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Supplementary information

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The role of tech workers in ethnicity- and class-based urban segregation

In the format provided by the authors and unedited

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Supplementary Discussion 1. Ethnic minorities in Estonia.

The bulk of Estonia's minority population formed between 1944 and 1991, when Estonia was under Soviet rule. This was largely due to sustained large-scale immigration from other Soviet republics, mostly from Russia, driven by political and ideological goals to redistribute populations across the Union. Russian became the dominant language during that period, resulting in relatively modest proficiency in the local language among many Russians. The development of minority populations in former Soviet countries has its own features stemming from policies of the Soviet regime and communist system, such as Union-wide strict top-down central planning, collective ownership, and strategic development of the settlement system. These features shaped urbanisation and segregation differently from the capitalist system, which is based on market forces and private property. At the time of their arrival in Estonia, the predominantly Russian-speaking minority population settled mainly in major cities and industrial areas, where they were accommodated in newly constructed, standardized high-rise housing estates. These neighbourhoods were equipped with ethnic infrastructure, such as Russian-language schools and kindergartens, which supported community needs but also contributed to spatial separation. As a result, migrants became heavily concentrated in these new housing estate areas, while many Estonians continued to reside in older housing, located both in inner city and outer city, leading to pronounced ethnic residential segregation[1].

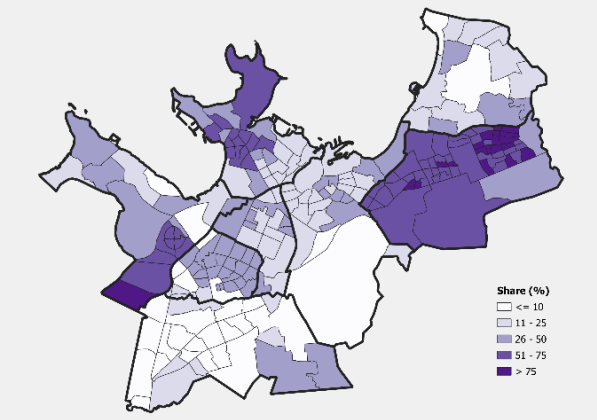
After the collapse of the Soviet Union and the regaining of independence in 1991, a substantial number of Russians and other minorities left Estonia. However, most of them remained, and today ethnic minorities make up roughly one-third of the population. Russians constitute about 80% of Estonia's minority population (the other bigger groups being Ukrainians and Belarusians) and are the minority group analysed in this study. The group's size allows for the examination of subgroups within the same ethnicity—such as tech workers and Estonian-born

versus foreign-born minorities—at a detailed spatial scale. Ethnic segregation has been a persistent feature of Tallinn and other major Estonian cities since the Soviet period[2]. Nearly 90% of the Russians are concentrated in two regions: the industrial cities of Northeast Estonia and the Tallinn urban region, where more than half of them reside. Within Tallinn itself, Russians make up close to half of the city's population.

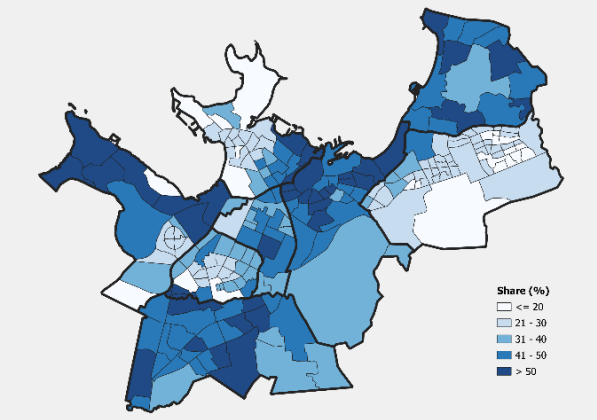
Following Estonia's independence, the country underwent rapid economic liberalization and societal restructuring. These changes gradually reshaped urban space and increased socio-economic inequalities and levels of residential segregation. In Tallinn, the level of residential segregation between occupational groups increased from a dissimilarity index value of 19 in 1989 to 39 in 2021 (Fig. 1). Occupational status is a particularly important dimension of socio-economic position for understanding spatial inequalities, whereas segregation by educational level is markedly lower. This likely reflects the greater internal heterogeneity within educational categories. Russian-speakers, who were the majority ethnic group in the former Soviet Union, became a minority in the newly independent Estonia. They have faced greater challenges during economic restructuring, partly due to limited proficiency in the local language, which constrains social mobility[3]. Limited mobility and the privatization of housing meant that many Russian-speakers remained in Soviet-era housing estates, reinforcing patterns of ethnic segregation (Fig. 1).

