasting residential communities, reducing the opportunity for positive contact between groups (Iyer and Pryce, 2024) which is recognised as a key mechanism in reducing bias and improving intergroup attitudes (Allport 1954; Pettigrew 2008; Pettigrew and Tropp 2008; Lemmer and Wagner 2015). There are also *territoriality effects*. Because social frontiers provide a clear demarcation of ingroup and outgroup residential territories, they are more likely to evoke territorial behaviour than blurred or ambiguous boundaries (Sack 1983; Iyer and Pryce 2024), which is likely to sour the limited opportunities for intergroup contact.

Moreover, social frontiers suggest "an absence or shortage of 'bridgebuilders'– those willing to live at the interface between communities" and who "cushion inter-group tensions" (Dean et al. 2019, p.265). The absence of the buffering effect provided by *bridgebuilders* may exacerbate divisions and further limit opportunities for intergroup contact.

Such divisions will likely generate *selection effects.* The emergence of social frontiers suggests an aversion to living near the outgroup. As a result, there will be lower housing demand and lower house prices near the frontier. This means that low-income households are likely to be selected into these areas, either by the market ("coming to the nuisance", Depro et al. 2015, p.439), or as a result of social housing allocations (Manley and van Ham 2011). The concentration of low income households near social frontiers may heighten the sense of scarcity and competition for resources, and anxiety stemming from outgroup threat (Esses et al. 2001; Iyer and Pryce 2024).

Finally, social frontiers may attract *protests and political messaging* as activists seek to exploit their ready symbolism. As a result, social frontiers may become preferred locations for demonstrations, marches and acts of terrorism or intimidation (Iyer and Pryce 2024). This will further exacerbate the sense of insecurity, intrusion and stress for those living in frontier communities.

In summary, there are good theoretical reasons to believe that social frontiers allow the negative mechanisms that sour intergroup relations to flourish, while preventing the positive mechanisms associated with intergroup contact from emerging.

In this paper we present the first empirical evidence on the association between mental health outcomes and social frontiers at the small area level in England. Specifically, we examine whether the prevalence of mental health problems is higher in small areas that are bounded by social frontiers.

Methods

Study design

We report on an ecological small-area study set in mainland England (excluding the isles of Wight and Scilly) for the last two census years of 2011 and 2021. Separate analyses are conducted for each year to assess the robustness of the results. England is partitioned into N=32,754 Lower Super Output Areas (LSOA), which have an average population of 1,600 individuals. To address boundary changes a common set of LSOAs based on the 2011 census are used for both time periods.

Mental health outcomes

Data on the prevalence of population-level mental health is obtained from the Place Based Longitudinal Data Resource (https://pldr.org/), and is restricted to individuals who are registered with a GP surgery. Disease prevalence is measured in two ways, which allows the robustness of our results to be assessed. The first is the percentage of the population in each LSOA that has a doctor diagnosis of depression (obtained since April 2006), while the second is the number of antidepressants prescribed to people living in each LSOA in a year. Note that antidepressants are a useful complement to the depression rate measure because they are prescribed not only for depression but also for other conditions that may be triggered or exacerbated by the stresses of living near social frontiers (e.g. anxiety disorders, OCD, eating disorders, migraines, chronic headaches and bedwetting in children). The list of antidepressants included in the second outcome are given with the data.

Social frontiers

Social frontiers represent locations where there are large differences between the populations living in geographically neighbouring LSOAs, which contradicts Tobler's first law of geography ("Everything is related to everything else, but near things are more related than distant things," Tobler 1970). We measure the sizes of ethnicity and religious social frontiers between each pair of neighbouring LSOAs in this study, using data on the percentages of the population who are: **Ethnicity -** (i) African; (ii) Caribbean; (iii) Chinese; (iv) Indian; (v) Pakistani; (vi) Bangladeshi; and (vii) White British; and **Religion -** (i) Christian; (ii) Hindu; (iii) Jewish; (iv) Muslim; and (v) none. Specifically, for each of the above groups we compute the absolute difference in the percentages between each pair of neighbouring LSOAs. Then, we measure the overall size of the social frontier surrounding each LSOA by either: (a) mean frontier size; or (b) maximum frontier size; across all its geographical neighbours (those sharing a common border).

Confounders

To accurately estimate the association between the prevalence of poor mental health and social frontiers, we need to account for confounding in the modelling process. The first set of confounders relate to demography, and include the percentages of the population in each LSOA who are female or who are in the following age groups: 16-24, 25-34, 35-44, 45-54, 55-64, 65-74, 75+ (the age groups used in the literature chosen by McManus et al. (2016) to report depression rates in England). Additionally, we include the percentages of the population who are in the set of ethnic and religious groups listed in the Social Frontiers subsection above as possible confounders (Nazroo 2003). The second set of confounders relate to household composition, specifically: (i) the percentage of single person households; and (ii) the percentage of households with dependent children. These variables are included because living alone may increase loneliness and hence poor mental health. Additionally, we also consider the population density in each LSOA (the number of people per km^2), because more densely populated LSOA have less individual space and would likely be more at risk from antisocial behaviour such as noise pollution from neighbours (MacCutcheon 2021).

