

The unequal cycling boom in Germany

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ABSTRACT

Over the last two decades, cycling in Germany has increased by more than 40%. This paper analyses how this overall increase is broken down by group, characterised by residence (rural and smaller towns vs. medium-sized and larger cities) and education (high vs. low). It analyses (1) how the composition of the population changes according to these groups, (2) how cycling behaviour develops within these groups, and (3) how the changes in composition and behaviour shape the overall volume of cycling. Data on mobility behaviour comes from the large-scale, representative German Mobility Panel from 1996 to 2018, and the analytical sample covers information on more than 28,000 persons over approximately 730,000 reported trips. Data on changes in population composition comes from the German Socio-Economic Panel. Results show that the increase in cycling is unbalanced and largely a consequence of highly educated people in cities who now cycle twice as much and whose share of the population has doubled. This reveals that the cycling boom is bypassing important parts of the population, which limits the contribution of cycling to sustainability goals. Furthermore, the uneven evolution of cycling amplifies social inequalities in finances and health. Finally, this paper shows that increased cycling comes not only from changing behaviour within groups, but also from altered population composition. The most impactful compositional shift is the increasing level of education, which will likely continue to boost cycling.

1. Introduction and background

Governments around the world promote cycling because it is environmentally sustainable, contributes to liveable and attractive localities, and is an effective tool for individual and public health (Blitz et al., 2020; Garrard et al., 2021; Gehl, 2013; Gössling et al., 2016; Götschi et al., 2016; Larsen, 2017; Oja et al., 2011; Pucher et al., 2021). The World Health Organization (WHO) recommends a minimum of 150 min of moderate-intensity physical activity per week, and encourages cycling as a simple means to achieving this (Jacob et al., 2020; Martin et al., 2014; World Health Organization, 2019).

In light of these benefits of cycling, policy makers are enthusiastic about the observation that cycling is ‘booming’ in Germany (BMVI, 2019; Lanzendorf and Busch-Geertsema, 2014; Prognos, 2020). However, this paper reveals that this boom is highly uneven. I analyse cycling behaviour in Germany between 1996 and 2018 and show that the cycling boom is mainly driven by well-educated people in medium-sized and large cities who have changed their cycling behaviour and who account for an increasingly large share of the population. In the 1990s, group differences in cycling were relatively small. Since then, highly educated people in medium-sized and large cities have doubled their bicycle use and now spend two-thirds more time on their bicycles than

people in cities with low education, twice as much as people in rural areas with high education, and even three times as much as people in rural areas with low education. The high-cycling group of educated urban dwellers has also doubled in size, which is explained by moderate urbanisation and, most of all, by rapid educational expansion.

Differences in cycling between more urban and more rural areas are a focal point of the scientific community and policy makers alike. Much of cycling research deals with urban areas, and in many spatio-temporal contexts, such as contemporary Denmark (Olafsson et al., 2016), the Netherlands (Schwanen et al., 2004), the United States (Buehler et al., 2020), the United Kingdom (Department for Transport, 2020), and Germany (Nobis, 2019), cycling is higher in urban than in rural areas. Urban areas have a higher density of population and amenities, which means that more relevant destinations can be reached within acceptable cycling limits (Schwanen et al., 2004). Furthermore, in cities, people might opt to cycle instead of drive because of increasingly restricted car parking space (Handy et al., 2012; Kirschner and Lanzendorf, 2020). However, these higher cycling rates in cities do not necessarily mean that the association between population size and cycling rate is linear. In fact, in many European countries, the cities with the highest cycling rates have a population size between 100,000 and 300,000 inhabitants (Buehler and Pucher, 2021); and some of the relatively cycling-friendly

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cities in Northern America fall into that size category (Handy et al., 2012). Compared to very large cities, medium-sized cities benefit from the fact that a greater part of the city is within cyclable distance, commutes tend to be shorter, and traffic tends to be less heavy (Handy et al., 2012; Pucher and Buehler, 2006).