SD1 Fig. 1. Changes in residential segregation by mother tongue (Estonian vs Russian), occupation (high vs low) and education (high vs low), 1989-2021.
Source: Statistics Estonia.

A concerning trend is the growing overlap of residential segregation between ethnic and occupational groups, or the eth-class segregation[4]. The Soviet-time socio-economically modestly segregated urban space has become increasingly divided along occupational lines, with socio-economically disadvantaged areas coinciding with neighbourhoods that have a high share of minority populations. Fig. 2 visualises these patterns: areas with a large Russian-speaking population—mainly Soviet-era high-rise housing districts—tend to have fewer residents in high-status occupations, reflecting lower overall socio-economic status. In contrast, individuals in higher-status occupations are predominantly concentrated in attractive central city areas and detached housing outer-city neighbourhoods such as Pirita, Haabersti, and Nõmme.



a) Russian-speakers
(from total population)



b) Workers in high occupations
(from total workforce)

SD1 Fig. 2. Share of Russian-speakers (a) and workers in high occupations (b) across Tallinn neighbourhoods in 2021. See Supplementary Fig. 1 for the district names and residential zones. Neighbourhood spatial data source: Department of Geography, University of Tartu. Maps created with QGIS 3.34.0.

When Estonia joined the European Union in 2004, a new wave of migration began. Over the past two decades, immigration has become much more heterogeneous in terms of migrants' backgrounds. Many have arrived from other EU countries, and immigration from third countries has also increased. Nevertheless, these flows are small and the largest groups still have come from former Soviet republics, particularly from Russia and, to a lesser extent, from Ukraine. In fact, the Ukrainian community in Estonia has developed through three distinct waves: during the Soviet period through labour and family migration, after Estonia's accession to the European Union in 2004 through labour migration, and since the outbreak of the war in Ukraine in 2022 through refugee arrivals. This group therefore warrants a separate study, as it has complex relations with the Russian community, into which many Ukrainians integrated during the Soviet era and which is generally regarded as part of the broader Russian-speaking population in Estonia[5]. Most new immigrants are highly educated, a trend shaped by Estonia's relatively strict migration policy that favours skilled workers, including tech workers.

Today, segregation is evident not only in residential areas but also in education and the labour market, with Russian speakers experiencing lower employment rates and having more limited interethnic social and professional networks. Despite some signs of integration, such as improved Estonian language proficiency, ethnic divisions in identity, employment, and everyday activity spaces remain pronounced. A shared linguistic environment and opportunities for professional and non-professional contacts would be key factors supporting better integration[6]. Russian minority tech workers—an expanding group, particularly among younger cohorts—may play a pivotal role in reshaping long-standing ethnic divides by bridging co-ethnic and professional networks. The same could characterise minority tech workers in other large cities, even if specific contexts differ. Yet, despite their potential significance, minority tech workers remain largely overlooked in existing research on residential segregation. This study addresses this gap by examining whether the residential outcomes of minority tech workers align more closely with class-based or co-ethnic residential patterns, based on the study of the Russian minority in Estonia.

Supplementary Discussion 2. Changing nationwide residential patterns of tech workers in Estonia.

To contextualise the core analysis of intra-urban segregation among minority tech workers, we first provide a background analysis of the nationwide distribution of our study groups—defined by ethnicity and education—or eth-class groups. Using municipalities as the units of analysis to calculate the dissimilarity index, we find that both majority- and minority-ethnicity tech workers have experienced a five-point increase in segregation (Table 1), from 34 to 39 (for 2021 values, see Table 2). The segregation of ethnic minority tech workers also increased in relation to all non-tech ethnic majority occupational groups (Table 1). Thus, ethnic minority tech workers became more segregated from the ethnic majority than non-tech minority tech workers (Table 2). However, ethnic majority tech workers remain consistently less residentially segregated from the ethnic minority than non-tech majority workers, with the lowest dissimilarity index value being 35 with minority non-tech workers working in higher occupations (Table 2).

SD2 Table 1. Segregation and desegregation between ethnic and occupational groups across municipalities of Estonia–dissimilarity indices in 2011 (in brackets - change of dissimilarity index values between 2011 and 2021).