The final set of confounders are measures of socio-economic deprivation. These are included because the link between poverty and mental health is well known (Propper et al. 2005). In England, LSOA-level socio-economic deprivation is measured by the English Index of Multiple Deprivation (IMD), which is a composite index comprising scores in the domains of: crime, education, environment, employment, health, housing and income. The health domain is removed because the outcome variable is health related, resulting in 6 variables for inclusion in the models. These IMD scores relate to the closest years to the censuses with matching LSOA definitions, which are 2015 and 2019 respectively. Finally, median annual property price is considered as a possible confounder, because the above measures of socio-economic deprivation measure the level of poverty rather than affluence, i.e., they can struggle to distinguish between moderately affluent and very affluent. A small number of LSOAs (around 1%) had missing property price values, which were imputed by spatio-temporal averaging of neighbouring data values.

Statistical models

The depression and antidepressant outcomes are modelled separately to each other and separately for each census year, resulting in four sets of model results. Both outcomes take

the form of counts, of the numbers of depression diagnoses or antidepressants prescribed for the population living in each LSOA. In the case of depression diagnoses each individual can only be diagnosed once or not at all. Hence, a binomial logistic regression model is appropriate for this outcome. In contrast, for the antidepressants outcome a Poisson log-linear model is appropriate, because each individual may have been prescribed multiple courses of antidepressants within the year and thus does not constitute a Bernoulli trial.

Initially, over-dispersed versions of these regression models are fitted to the data to allow the variance to be greater than that specified by the binomial or Poisson assumptions, which is achieved using maximum quasi-likelihood estimation (McCullagh and Nelder 1989). These models assume the residuals are independent, which as evidenced by Moran's I statistics (Moran 1950) is not the case. Therefore the models are re-fitted allowing for spatial autocorrelation, which is accounted for by a simultaneous autoregressive (SAR) type structure (Lee and Neocleous 2010). For a review of SAR type models see Haining and Li (2020). In the case of the binomial model (depression outcomes) the average spatial lag of the logit raw proportions is included as a covariate, while for the Poisson model (antidepressant outcomes) the log raw rate is spatially lagged instead. In both cases the spatial lag is computed based on the 6 nearest neighbours in terms of inter-centroidal distance, with 6 being chosen because it matches the average number of neighbours from the border sharing rule. Note, border sharing was not used to construct the spatial lagged variables because it results in boundary effects, where LSOAs on the edge of the study region have many fewer neighbours than those LSOAs not on the edge. All models were fitted using maximum quasi-likelihood estimation in R using the glm() function.

Results

Social frontiers

Table 1 presents the mean, minimum and maximum values for all the social frontier metrics, which shows large variation in frontier size across England. The groups with the lowest and highest mean frontier sizes are Caribbean (0.5%) and White British (5.3%) for ethnicity, and Jewish (0.34%) and Christian (5.4%) for religion. Additionally, frontier size has either stayed roughly similar (e.g., Caribbean and Jewish) or increased (e.g., Muslim and White British) from 2011 to 2021, suggesting that social frontiers have generally become larger and more common over the 10-year period. Additional analysis comparing these metrics across the two censuses is presented in the supplementary material accompanying this paper.

Table 1. *Summary of the 2 social frontier metrics for each year and ethnic / religious grouping.*

Quantity	Variable	Year	
		2011	**2021**
Mean frontier size Mean (Min, Max)	**African**	0.98 (0.00, 22.04)	1.35 (0.00, 34.85)
	Bangladeshi	0.57 (0.00, 39.07)	0.67 (0.00, 36.56)
	Caribbean	0.50 (0.00, 18.07)	0.50 (0.00. 15.38)
	Chinese	0.51 (0.00, 21.66)	0.51 (0.00, 21.71)
	Indian	1.31 (0.00, 46.62)	1.52 (0.00, 46.70)
	Pakistani	1.17 (0.00, 46.54)	1.42 (0.00, 43.24)
	White British	4.93 (0.03, 54.05)	5.70 (0.02. 52.77)
	Christian	5.33 (0.07, 38.23)	5.51 (0.01, 33.10)
	Hindu	0.80 (0.00, 29.48)	0.93 (0.00, 28.79)
	Jewish	0.34 (0.00, 38.34)	0.34 (0.00, 33.48)
	Muslim	2.26 (0.00, 52.83)	2.76 (0.00, 51.95)
	None	4.50 (0.12, 23.62)	5.32 (0.05, 27.83)
Maximum frontier size Mean (Min, Max)	**African**	2.04 (0.00, 33.69)	2.81 (0.00, 45.93)
	Bangladeshi	1.25 (0.00, 58.67)	1.48 (0.00. 57.97)
	Caribbean	1.02 (0.00, 25.82)	1.02 (0.00, 20.19)
	Chinese	1.08 (0.00, 28.86)	1.08 (0.00, 28.55)
	Indian	2.77 (0.00, 68.89)	3.20 (0.00, 68.22)
	Pakistani	2.56 (0.00, 72.27)	3.06 (0.00, 76.00)
	White British	10.35 (0.04, 94.37)	11.88 (0.03, 89.37)
	Christian	10.52 (0.11, 72.94)	10.77 (0.01, 67.27)
	Hindu	1.68 (0.00, 62.00)	1.94 (0.00, 64.88)
	Jewish	0.74 (0.00, 64.83)	0.73 (0.00, 60.68)
	Muslim	4.84 (0.00, 94.19)	5.84 (0.00, 88.35)
	None	8.79 (0.12, 38.55)	10.39 (0.05, 45.54)

