

Supplementary Material

Neighborhood disadvantage and the risk of dementia and mortality among older refugees in Denmark: A quasi-experimental study

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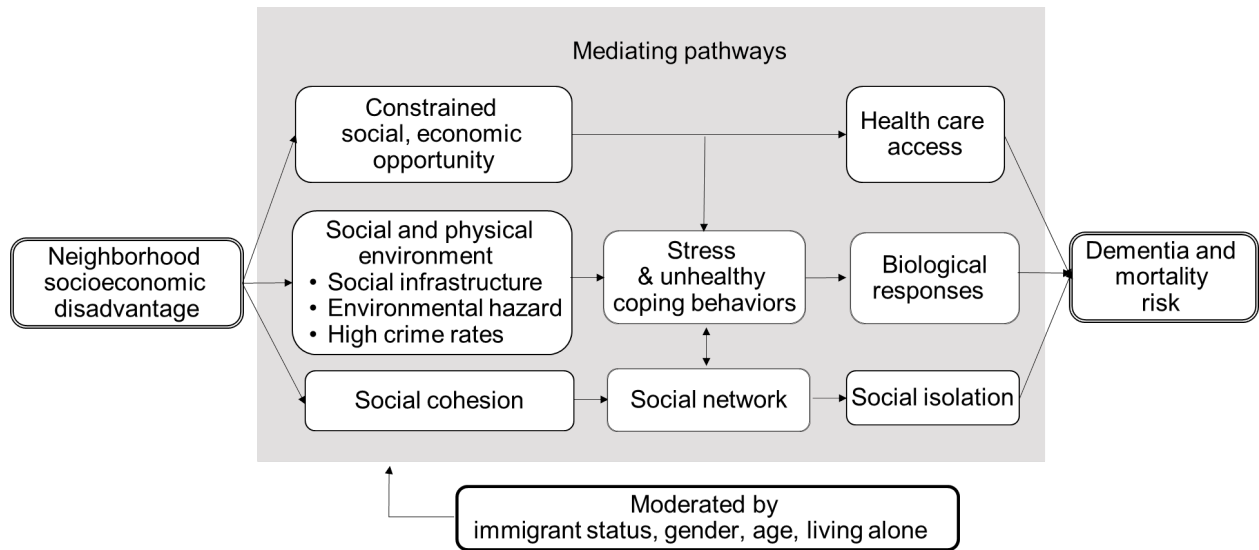
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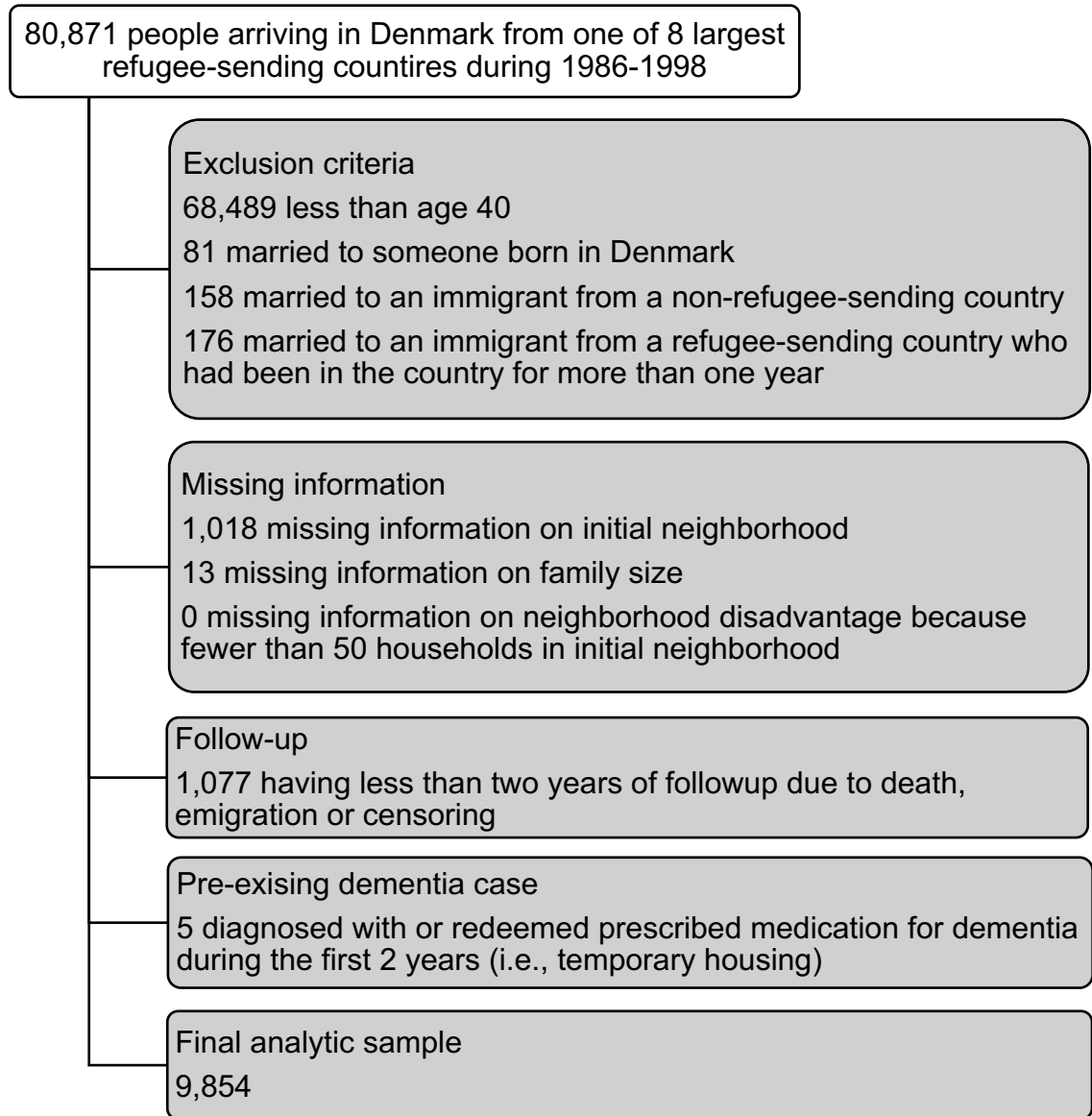
Figure S1. Conceptual diagram