There are only few studies that examine the link between education and cycling in detail, but the available evidence from the United States (Buehler et al., 2020), the Netherlands (Kroesen and Handy, 2014; Scheepers et al., 2013), the United Kingdom (Carse et al., 2013; Goodman and Aldred, 2018), and Germany (Blitz et al., 2020; Buehler et al., 2019; Kreyenfeld and Konietzka, 2017), as well as from the urban areas of Paris (Brondeel et al., 2016), Brisbane (Rachele et al., 2015), and Bogota (Parra et al., 2018) suggest that people with higher education tend to have better access to cycling infrastructure and tend to cycle more. Note that educational level is a part of socioeconomic status (SES), but different aspects of SES, e.g. education and income, are not interchangeable. They have different and sometimes opposing effects on behaviour, including behaviours concerning health, sustainability, and status signalling (Blitz et al., 2020; Friehe and Mechtel, 2014; Geyer et al., 2006; Griskevicius et al., 2010; Huisman et al., 2005; Kroesen and Handy, 2014; Moav and Neeman, 2012; Pampel et al., 2010; Spellberg, 1996). Therefore, one cannot infer the impact of education on cycling from the research on income.

In Germany, only a smaller part of educational differences in cycling is explained by different probabilities of living in cycling-friendly neighbourhoods and cities (Hudde, 2021). Rather, these educational differences might be explained by the social meaning of cycling, group-specific social norms, and status signalling (Bourdieu, 1984; Frater and Kingham, 2020; Horton et al., 2016; Hudde, 2021; Steinbach et al., 2011). In tendency, cycling has more positive connotations among highly educated people, where it is considered a voluntary lifestyle choice that is associated with health and environmental friendliness – values that are increasing in importance (Brick et al., 2017; Elliott, 2013; Griskevicius et al., 2010; Horton et al., 2016; Kennedy and Horne, 2019; Steinbach et al., 2011). Meanwhile, among those with lower education, cycling tends to have more negative connotations and is more often interpreted as a forced behaviour and a sign of a lack of wealth (Horton et al., 2016; Steinbach et al., 2011). For a more detailed discussion of these arguments and analyses, see Hudde (2021).

To my knowledge, no study analyses time trends in the gradients of cycling by education and location size using representative data. Educational expansion is a far-reaching, global characteristic of modern societies (Breen, 2010; Lutz and Samir, 2011) that leads to greater mobility in general (Holz-Rau and Scheiner, 2019) but it is currently not a focal point of research on transport mode choice. However, education influences mobility behaviour and therefore it is relevant to study whether the growth in the share of the population with high education affects the prevalence of cycling.

2. Material and methods

2.1. Data

I analyse data on mobility behaviour from the nationally representative German Mobility Panel (MOP), waves 1996–2018 (Ecke et al., 2020), in combination with information on population composition by education and residence from the German Socio-Economic Panel (SOEP), Version 36 (Goebel et al., 2019). SOEP is Germany's longest-running and most important multi-topic household survey with high representativeness standards, especially concerning social inequality, and a large sample (Turek and Leopold, 2021). I apply survey weights and access the data via SOEPremote (a tool to access restricted data remotely) because the information on respondents' residence is not available in the scientific use file (Knies and Spiess, 2007).

MOP collects information on households, their members, and the trips they take during a seven-day period. Annual surveys are conducted

during fall, mainly between mid-September and mid-November. Cycling is highly seasonal, but this period roughly represents the yearly average (Nobis, 2019). The Eastern German regions are only covered by MOP starting in 1999. The main analysis combines data from both regions and, as described in section 4, I further conduct separate analyses for Eastern and Western Germany. Sampling in the MOP is stratified by type of area, household type, and household car ownership (Buehler et al., 2019). MOP covers a complete sample of 22,663 distinct individuals who participated in 2.1 waves on average (47,408 person-years) and reported an average of 23.9 trips per week or 3.4 trips per day (1,131,374 reported trips). The unit of analysis is person-years (from now on only called persons or individuals). The sample grew over time. It was relatively small in the first two years (1994: 517 individuals, 1995: 737), fluctuated roughly between 1000 and 1500 between 1996 and 2011, and then increased up to almost 2400 in 2018.