4.2. Social frontier effects on mental health

Separate regression models were built for each mental health outcome and census year, resulting in 4 sets of model results. Within each set of results a single model contains one social frontier metric and a set of confounders, which allows us to observe the individual effects of the different social frontier metrics. A description of the model building process is given in the supplementary material. The results for the depression diagnoses outcome are obtained from binomial logistic regression models, and hence the estimated effect sizes are presented as odds ratios (OR). In contrast, the results for the antidepressant usage outcome are obtained from Poisson log-linear regression models, and hence the estimated effect sizes are presented as relative risks (RR). Both OR and RR relate to a 5% change in the social frontier metric, i.e., what is the associated change in mental health if the mean or maximum social frontier size goes from 15% to 20% or from 30% to 35%. Further details of this are given in the supplementary material accompanying this paper.

Estimates of OR, RR and 95% confidence intervals are displayed in Tables 2 to 5, which respectively relate to depression and ethnicity frontiers, depression and religion frontiers, antidepressants and ethnicity frontiers, and antidepressants and religion frontiers. In all cases separate results are displayed for the mean frontier size and maximum frontier size metrics. Statistically significant harmful effects of social frontiers at the 5% level are highlighted in red, while significant beneficial effects are in blue. Note, as Tables 2-5 contain 96 separate effect estimates, we do not draw conclusions on the basis of a single significant effect as this could be a result of multiple testing. In fact, the statistical significance (yes / no) of the individual results are largely consistent across multiple similar pairs of social frontiers and mental health outcomes. For example, 83% of the significance levels are the same when comparing mean or maximum frontier size, 77% are the same when comparing the two census years, and 71% are the same when comparing the depression and antidepressant outcomes. There is also no evidence that social frontiers are beneficial to health, as only 4 (4.2%) of the OR and RR results are significantly less than 1 and their corresponding effect sizes are very small.

Focusing on ethnicity, consistent significant harmful effects of social frontiers on mental health were observed for Indian (all 8 estimates are significant), Pakistani (8), Chinese (7) and White British (7). The average estimated effect sizes for these groups range between a 0.2% increased odds / risk if the White British social frontier increased by 5%, compared to an average 2.5% increased odds / risk if the Chinese social frontier increased by 5%. The remaining ethnic groupings did not show consistent significant effects. Similarly, some religious social frontiers also show consistent significant harmful effects on mental health, including the 3 minority groups of Hindu (all 8 estimates are significant), Jewish (8) and Muslim (8). These estimated effect sizes are similar, with most OR and RR results for a 5% increase in the frontier size rise by up to 1% for Muslim and up to 2% for Hindu and Jewish. In contrast, there is no evidence that social frontiers relating to either Christianity or having no religion have any association with mental health.

Table 2. *Odds ratios for the association between* ***ethnic social frontier*** *metrics and* ***depression diagnoses****. In each case the odds ratio relates to the change in depression diagnoses associated with increasing the size of the social frontier by 5 (on a percentage absolute difference scale). Elements in red (harmful social frontiers) and blue (beneficial social frontiers) are significant at the 5%.*

Ethnic group	Year	Odds ratios	
		Mean frontier size	Max frontier size
African	2011	1.010 (1.001, 1.018)	1.005 (1.002, 1.009)
	2021	0.999 (0.995, 1.003)	1.000 (0.999, 1.002)
Bangladeshi	2011	1.002 (0.995, 1.009)	1.003 (1.000, 1.006)
	2021	0.999 (0.995, 1.003)	1.002 (1.000, 1.003)
Caribbean	2011	1.013 (0.998, 1.029)	1.008 (1.001, 1.015)
	2021	0.998 (0.988, 1.008)	0.000 (0.995, 1.004)
Chinese	2011	1.022 (1.004, 1.039)	1.019 (1.013, 1.025)
	2021	1.022 (1.011, 1.033)	1.015 (1.011, 1.019)
Indian	2011	1.008 (1.003, 1.013)	1.006 (1.004, 1.008)
	2021	1.009 (1.006, 1.012)	1.005 (1.004, 1.007)
Pakistani	2011	1.017 (1.013, 1.021)	1.009 (1.008, 1.011)
	2021	1.008 (1.005, 1.010)	1.004 (1.004, 1.005)
White British	2011	1.003 (1.001, 1.005)	1.003 (1.002, 1.004)
	2021	1.001 (1.000, 1.002)	1.001 (1.000, 1.001)