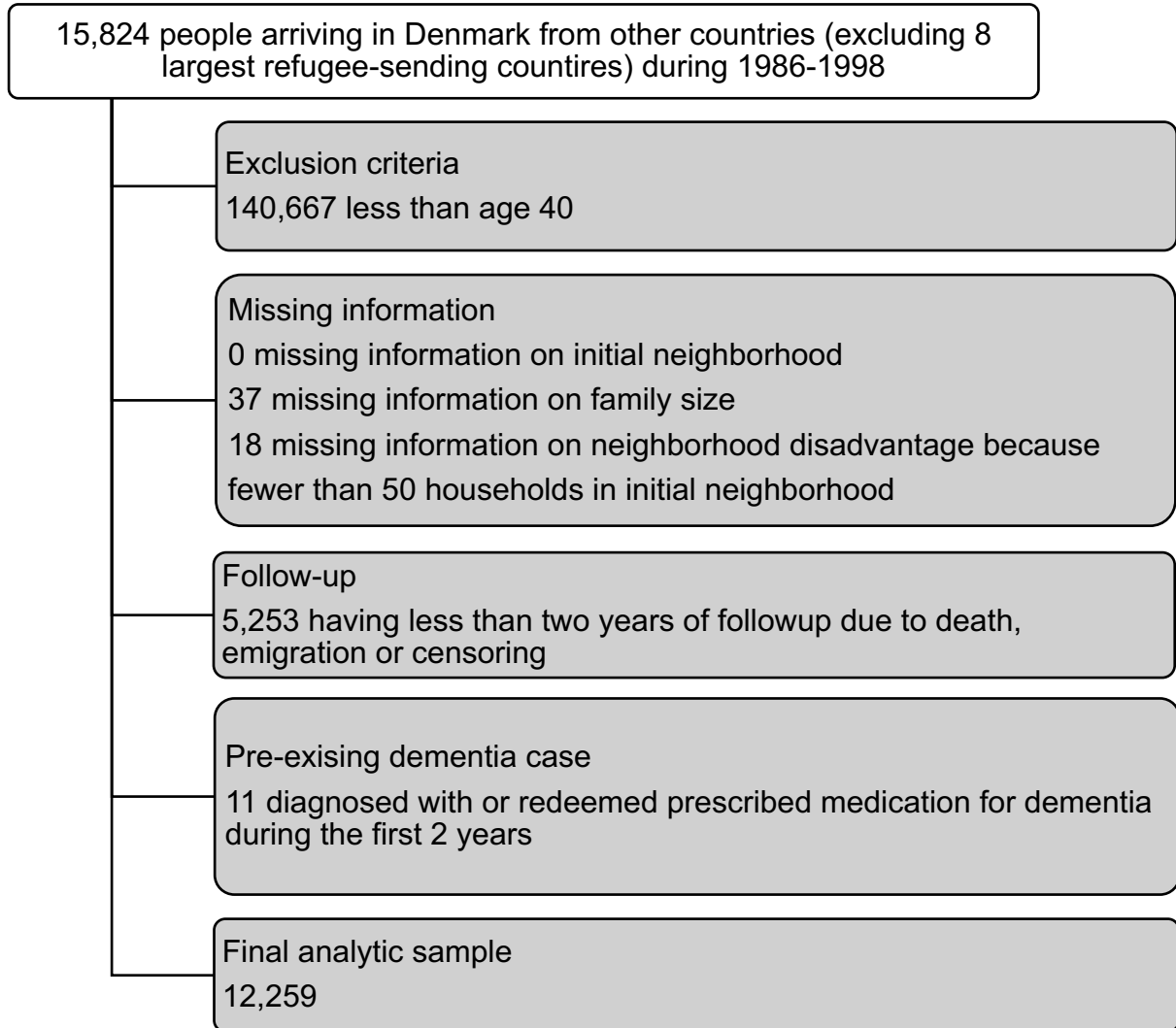
Note: Conceptual diagram adapted from Agyemang & Norredam (2020); Diez Roux & Mair (2010).