	Tech minority	High minority	Middle minority	Low minority
Tech majority	34 (+5)	33 (+2)	36 (+1)	41 (-3)
High majority	49 (+2)	46 (0)	47 (0)	44 (+2)
Middle majority	50 (+3)	47 (0)	48 (0)	45 (+1)
Low majority	68 (+2)	64 (-1)	65 (-1)	60 (0)
Tech minority		26 (+3)	29 (-3)	35 (+4)
High minority	26 (+3)		5 (+1)	11 (+1)
Middle minority	29 (-3)	5 (+1)		8 (+6)
Low minority	35 (+4)	11 (+1)	8 (+6)	
Standard deviation (2021-2011)	2.37	1.25	2.56	2.66

SD2 Table 2. Dissimilarity indices of Estonian majority and Russian minority working population across Estonian municipalities in 2021.

2021:	Tech minority	High minority	Middle minority	Low minority
Tech majority	39	35	37	38
High majority	51	46	47	46
Middle majority	53	47	48	46
Low majority	70	63	64	60
Tech minority		29	26	39
High minority	29		6	12
Middle minority	26	6		14
Low minority	39	12	14	

To gain further insight into ethnic differences in the nationwide residential patterns of minority tech workers and of the within-group heterogeneity, we present findings in their location within Estonia's monocentric settlement system, where about half of the population lives in the capital-city urban region. More specifically, we fitted a multinomial regression model to analyse the likelihood of living in the capital city, its suburbs, or the rest of the country. The model took the following form:

$$\ln\left[\frac{P(Y=j)}{P(Y=1)}\right] = \beta_{0j} + \beta_{1j}X_1 + \beta_{kj}X_k \quad \text{, where}$$

$P\ (Y=\ j)$ denotes the three outcome categories of living in Tallinn (1, reference category), suburbs of Tallinn (2) and in the rest of Estonia (3); $ß_{0j}$ is the intercept for category j; $ß_{1j}$, … , $ß_{kj}$ are the coefficients for the predictors X_1, …, X_k , associated with category j, and k is the number of variables in each model. Model 1 covers both majority and minority tech workers and includes three categories of variables. The first is our key variable of interest, which is ethnicity or being an Estonian or Russian based on the ethnic self-identification of people. The second group includes demographic variables to control for different life course and family-

related characteristics, including age, sex, and presence of under-aged children in the family. The third group includes socio-economic variables that reflect education and income. The income variable was sourced from Statistics Estonia and is based on individuals' yearly income from all sources, divided by 12 to represent the average monthly income. We then split models by ethnicity to learn whether the demographic and socio-economic variables act in a similar way among members of the majority and minority populations. Finally, we ran an additional Model 4 for minorities to account for the role of personal-level integration, by adding country of birth variable.