Table 3. *Odds ratios for the association between* ***religious social frontier*** *metrics and* ***depression diagnoses****. In each case the odds ratio relates to the change in depression diagnoses associated with increasing the size of the social frontier by 5 (on a percentage absolute difference scale). Elements in red (harmful social frontiers) and blue (beneficial social frontiers) are significant at the 5%.*

Religion	Year	Odds ratios	
		Mean frontier size	Max frontier size
Christian	2011	1.001 (0.999, 1.004)	1.003 (1.002, 1.004)
	2021	1.000 (0.999, 1.002)	1.000 (1.000, 1.001)
Hindu	2011	1.018 (1.010, 1.027)	1.011 (1.007, 1.014)
	2021	1.012 (1.006, 1.017)	1.007 (1.005, 1.009)
Jewish	2011	1.013 (1.004, 1.022)	1.007 (1.004, 1.011)
	2021	1.016 (1.010, 1.022)	1.008 (1.005, 1.010)
Muslim	2011	1.010 (1.007, 1.012)	1.006 (1.005, 1.007)
	2021	1.004 (1.003, 1.006)	1.003 (1.002, 1.004)
None	2011	1.000 (0.997, 1.003)	1.001 (0.999, 1.002)
	2021	1.000 (0.998, 1.002)	1.000 (1.000, 1.001)

Table 4. *Relative risks for the association between* ***ethnic social frontier*** *metrics and* ***antidepressant usage****. In each case the relative risk relates to the change in antidepressant usage associated with increasing the size of the social frontier by 5 (on a percentage absolute difference scale). Elements in red (harmful social frontiers) and blue (beneficial social frontiers) are significant at the 5%.*

Ethnic group	Year	Relative Risks	
		Mean frontier size	Max frontier size
African	2011	0.998 (0.992, 1.003)	1.000 (0.998, 1.003)
	2021	0.996 (0.993, 1.000)	0.999 (0.997, 1.000)
Bangladeshi	2011	1.007 (1.002, 1.011)	1.004 (1.002, 1.006)
	2021	1.001 (0.997, 1.004)	1.002 (1.000, 1.003)
Caribbean	2011	1.007 (0.997, 1.018)	1.002 (0.997, 1.007)
	2021	0.991 (0.981, 1.001)	0.998 (0.994, 1.002)
Chinese	2011	1.004 (0.992, 1.015)	1.027 (1.023, 1.031)
	2021	1.044 (1.034, 1.054)	1.024 (1.021, 1.028)
Indian	2011	1.011 (1.007, 1.014)	1.006 (1.005, 1.008)
	2021	1.011 (1.008, 1.013)	1.007 (1.005, 1.008)
Pakistani	2011	1.012 (1.010, 1.015)	1.006 (1.005, 1.007)
	2021	1.007 (1.005, 1.009)	1.004 (1.003, 1.005)
White British	2011	1.002 (1.001, 1.003)	1.002 (1.002, 1.003)
	2021	1.003 (1.002, 1.004)	1.002 (1.002, 1.002)

Table 5. *Relative risks for the association between* ***religious social frontier*** *metrics and* ***antidepressant usage****. In each case the relative risk relates to the change in antidepressant usage associated with increasing the size of the social frontier by 5 (on a percentage absolute difference scale). Elements in red (harmful social frontiers) and blue (beneficial social frontiers) are significant at the 5%.*

Religion	Year	Relative Risks	
		Mean frontier size	Max frontier size
Christian	2011	0.997 (0.996, 0.999)	1.000 (1.000, 1.001)
	2021	0.999 (0.998, 1.000)	1.000 (0.999, 1.001)
Hindu	2011	1.015 (1.009, 1.021)	1.010 (1.008, 1.012)
	2021	1.011 (1.006, 1.016)	1.008 (1.006, 1.010)
Jewish	2011	1.014 (1.008, 1.020)	1.006 (1.004, 1.008)
	2021	1.015 (1.010, 1.020)	1.006 (1.004, 1.008)
Muslim	2011	1.010 (1.008, 1.011)	1.005 (1.004, 1.005)
	2021	1.006 (1.005, 1.007)	1.003 (1.003, 1.004)
None	2011	0.996 (0.995, 0.998)	0.999 (0.998, 1.000)
	2021	1.001 (1.000, 1.002)	1.001 (1.000, 1.002)

Discussion

Our results represent the first attempt to investigate the association between mental health and social frontiers (abrupt neighbourhood borders). We examined this association among the most popular ethnic and religious groups in the UK. In doing so, we extended previous research by Maguire et al. (2016) which focussed exclusively on Peace Walls in Northern Ireland.