Figure S2. Flowcharts of study sample selection

(A) Refugee cohort



(B) Non-refugee immigrant cohort



(C) Native-born Dane cohort

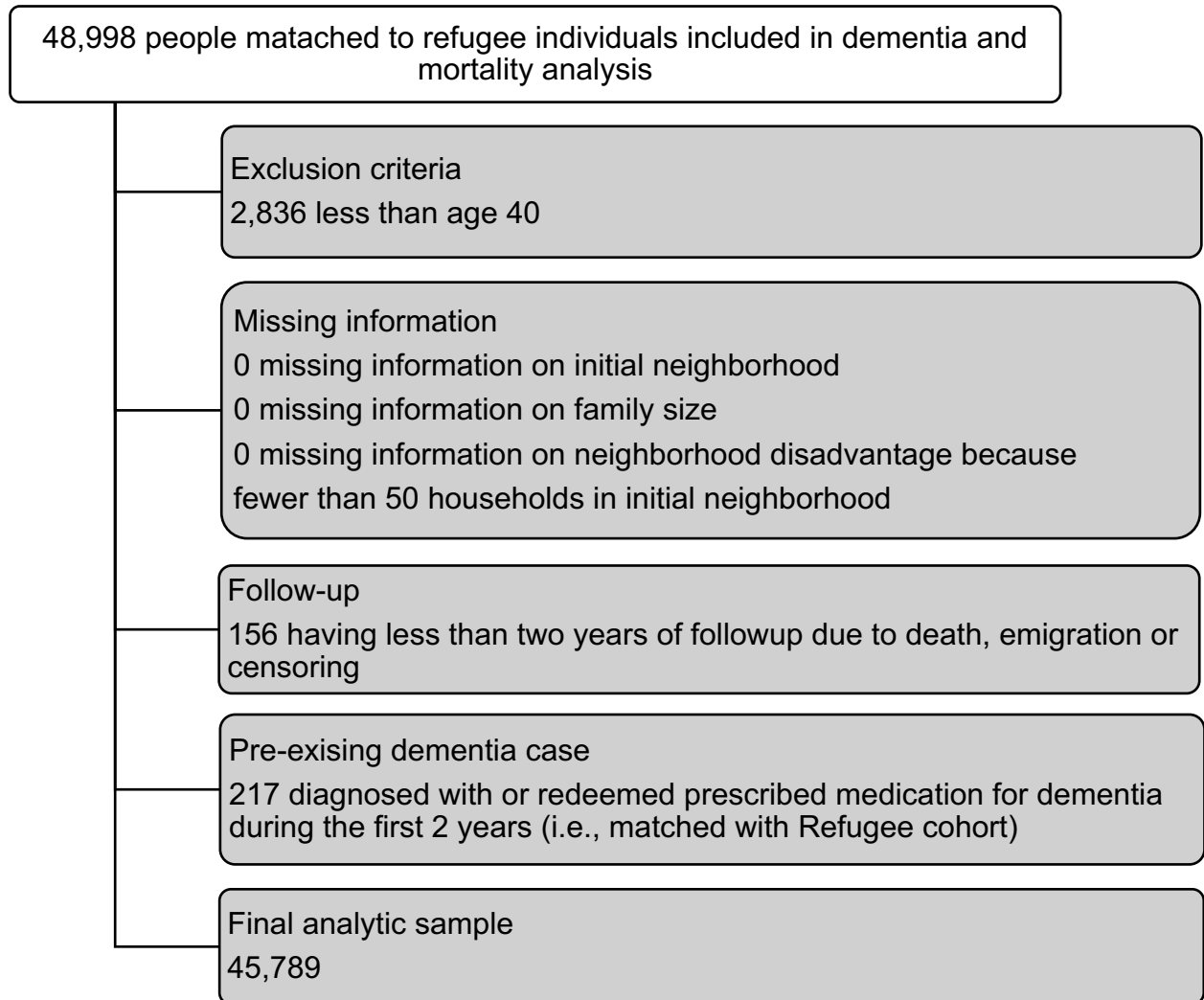
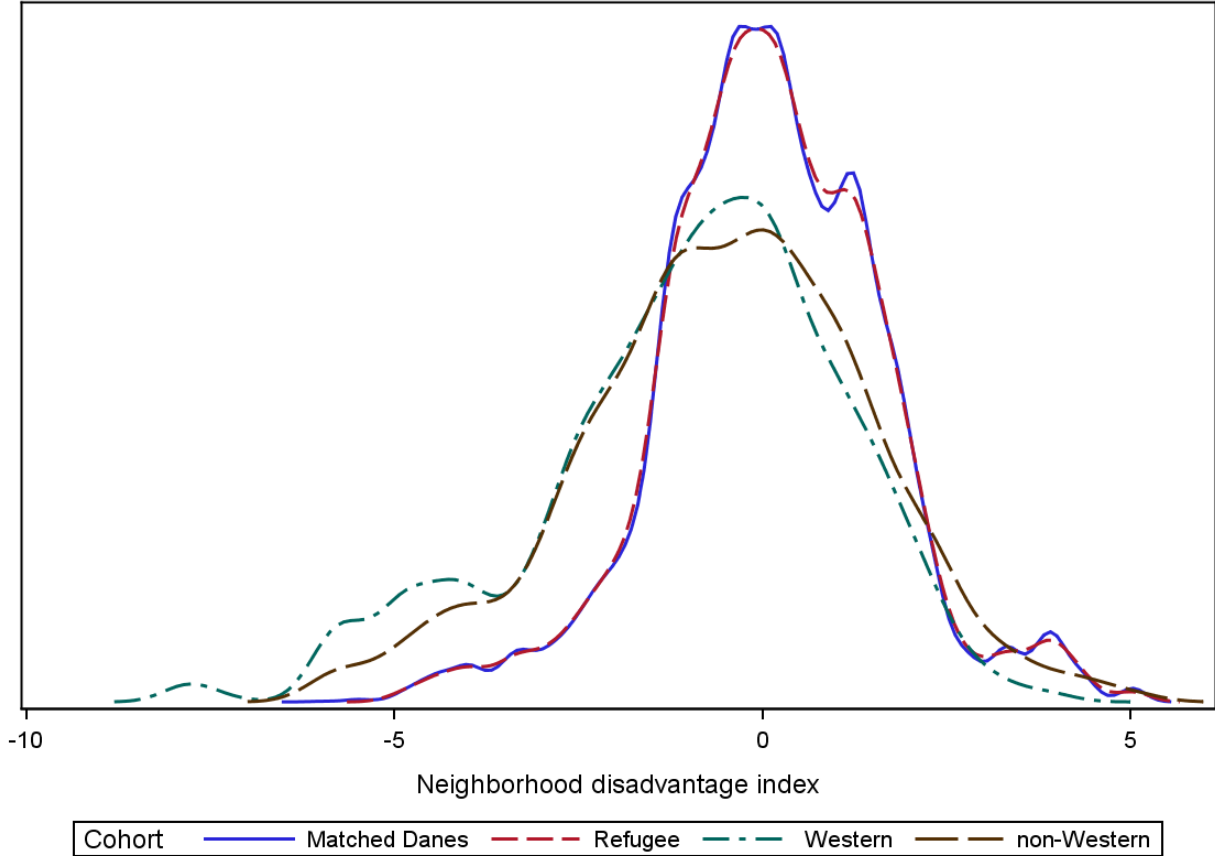