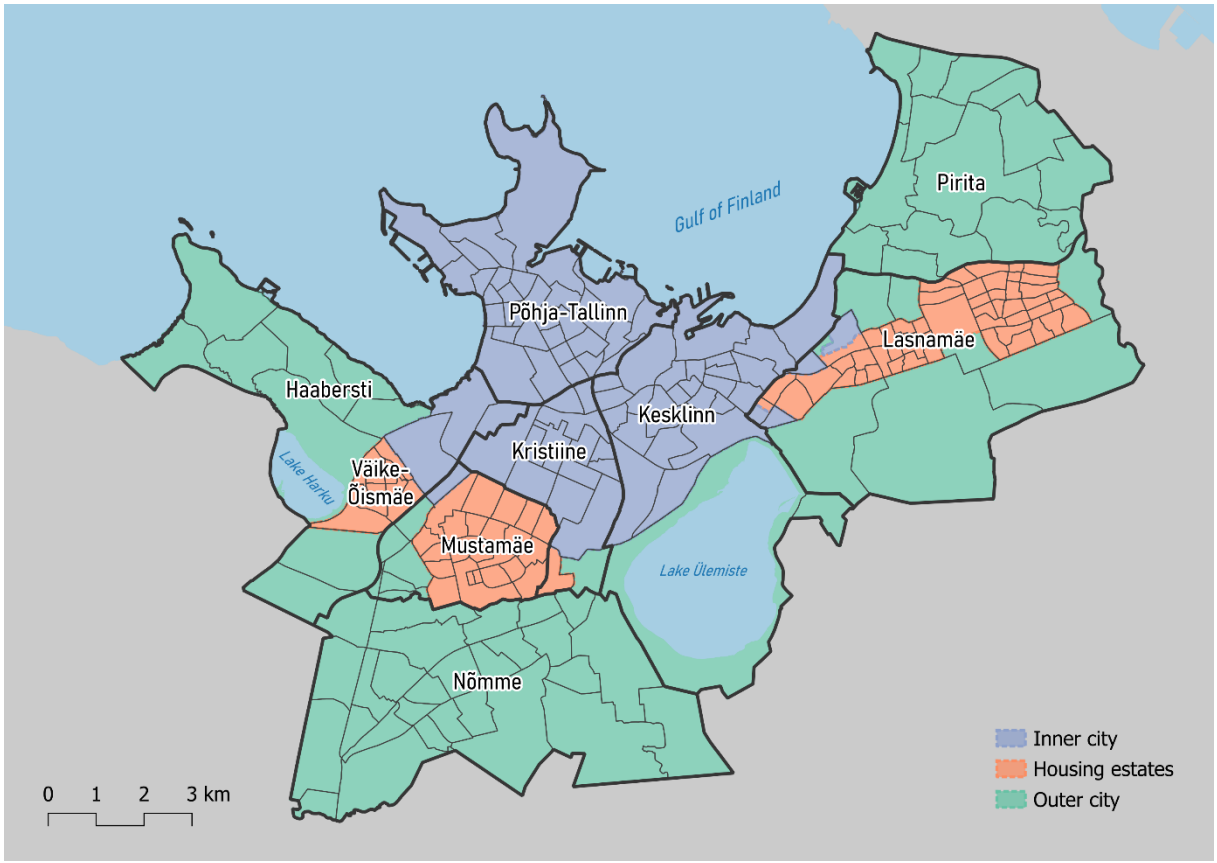
The results confirm significant ethnic differences in nationwide residential distribution among tech workers. Specifically, minority tech workers have significantly lower odds of living in both the suburbs of the capital city and other regions of the country compared to their majority counterparts (Table 3, overall model). Thus, strong large city orientation of the minority tech workers strengthens the role of cities in national and global economy, on the one hand, and as arenas of ethnic integration, on the other hand. Among the control variables, having children in the household increases the likelihood of residing in the suburbs of the capital city. Additionally, while higher income is associated with a greater likelihood of living in the suburbs rather than in the capital, the opposite trend is observed when considering residence in the rest of the country. In other words, increased income is associated with higher odds of living in the suburbs and lower odds of living in the rest of the country compared to living in Tallinn. This pattern remains largely consistent when the models are split by ethnicity, indicating similar role of family and financial determinants in residential orientation of ethnic majority or minority groups. Somewhat surprisingly, we also find that the youngest generation—for both majority and minority ethnic groups—are less likely to live in the capital city than outside of the capital city urban region. This suggests that life course dynamics plays a role in shaping

the residential outcomes of tech workers, and urban living becomes the common option only in more established life stages. Finally, native-born minority tech workers have higher odds of living in the suburbs and in the rest of the country compared to the foreign-born tech workers.

SD2 Table 3. Multinomial regression with odds ratios (Exp(B)) of nationwide residential distribution of Estonian and Russian tech workers in 2021.