Using data on LSOAs in England for both 2011 and 2021, we find strong and consistent evidence of a negative association between the intensity of social frontiers and mental health outcomes.

For most ethnic and religious groups, our results suggest that living in an area segregated by social frontiers is detrimental to mental health. This negative association could be due to the nature of these social frontiers that impose a strict geographical division, limiting opportunities for intergroup contact. Without intergroup contact, the involved groups miss one of the key mechanisms contributing to more positive intergroup attitudes and relations (Pettigrew and Tropp 2008). Instead, the presence of these frontiers can exacerbate negative mechanisms such as territorial effects and stronger divisions between groups, which may contribute to ingroup favouritism (Tajfel and Turner 1978) and potential polarisation between groups.

It is important to note groups such as the Caribbean or Christians where such effects were not found. This may be due to mitigating factors. For example, research has shown that African Americans tend to more strongly identify with their racial group in the presence of discrimination and this may fully counteract the negative effect of discrimination on well-being (Branscombe et al. 1999). Also, there might be some ethnic density effects when a high ingroup proportion provides protective effects on mental health (Bosqui et al. 2014; Das-Munshi et al. 2010). In our study we aimed to provide an overview of the social frontier effects across major ethnic and religious groups in the UK. More detailed information and analysis could be provided by future research focusing on the specific characteristics of each group and the particular relationships developed with the other group or groups in a social frontier.

We have focussed on establishing whether there is an association between social frontiers and depression. A natural extension of this work would be to develop causal inference strategies to identify the direction and magnitude of the causal relationship. More research is also needed on the factors that cause social frontiers to emerge, such as social housing allocation decisions and town planning. The latter may be especially salient because of the tendency for neighbourhood boundaries to follow existing physical barriers such as main roads, waste-land, railways, parks and rivers (Noonan 2005). Moreover, infrastructure and planning decisions may be manipulated by the majority group to deliberately impose “barricades” (Sharkey 2020) that help maintain a degree of physical and perceived distance from the minority group, and minimise the flows of people between the two communities. Our results provide the first set of results across multiple urban areas that such separation of groups might have implications for mental health, which suggests that planners need to be cognizant of the social cohesion impacts of their decisions.

Conclusion

The social psychology and human geography literatures have suggested a number of theoretical reasons why social frontiers – abrupt ethnic/religious boundaries between neighbourhoods – are likely to have a negative association with mental health. Previous empirical research has found significantly higher take up of antidepressants and anxiolytic drugs near Peace Walls in Northern Ireland. However, there are have been no published studies that have explored the association between social frontiers and mental health beyond the unique and extreme context of religious segregation in Northern Ireland.

Using data on all neighbourhoods (Lower Super Output Areas, LSOAs) in England for both 2011 and 2021, this study has found strong and consistent evidence of a negative association between the intensity of social frontiers and depression. The link between social frontiers and depression was statistically significant both for ethnicity frontiers (particularly Chinese and Pakistani communities) and for religious frontiers (especially for Hindus, Jews and Muslims). The link between social frontiers and depression was significant both for ethnicity frontiers (particularly Chinese and Pakistani communities) and for religious frontiers (especially for Hindu, Jewish and Muslim communities).

Our results add to a growing body of research that emphasises the importance of neighbourhood boundaries as an important and previously overlooked dimension of residential segregation. Policy makers need to be cognizant of the potential impacts of social frontiers when developing social cohesion strategies, allocating housing and making planning decisions. These findings also provide an imperative for further research into the causal mechanisms that underpin the link between social frontiers and mental health.

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Ethics Statement

For studies using secondary anonymised data the University of XXX does not require ethical review. However, we submitted a voluntary ethics approval request which was approved in Oct 2024 (University of XXX Ethics Application 064996).

Supplementary material

This supplementary material contains additional results not presented in the main paper ("Do Social Frontiers Matter for Depression? Estimating the association between social frontiers and neighbourhood depression rates in England") due to space constraints.

Supplementary Materials Contents

Why many measures of segregation do not capture social frontier prevalence

We have argued that an important but often overlooked aspect of residential segregation is the degree of residential mixing at neighbourhood borders. These areas of geographical transition can manifest themselves as social boundaries that have important implications for intergroup relations, particularly when they take the form of 'social frontiers'. Social Frontiers (or simply Frontiers) arise when there are sharp spatial divisions in the residential make-up of adjacent communities (Dean et al., 2018), as opposed to more gradual blending of groups. We argue that these community boundaries are not well captured by traditional measures of segregation, such as the index of dissimilarity, D, because such measures tend to focus on the overall distribution of a population group but overlook the spatial juxtaposition of those groups.

To illustrate, consider the two hypothetical cities in Fig.S1 where the density of shading reflects the share of migrants in each areal unit represented by grid squares. Both cities comprise four rectangular administrative neighbourhoods delineated by thick blue lines. Each city has exactly the same distribution of migrant shares across grid-squares.

Fig. S1. Contrasting social frontier prevalence for two cities with the same index of dissimilarity.