Figure S3. Distribution of neighborhood disadvantage exposure, by cohort



Note: The neighborhood disadvantage index was constructed for 2,097 parishes (nested within 271 Danish municipalities) using principal component analysis, in which a year-specific disadvantage value based on the variable loadings from the first principal component was assigned to each parish. Higher values indicate greater disadvantage. “Western” and “non-Western” refer to categories of non-refugee immigrants as defined by Statistics Denmark.

Table S1. Register data used in the study

Data element	Register	Years	Variables
Neighborhood characteristics	Statistics Denmark Registers	1986-1998	Income, unemployment, education, and receipt of welfare benefits at the parish level
Baseline characteristics of individuals	Statistics Denmark Registers	1986-1998	Country of origin, year of arrival, age, sex, marital status, and number of children
Vital status	Statistics Denmark Population Register	1986-2018	Date of death
Inpatient hospital stays & outpatient contacts	Danish National Patient Registry	Inpatient: 1986-2018 Outpatient: 1995-2018	ICD-8 codes through 1994 and subsequently ICD-10 codes
Inpatient hospital stays & outpatient contacts	Danish Psychiatric Central Register	Inpatient: 1986-2018 Outpatient: 1995-2018	ICD-8 codes through 1994 and subsequently ICD-10 codes
Prescription medications	Danish National Prescription Registry	1995-2020	Anatomical Therapeutic Chemical codes and dates of prescription redemption

Abbreviation: ICD, *International Classification of Diseases*

Table S2. Code used for identifying dementia cases

Disease name	ICD-8	ICD-10	Medication (ATC code)
Alzheimer's disease	290.1	F00.0-00.9, G30.0-30.9	Donepezil/N06DA02 Rivastigmine/N06DA03 Galantamine/N06DA04 Memantine/N06DX01
Vascular dementia	293.09-19	F01.0-01.9	
Frontotemporal dementia	290.11	F02.0	
Other dementias	290.18	G31.8	
Unspecified dementia	290.09, 290.19	F03.9, G31.9	

Source: Taudorf L., Nørgaard, A., Waldemar, G., & Laursen, T. M. (2021). Mortality in dementia from 1996 to 2015: a national registry-based cohort study. *Journal of Alzheimer's Disease*, 79(1), 289-300.
Abbreviations: ICD, *International Classification of Diseases*; ATC, *Anatomical Therapeutic Chemical*