	Suburbs				Rest of Estonia			
	Overall	Majority	Minority 1	Minority 2	Overall	Majority	Minority 1	Minority 2
Ethnicity (ref.: majority)								
Minority	0.30*** (<0.001)				0.19*** (<0.001)			
Age (ref.:<25)								
25-34	0.65*** (<0.001)	0.66*** (0.002)	0.83 (0.653)	0.88 (0.755)	0.68*** (<0.001)	0.74*** (<0.001)	0.40*** (<0.001)	0.42*** (<0.001)
35-44	0.87 (0.279)	0.88 (0.350)	1.13 (0.758)	1.16 (0.707)	0.64*** (<0.001)	0.69*** (<0.001)	0.42*** (<0.001)	0.44*** (<0.001)
45-54	1.19 (0.211)	1.24 (0.150)	1.17 (0.726)	1.23 (0.649)	0.47*** (<0.001)	0.48*** (<0.001)	0.49** (0.021)	0.56* (0.058)
>54	1.32 (0.151)	1.33 (0.162)	1.30 (0.689)	1.55 (0.506)	0.67*** (0.005)	0.63*** (0.002)	1.08 (0.823)	1.48 (0.280)
Sex (ref.: female)								
Male	0.97 (0.604)	0.99 (0.900)	0.80 (0.250)	0.82 (0.314)	1.45*** (<0.001)	1.49*** (<0.001)	1.44** (0.019)	1.44** (0.020)
Children in household (ref.: no)								
Yes	2.48*** (<0.001)	2.46*** (<0.001)	2.63*** (<0.001)	2.56*** (<0.001)	1.18*** (<0.001)	1.18*** (<0.001)	1.12 (0.436)	1.09 (0.561)
Education (ref.: non-academic higher or other)								
Academic higher	0.80*** (0.001)	0.82*** (0.005)	0.75 (0.123)	0.82 (0.286)	0.80*** (<0.001)	0.82*** (<0.001)	0.70** (0.017)	0.78 (0.110)
Monthly income (ref.: <2000€)								
2000-2999€	1.21** (0.026)	1.25** (0.015)	1.06 (0.832)	1.04 (0.867)	0.88** (0.022)	0.93 (0.260)	0.64*** (0.007)	0.64*** (0.008)
3000-3999€	1.15 (0.132)	1.11 (0.278)	1.64** (0.047)	1.67** (0.040)	0.61*** (<0.001)	0.68*** (<0.001)	0.26*** (<0.001)	0.27*** (<0.001)
4000-4999€	1.18 (0.131)	1.26* (0.054)	1.03 (0.923)	1.08 (0.803)	0.48*** (<0.001)	0.54*** (<0.001)	0.22*** (<0.001)	0.24*** (<0.001)
>4999€	1.33*** (0.006)	1.29** (0.023)	1.79** (0.031)	1.87** (0.020)	0.49*** (<0.001)	0.55*** (<0.001)	0.19*** (<0.001)	0.20*** (<0.001)
Country of birth (ref.: native-born)								
Foreign-born				0.59*** (0.003)				0.50*** (<0.001)
N	11415	8931	2484	2484				
Nagelkerke R^2	0.16	0.07	0.13	0.14				
Log likelihood	-1089.55	-706.62	-339.31	-451.66				
Chi-Square (df)	1678.08 (24)	594.51 (22)	227.77 (22)	253.21 (24)				

Two-sided Wald chi-square tests. Reference: Tallinn. Significance levels: *p < 0.10; **p < 0.05; ***p <0.01. Minority 2: same population as Minority 1, with additional variable 'country of birth'.



Supplementary Fig. 1. Map of the neighbourhood units, districts and residential zones of Tallinn. Spatial data sources: neighbourhoods - Department of Geography, University of Tartu; waterbodies - Estonian Land Board 2021. Map created with QGIS 3.34.0.

Supplementary Table 1. Dissimilarity indices of Estonian majority and Russian minority working population living in Tallinn in 2021.

2021:	Tech minority	High minority	Middle minority	Low minority
Tech majority	33	42	47	53
High majority	34	42	48	54
Middle majority	30	35	40	46
Low majority	30	30	33	37
Tech minority		22	28	36
High minority	22		10	18
Middle minority	28	10		13
Low minority	36	18	13	

Supplementary Table 2. Mean share of ethnic Estonians in the neighbourhood of residence for different eth-class groups in Tallinn in 2021.

Eth-class group and year of arrival	Mean share (%)
Tech majority	63,8
High majority	65,0
Middle majority	61,3
Low majority	57,8
Tech minority, <1990	46,4
Tech minority, 1990-2014	50,8
Tech minority, >2014	56,9
Tech minority, native-born	47,9
High minority	45,5
Middle minority	42,8
Low minority	40,7

Supplementary Table 3. Relative share (%) of Tallinn inhabitants of Russian ethnicity in high occupations by occupational group and year of arrival in Estonia, in 2011 and 2021.

2011:	Tech	Non-tech	2021:	Tech	Non-tech
1989 or before	15.7	31.6	1989 or before	6.0	19.7
1990 - 2004	3.3	3.1	1990 - 2014	5.5	5.1
2005 or after	4.6	2.2	2015 or after	28.2	4.5
Born in Estonia	76.5	63.1	Born in Estonia	60.3	70.7

Supplementary Table 4. Neighbourhood typology based on the concentrations of Estonian majority and Russian minority tech workers, location quotients (LQ).

Majority LQ	Minority LQ	Neighbourhood typology
>1.2	>1.2	High majority - High minority
>1.2	<0.85	High majority - Low minority
<0.85	>1.2	Low majority - High minority
<0.85	<0.85	Low majority - Low minority
Other combinations		Mixed-ethnic neighbourhood

Supplementary References

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