As a result, both have exactly the same Index of Dissimilarity (one of the most commonly used measures of segregation) equal to 0.5.

The fact that the D value for both cities is the same, but the spatial patterning is very different, illustrates the aspatial nature of many measures of segregation. City A has a very distinct social frontier delineating the high migrant share of grid-squares clustered around the city centre (in red) and surrounded by zero-migrant neighbourhoods (in white), while

City B has a spatial configuration that leads to much more shallow gradients between high and low migrant areas, and hence has no social frontiers. In this sense, we can think of social frontiers as “cliff edges” in the socio-economic geography of neighbourhoods that are invisible to many traditional measures of segregation. As with many social processes, these frontiers may not correspond to the administrative boundaries normally used to define neighbourhoods (Manley et al., 2006). Moreover, as Fig.S1 shows for City A they can occur at smaller scales and cut across them. Our argument is that it is these social frontiers, rather than the arbitrary neighbourhood boundaries or the overall distribution that may have the greatest impact on the lives of people. Yet, none of the main approaches to segregation measurement (e.g., the five dimensions of residential segregation considered by Massey and Denton, 1988) adequately account for these social frontiers.

This could explain why some studies find negative effects of segregation on mental health, while others find the effects to be insignificant or to vary in unexplained ways. It may be, for example, that the study areas used in one paper have high levels of social frontiers, while the study area used in another does not.

Additional summaries of the variables used to construct social frontiers

Scatterplots of the social frontier metrics (mean frontier size) comparing the two census years are displayed in Figures S2 (ethnicity) and S3 (religion). For ethnicity, the metrics exhibit strong correlations except for Chinese ethnicity, with Pearson’s correlation coefficients ranging between 0.85 for Caribbean and 0.96 for Pakistani. For religion, the correlations are high for Hindu (0.88), Jewish (0.97) and Muslim (0.94), but only moderate for Christian (0.67) and none (0.66).

The results presented in the main paper showed general increases in the size of the social frontiers separating neighbouring communities in 2021 compared with 2011. However, these increases do not correspond to similar increases in general segregation between the two census years, as measured by the index of dissimilarity (Duncan and Duncan, 1955). The values of this segregation index are given in Table S1 for the percentages of the populations in each original ethnic / religious grouping. The table shows that overall there has been little difference in this index over the 10 year period, with 8 ethnic / religious groupings exhibiting slightly reduced segregation while 4 exhibit slightly increased segregation.