Table S3. Socioeconomic variables included in the neighborhood disadvantage index

Variable	Description	Median/ %	Minimum	Maximum
Income	Median inflation-adjusted equivalized disposable family income in 2020 USD	117,269	38,080	254,831
Education	Proportion of inhabitants (aged 25-69 years) with less than 10 years of schooling	41.2	10.4	77.9
Unemployment	Proportion of inhabitants aged 18-59 years in the labour force who had been unemployed for more than half a year	6.5	0.0	27.2
Welfare benefits	Proportion of families receiving welfare benefits due to unemployment, sickness, or parental leave	36.4	11.8	67.1

Note: This includes 2,097 parishes, nested within 271 municipalities, for years 1986-1998, which were used in the creation of the disadvantage index using principal component analysis.

Table S4. Principal component analyses: eigenvalues, and proportion of variance explained

Year	Component 1		Component 2		Component 3		Component 4	
	Eigenvalues	Proportion of variance explained	Eigenvalues	Proportion of variance explained	Eigenvalues	Proportion of variance explained	Eigenvalues	Proportion of variance explained
1986	2.12	0.53	0.86	0.21	0.79	0.20	0.23	0.06
1987	2.17	0.54	0.80	0.20	0.78	0.20	0.24	0.06
1988	2.30	0.58	0.75	0.19	0.70	0.18	0.24	0.06
1989	2.33	0.58	0.73	0.18	0.67	0.17	0.27	0.07
1990	2.32	0.58	0.71	0.18	0.69	0.17	0.27	0.07
1991	2.30	0.58	0.75	0.19	0.67	0.17	0.28	0.07
1992	2.25	0.56	0.79	0.20	0.67	0.17	0.29	0.07
1993	2.26	0.56	0.79	0.20	0.63	0.16	0.32	0.08
1994	2.08	0.52	0.91	0.23	0.69	0.17	0.32	0.08
1995	2.00	0.50	0.97	0.24	0.71	0.18	0.32	0.08
1996	2.07	0.52	0.94	0.24	0.66	0.17	0.32	0.08
1997	2.10	0.53	0.92	0.23	0.65	0.16	0.33	0.08
1998	2.10	0.53	0.92	0.23	0.66	0.16	0.32	0.08

Note: Eigenvalues and proportion of variance explained were obtained from principal component analyses, with separate analyses conducted for each year during 1986-1998

Table S5. Principal component analyses: variable loadings

Year	Income	Education	Unemployment	Welfare benefits
1986	-0.57	0.58	0.38	0.43
1987	-0.56	0.57	0.42	0.43
1988	-0.55	0.55	0.45	0.43
1989	-0.54	0.54	0.47	0.45
1990	-0.53	0.54	0.47	0.46
1991	-0.52	0.53	0.48	0.46
1992	-0.53	0.53	0.47	0.45
1993	-0.53	0.54	0.49	0.44
1994	-0.56	0.55	0.46	0.41
1995	-0.58	0.56	0.42	0.41
1996	-0.57	0.56	0.44	0.41
1997	-0.56	0.56	0.44	0.42
1998	-0.56	0.57	0.40	0.45

Note: Variable loadings from the first component calculated in the principal component analysis, with separate analyses conducted for each year during 1986-1998.

Table S6. Neighborhood socioeconomic characteristics by neighborhood disadvantage tertiles

Neighborhood characteristics	Neighborhood disadvantage index			
	Total	Q1 (low disadvantage)	Q2	Q3 (high disadvantage)
Median household income	119,105	130,141	116,877	110,298
Proportion of education <10 years	36.24	31.73	42.12	48.55
Proportion unemployed (%)	6.98	5.27	6.51	9.15
Proportion under welfare support (%)	40.80	32.08	36.58	40.06

Note: We included 2,097 parishes nested within 271 municipalities for years between 1986 and 1998 to create the disadvantage index using principal component analysis. The neighborhood disadvantage index has been reversed, so higher values equal a higher disadvantage level. The index also has been divided into tertiles.