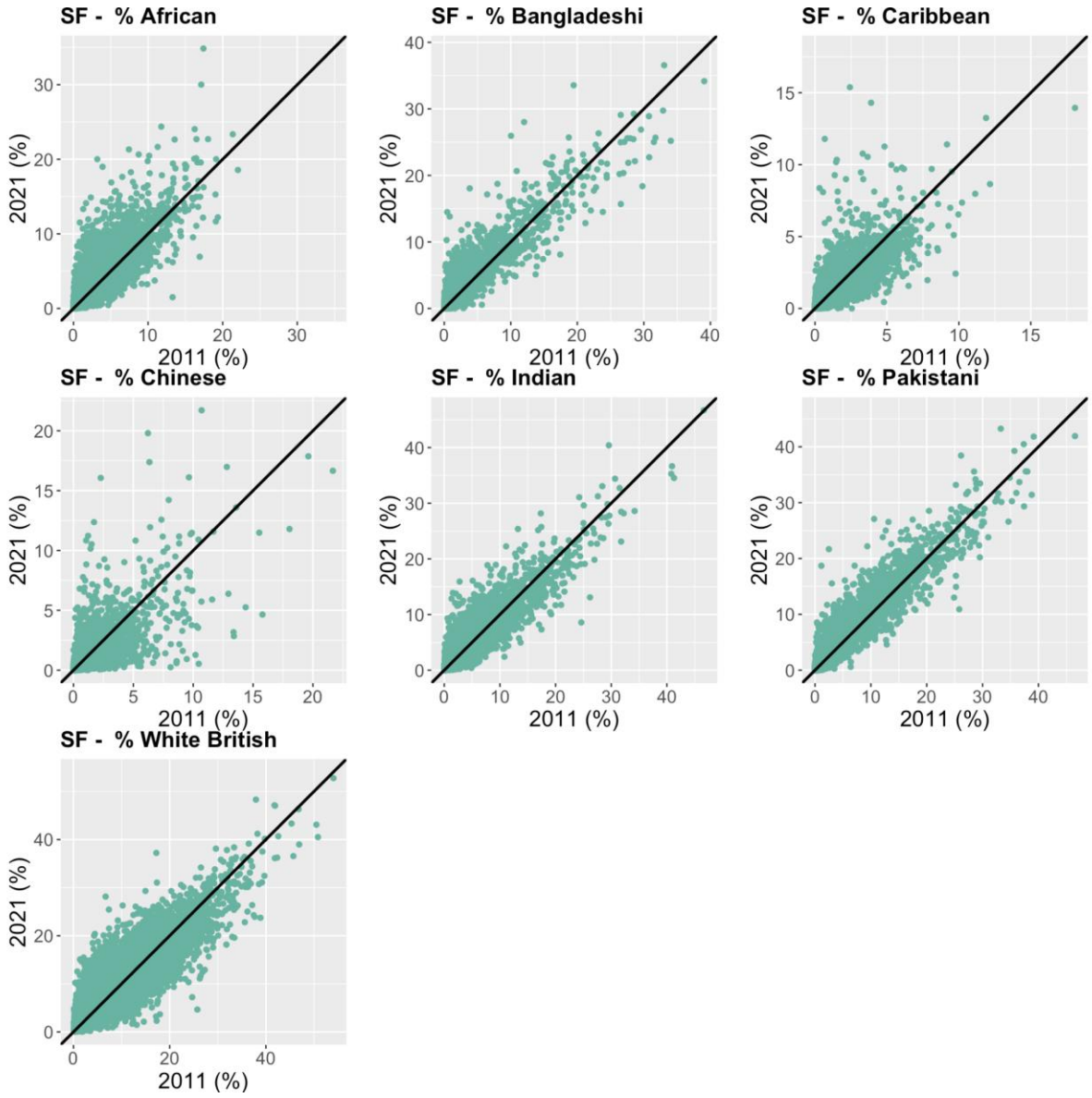

Figure S2 - Scatterplots of the mean frontier size metrics for each census year (2011 and 2021). Each panel relates to a different ethnicity.

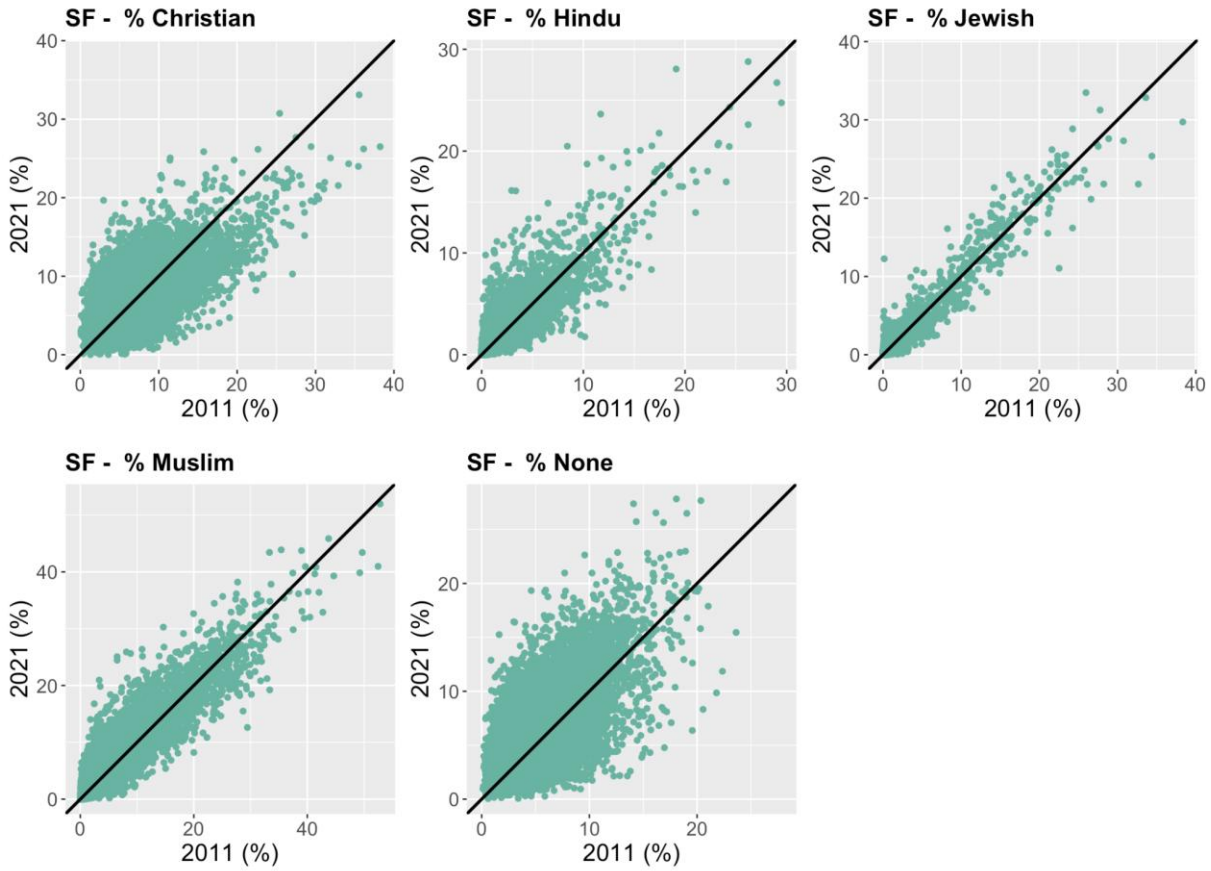

Figure S3 - Scatterplots of the mean frontier size metrics for each census year (2011 and 2021). Each panel relates to a different religion.