Table S7. Balancing tests

	(1) Low			(2) Moderate			(3) High		
	Estimate	S.E.	P-value	Estimate	S.E.	P-value	Estimate	S.E.	P-value
Female	-0.01	0.01	0.34	0.00	0.01	0.40	0.01	0.01	0.08
Not married	0.02	0.01	0.17	0.00	0.01	0.74	-0.01	0.01	0.30
Age (years)	0.00	0.00	0.09	0.00	0.00	0.25	0.00	0.00	0.57
Number of family members									
1-2 (reference)	-	-	-	-	-	-	-	-	-
3-4	0.01	0.01	0.52	-0.01	0.01	0.46	0.00	0.01	0.90
5+	-0.01	0.02	0.74	0.01	0.02	0.48	-0.01	0.02	0.71
Country of origin									
Former Yugoslavia (reference)	-	-	-	-	-	-	-	-	-
Iraq	0.00	0.03	0.95	-0.03	0.03	0.29	0.03	0.03	0.27
Iran	0.03	0.03	0.20	0.03	0.03	0.37	-0.06	0.03	0.05
Afghanistan	-0.01	0.03	0.67	-0.01	0.03	0.73	0.03	0.04	0.52
Vietnam	0.00	0.03	0.96	-0.01	0.04	0.81	0.01	0.04	0.85
Sri Lanka	-0.02	0.03	0.56	0.00	0.03	0.99	0.02	0.03	0.64
Somalia	0.00	0.03	0.99	-0.04	0.03	0.16	0.04	0.03	0.17
Lebanon (Palestinians)	0.01	0.03	0.70	-0.05	0.03	0.17	0.03	0.03	0.27
Education									
Basic education (reference)	-	-	-	-	-	-	-	-	-
Upper secondary education	-0.01	0.01	0.36	0.01	0.01	0.35	0.00	0.01	0.99
Higher education	0.00	0.01	0.74	0.00	0.01	0.85	-0.01	0.01	0.60
Unknown	0.02	0.01	0.13	0.00	0.01	0.99	-0.02	0.01	0.11

Abbreviations: SE, standard errors. Note: Balance tests examined whether the refugee characteristics at arrival were associated with the probability of assignment to a (1) low-disadvantage, (2) moderate-disadvantage or (3) high-disadvantage neighborhoods. We used three separate linear probability models. Each column represents a different balancing test testing whether refugees with certain characteristics are more likely to be placed in neighborhoods with different disadvantage levels (dependent variables). All models included indicators for municipality and year fixed effects. Robust standard errors were clustered at the parish level.

Table S8. Characteristics of the non-refugee immigrant cohort, by neighborhood disadvantage tertiles

	Neighborhood disadvantage		
	Low (n = 6,600)	Moderate (n = 2,744)	High (n = 2,915)
	% or Mean (SD)	% or Mean (SD)	% or Mean (SD)
Female	50	52.1	52.8
Married	69.4	67.4	69.1
Age (years)	50.3 (9.8)	50.8 (10.1)	50.9 (9.8)
Number of family members			
1-2	66.5	70.9	70.1
3-4	26.6	22.0	22.5
5+	6.9	7.1	7.4
Country of origin			
Western	69.5	67.3	61.0
Non-Western	30.5	32.7	39.0
Education			
Basic education	8.8	11.9	13.2
Upper secondary education	17.6	21.3	22.7
Higher education	23.1	20.0	19.7
Unknown	50.5	46.8	44.4
Co-regional composition	2 (1.9)	1.9 (1.8)	2.7 (3.1)
Population density (person/km ²)	3,809 (5,822)	3,394 (6,730)	6,138 (9,659)
Follow-up years ^a	11.1 (9.8)	12.9 (9.6)	13.3 (9.3)
Emigration	60.4	50.7	49.9
Outcomes, incidence rates per 1000 person-years			
Dementia	2.15 (1.84,2.51)	2.11 (1.68,2.65)	1.78 (1.40,2.25)
Mortality ^b	13.31 (12.51,14.17)	13.88 (12.71,15.15)	13.91 (12.79,15.13)

Abbreviations: SD, standard deviation, N/A, not applicable.

Notes: N = 147,827 person-years. This cohort included immigrants 40 years or older at time of arrival to Denmark (1968-1998), with 2-year washout period (i.e., excluding individuals with dementia incidents or had died within the first 2 years of follow-up after the year of arrival to minimize influences of preexisting conditions). The classification of the disadvantage index into tertiles is based on year and parish.

^aThese values represent years of follow-up using dementia as the outcome.

^bThese values represent models from mortality analysis, where we do not censor at dementia.

Table S9. Characteristics of the matched native-born Dane cohort, by neighborhood disadvantage tertiles

	Neighborhood disadvantage		
	Low (n = 15,414)	Moderate (n = 14,160)	High (n = 16,215)
	% or Mean (SD)	% or Mean (SD)	% or Mean (SD)
Female	50	50.8	51.6
Married	53.8	54.3	48.1
Age (years)	54.5 (10.3)	54.6 (10.0)	54.7 (10.4)
Number of family members			
1-2	66.5	68.8	74.1
3-4	29.7	27.1	23.0
5+	3.7	4.1	2.9
Education			
Basic education	37.6	45	50.1
Upper secondary education	38.7	35.8	34.5
Higher education	18.1	13.6	9.6
Unknown	5.7	5.6	5.8
Co-regional composition	95 (2.5)	95 (2.9)	88.8 (8.0)
Population density (person/km ²)	2,236 (3,915)	1,664 (3,127)	3,948 (6,781)
Follow-up years ^a	37.2 (20.6)	36.2 (20.0)	34.6 (20.6)
Emigration	11.6	10.5	11.9
Outcomes, incidence rates per 1000 person-years			
Dementia	1.84 (1.73,1.96)	1.73 (1.62,1.84)	1.85 (1.74,1.97)
Mortality ^b	10.31 (10.05,10.58)	10.67 (10.39,10.96)	12.41 (12.12,12.71)

Abbreviations: SD, standard deviation; N/A, not applicable.

Notes: N = 1,646,504 person-years. This cohort included matched native-born Danes with 2-year washout period (excluding individuals with dementia incidents or had died within the first 2 years of follow-up after the matched year of refugee placement). The classification of the disadvantage index into tertiles is based on year and parish.

^aThese values represent years of follow-up using dementia as the outcome.

^bThese values represent models from mortality analysis, where we do not censor at dementia.

Table S10. Association of neighborhood disadvantage (tertiles) with emigration risk, comparing refugee with non-refugee immigrants and matched native-born Danes

Neighborhood disadvantage level	Refugee		Non-refugee		Matched Danes	
	HR	(95% CI)	HR	(95% CI)	HR	(95% CI)
Moderate	0.91	(0.81,1.03)	0.88	(0.81, 0.96)	0.91	(0.83, 1.00)
High	0.90	(0.80,1.02)	0.74	(0.66, 0.83)	1.04	(0.93, 1.17)

Notes: N = 9,854 refugee and N = 12,259 non-immigrant refugees aged 40 and older at arrivals during 1986-1998; N = 45,789 matched native-born Danes. Estimates are from Cox proportional hazards models with low-disadvantage neighborhoods as the reference. All models are adjusted for age, sex, country of origin, number of family members, marital status, and fixed effects (i.e., indicator variables) for year of placement and municipality.

Table S11. Association of neighborhood disadvantage with dementia and mortality risks, stratified by age group

Exposure type	Total		Age 40-59		Age 60 and over	
	HR	(95% CI)	HR	(95% CI)	HR	(95% CI)
Dementia						
Disadvantage index (tertiles)						
Moderate	0.94	(0.70, 1.26)	0.96	(0.56, 1.63)	0.82	(0.54, 1.26)
High	0.82	(0.61, 1.11)	0.88	(0.52, 1.48)	0.68	(0.44, 1.04)
Disadvantage index (continuous)	0.94	(0.86, 1.03)	0.92	(0.79, 1.07)	0.93	(0.82, 1.06)
Mortality						
Disadvantage index (tertiles)						
Moderate	0.90	(0.78, 1.03)	0.89	(0.72, 1.10)	0.92	(0.76, 1.12)
High	0.90	(0.79, 1.01)	0.90	(0.74, 1.08)	0.90	(0.76, 1.06)
Disadvantage index (continuous)	0.96	(0.93, 0.99)	0.97	(0.92, 1.02)	0.95	(0.91, 0.99)

Notes: N = 9,854 aged 40 and older at arrival during 1986-1998. Estimates are from Cox proportional hazards models using neighborhood disadvantage as tertiles and continuous variable. Models are stratified by age at arrival (40-59 vs. 60+). All models are also adjusted for age, sex, country of origin, number of family members, marital status, and fixed effects (i.e., indicator variables) for year of arrival and municipality. While it is beyond the current study's scope, we also ran models estimating neighborhood disadvantage and all-cause and cause-specific mortality associations across life-course stages (e.g., testing the association among refugees less than age 40 at arrival). In general, these models were underpowered given the small number of events. Future research with longer follow-ups will help understand the heterogeneous effects of neighborhood disadvantage on mortality by life-course stages.

Table S12. Association of neighborhood disadvantage with dementia and mortality risks, stratified by family size

Exposure type	Total		Family size (1)		Family size (2+)	
	HR	(95% CI)	HR	(95% CI)	HR	(95% CI)
Dementia						
Disadvantage index (tertiles)						
Moderate	0.94	(0.70, 1.26)	0.89	(0.51, 1.55)	1.03	(0.68, 1.55)
High	0.82	(0.61, 1.11)	0.58	(0.31, 1.07)	0.94	(0.59, 1.49)
Disadvantage index (continuous)	0.94	(0.86, 1.03)	0.87	(0.72, 1.05)	0.99	(0.86, 1.13)
Mortality						
Disadvantage index (tertiles)						
Moderate	0.90	(0.78, 1.03)	0.90	(0.69, 1.16)	0.90	(0.77, 1.05)
High	0.90	(0.79, 1.01)	1.15	(0.92, 1.43)	0.79	(0.68, 0.93)
Disadvantage index (continuous)	0.96	(0.93, 0.99)	1.04	(0.98, 1.11)	0.92	(0.89, 0.96)

Notes: N = 9,854 aged 40 and older at arrival during 1986-1998. Estimates are from Cox proportional hazards models using neighborhood disadvantage as tertiles and continuous variable. Models are stratified by family size at arrival (1 vs. 2+). All models are also adjusted for age, sex, country of origin, number of family members (only for the subgroup family size +2), marital status, and fixed effects (i.e., indicator variables) for year of arrival and municipality.