Table S1 - Index of dissimilarity for each ethnic and religious grouping.

Variable	Year	
	2011	**2021**
African	0.65	0.61
Bangladeshi	0.76	0.77
Caribbean	0.67	0.63
Chinese	0.50	0.51
Indian	0.62	0.6
Pakistani	0.77	0.74
White British	0.57	0.55
Christian	0.20	0.17
Hindu	0.64	0.61
Jewish	0.71	0.73
Muslim	0.69	0.67
None	0.17	0.19

Description of the model building process

The results presented in the main paper are based on either binomial (depression outcomes) or Poisson (antidepressant outcomes) regression models, which include both a single social frontier metric and an appropriate set of confounders as covariates. To determine the final confounder set for inclusion in the models, the confounders were initially assessed for collinearity. For both census years the employment and income scores of the IMD had Pearson's correlation coefficients of 0.95, and as a result the employment score was not considered for inclusion in any models. All other confounders had pairwise correlations below 0.9 and were hence considered in the model building process. The selection of the confounders was based on over-dispersed quasi-binomial (depression outcome) or quasi-Poisson (antidepressant outcome) regression models using a backwards elimination approach, where initially social frontier metrics were excluded from the models. Confounders that were not significant at the 5% level were eventually removed, with the one having the highest p-value (if above 0.05) being removed in each step of the algorithm. The exceptions to this are the variables used to create the social frontier metrics (e.g., percentage Pakistani), which are retained in the corresponding model as covariates when estimating the effect of that variable's social frontier. This inclusion ensures that the estimated social frontier effects are not confounded by the lack of the corresponding areal-level main effect for that variable in the model.

The residuals from each of these final covariate models were checked for the presence of spatial autocorrelation using Moran's I statistic, where a p-value was computed against the null hypothesis of no correlation using a permutation testing approach. The residuals from all models exhibited statistically significant spatial autocorrelation at the 0.1% level, with Moran's I statistics of: (a) depression 2011 – 0.77; (b) depression 2021 - 0.76; (c) antidepressants 2011 – 0.73; (d) antidepressants 2021 – 0.70. As a result, all final models incorporated an additional spatially lagged response variable to account for this autocorrelation, and its construction is described in the methods section.

Odds ratios and relative risks

We have presented the odds ratios and relative risks for a common increase of 5% across all social frontier metrics for ease of exposition, but appreciate that these metrics have different levels of variation across the ethnicity / religious variables as well as between the mean and max frontier sizes. Thus, a 5% increase in the mean frontier size for being Jewish covers a much larger proportion of its distribution (IQR - 0.14%) than the same increase in the maximum frontier size for being Christian (IQR - 6.6%). However, we note that although the absolute size of the effect sizes will change depending on the increase chosen (e.g., 5%), the statistical significance of the effects remain unchanged.

Data sources

Depression data both years
https://pldr.org/dataset/2ldz5/quality-and-outcomes-framework-indicators-depression-prevalence-qof412.

Age and sex data 2011
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/adhocs/009983populationestimatesforlowerlayersuperoutputareaslsoainenglandandwalessingleyearofageandsexmid2001tomid2017

Age and sex data 2021
https://www.ons.gov.uk/datasets/RM121/editions/2021/versions/1

Ethnicity data 2021
https://www.ons.gov.uk/datasets/TS021/editions/2021/versions/3

Ethnicity data 2011
https://infuse.ukdataservice.ac.uk/

Ethnic Groupings

Both census years use the following groupings:

Afro-caribbean
Black, Black British, Black Welsh, Caribbean or African: African
Black, Black British, Black Welsh, Caribbean or African: Caribbean

Pakistani
Asian, Asian British or Asian Welsh: Pakistani

White British
White: English, Welsh, Scottish, Northern Irish or British

Black
Black, Black British, Black Welsh, Caribbean or African: African
Black, Black British, Black Welsh, Caribbean or African: Caribbean
Black, Black British, Black Welsh, Caribbean or African: Other Black

Asian - 1,2,3,4,5
Asian, Asian British or Asian Welsh: Bangladeshi
Asian, Asian British or Asian Welsh: Chinese
Asian, Asian British or Asian Welsh: Indian
Asian, Asian British or Asian Welsh: Pakistani
Asian, Asian British or Asian Welsh: Other Asian

English index of multiple deprivation
https://www.gov.uk/government/collections/english-indices-of-deprivation

Religion data 2021
https://www.ons.gov.uk/datasets/TS030/editions/2021/versions/3

Religion data 2011
https://www.nomisweb.co.uk/census/2011/qs210ew

House prices both years

https://www.ons.gov.uk/peoplepopulationandcommunity/housing/datasets/medianpricepaidbylowerlayersuperoutputareahpssadataset46