Table S13. Association of neighborhood disadvantage with dementia and mortality risk including population density and co-regional composition as covariates, stratified by sex

Exposure type	Total		Female		Male	
	HR	(95% CI)	HR	(95% CI)	HR	(95% CI)
Dementia						
Disadvantage index (tertiles)						
Moderate	0.93	(0.69, 1.24)	0.79	(0.52, 1.20)	1.08	(0.68, 1.73)
High	0.78	(0.56, 1.08)	0.65	(0.39, 1.09)	0.92	(0.57, 1.47)
Disadvantage index (continuous)	0.92	(0.83, 1.02)	0.89	(0.77, 1.02)	0.97	(0.83, 1.14)
Mortality						
Disadvantage index (tertiles)						
Moderate	0.91	(0.79, 1.05)	0.80	(0.64, 0.99)	1.05	(0.87, 1.26)
High	0.93	(0.82, 1.07)	0.95	(0.78, 1.17)	0.95	(0.79, 1.15)
Disadvantage index (continuous)	0.97	(0.93, 1.01)	0.97	(0.91, 1.04)	0.98	(0.93, 1.03)

Notes: N = 9,854 (4,943 females; 4,911 males) aged 40 and older at arrival during 1986-1998. Estimates are from separate Cox proportional hazards models using neighborhood disadvantage as tertiles and continuous variable. Models are stratified by sex. All models are also adjusted for age, country of origin, number of family members, marital status, neighborhood co-regional composition and population density, and fixed effects (i.e., indicator variables) for year of arrival and municipality.

Table S14. Association of neighborhood disadvantage (tertile) with dementia risk in comparison cohorts, by sex and region of origin (for non-refugee immigrant cohort)

Neighborhood disadvantage	All		Female		Male	
	HR	(95% CI)	HR	(95% CI)	HR	(95% CI)
<i>All non-refugee immigrants</i>						
Moderate	0.92	(0.64, 1.32)	0.98	(0.58, 1.65)	0.64	(0.37, 1.12)
High	0.94	(0.60, 1.46)	1.14	(0.65, 2.00)	0.70	(0.33, 1.51)
<i>Western</i>						
Moderate	1.30	(0.86, 1.96)	1.65	(0.87, 3.15)	0.84	(0.46, 1.52)
High	1.08	(0.66, 1.78)	1.52	(0.77, 2.99)	0.96	(0.39, 2.38)
<i>Non-Western</i>						
Moderate	0.65	(0.30, 1.41)	0.70	(0.24, 2.02)	0.55	(0.14, 2.16)
High	0.97	(0.46, 2.07)	1.13	(0.44, 2.93)	0.52	(0.14, 1.88)
<i>Matched Dane</i>						
Moderate	1.01	(0.91, 1.12)	1.00	(0.87, 1.16)	1.04	(0.88, 1.22)
High	1.09	(0.93, 1.28)	1.13	(0.95, 1.35)	1.04	(0.83, 1.31)

Notes: N = 12,259 non-immigrant refugees aged 40 and older at arrivals during 1986-1998 and N = 45,789 matched native-born Danes. Estimates are from Cox proportional hazards models with low-disadvantage neighborhoods as the reference. Models are stratified by sex. All models are also adjusted for age, region of origin (only for non-refugee immigrants), number of family members, marital status, and fixed effects (i.e., indicator variables) for year of arrival and municipality.

Table S15. Association of neighborhood disadvantage (tertiles) with mortality risk among comparison cohorts, by sex and region of origin (for non-refugee immigrant cohort)

Neighborhood disadvantage	All		Female		Male	
	HR	(95% CI)	HR	(95% CI)	HR	(95% CI)
<i>All non-refugee immigrants</i>						
Moderate	1.04	(0.90, 1.20)	0.98	(0.79, 1.21)	1.13	(0.93, 1.38)
High	1.22	(1.06, 1.41)	1.15	(0.96, 1.39)	1.39	(1.13, 1.70)
<i>Western</i>						
Moderate	1.14	(0.96, 1.34)	0.97	(0.74, 1.29)	1.25	(0.97, 1.60)
High	1.21	(1.01, 1.45)	1.01	(0.76, 1.34)	1.45	(1.11, 1.88)
<i>Non-Western</i>						
Moderate	0.98	(0.73, 1.31)	1.08	(0.77, 1.52)	0.85	(0.59, 1.23)
High	1.38	(1.09, 1.74)	1.39	(1.04, 1.86)	1.45	(1.01, 2.06)
<i>Matched Dane</i>						
Moderate	1.12	(1.04, 1.20)	1.09	(0.99, 1.19)	1.16	(1.07, 1.26)
High	1.35	(1.20, 1.52)	1.34	(1.18, 1.53)	1.37	(1.21, 1.55)

Notes: N = 12,259 non-immigrant refugees aged 40 and older at arrivals during 1986-1998 and N = 45,789 matched native-born Danes. Estimates are from Cox proportional hazards models with low-disadvantage neighborhoods as the reference. Models are stratified by sex. All models are also adjusted for age, sex, region of origin (only for non-refugee immigrants), number of family members, marital status, and fixed effects (i.e., indicator variables) for the year of arrival for non-refugee immigrants (or matched year of arrival to refugees for native-born Danes) and municipality. Other time-varying measures are assessed at the (matched) year of arrival.