2.2. Sample selection

The waves 1994 and 1995 are dropped because information on city size is not available. In Germany, cycling rates are high among people in education, while senior people might cycle less for health reasons. Therefore, to keep the sample more homogeneous and avoid results heavily driven by students or people with health impairments due to age, I restrict the sample to people of typical working age (25 to 64 years). Individuals with missing information on the relevant variables, transport mode, trip duration or education, were dropped from the analysis (1.2% of persons).¹ The overall analytical sample covers 28,846 individuals with 730,074 reported trips.

2.3. Measures

Main outcome: minutes of cycling per week. Minutes of cycling per week is a direct measure of the (change in) cycling activity and is proportional to its positive health impact. To avoid results that are excessively driven by outliers, values above 420 min (1 h per day) are recoded to 420 min.

Grouping by location and education. The education measure is binary and distinguishes whether people have *Abitur*, a school-leaving certificate that is typically awarded after 12 or 13 years of schooling, or whether respondents have at maximum a lower educational school leaving certificate (*Hauptschulabschluss*, which is typically awarded after 9 years of schooling; *Mittlere Reife*, typically awarded after 10 years of schooling; or no school leaving certificate). The German educational system is tracked, i.e. at age 10, pupils are typically divided into one of three different school types; two of them prepare for vocational training (those that lead to *Hauptschulabschluss* and *Mittlere Reife*), and one academic track leads to *Abitur* and prepares for university education (Van de Werfhorst and Mijs, 2010). *Abitur* is the typical entry requirement for university and two-thirds or more of *Abitur*-graduates attend university (Reimer, 2013; Ziefle, 2016). Such a binary distinction is meaningful in the German case (Ziefle, 2016), and allows for an unambiguous and intuitive display and interpretation of results. This simple measure is also chosen because information on educational level is limited in MOP data. In the waves before 2013, there is no distinction between people who have a degree from a university (or university of applied sciences) and those that 'only' have the university entrance certificate (*Abitur*) but

¹ If individuals had missing information on education in one wave but valid information in another wave, the valid information was taken for all years.

no university degree. Therefore, the alternative binary distinction between people with and without a university degree is not possible in the German Mobility Panel.²

I use a binary measure to distinguish between people living in medium-sized and larger cities, defined as having at least 100,000 inhabitants, and those that live in smaller towns or villages. For brevity, these places are referred to as *city/urban* and *rural* for short. As shown below, a robustness check moves this cut-off value from 100,000 to 50,000 inhabitants.

3. Method

This paper traces cycling behaviour in aggregate and by subgroup (location and education) over 23 years. Observed cycling patterns in one specific year could be blurred by sampling error or the specific weather condition during one survey period. To account for this, all data are smoothed using local linear smoothing (Fan and Gijbels, 1996; Gutierrez et al., 2003).

Smoothing techniques, such as local linear smoothing, are used to identify trends or other relationships between variables without making strong prior assumptions about the shape of the association (Fan and Gijbels, 1996). Thus, the aim is to let 'the data themselves determine the functional relationship between the two variables' (Andersen, 2009, p. 68).

Here is a brief, non-technical description of the procedure. For (technical) details see e.g., (Fan and Gijbels, 1996) and (Gutierrez et al., 2003). To estimate a smoothed value – for example, cycling minutes for the year 2000 – we first define a window around that year, which is the bandwidth of the estimation. In this case, this bandwidth is defined as three years in both directions (1997–2003). The algorithm then runs a weighted linear regression over all observations within this bandwidth. The model is weighted such that observations have greater influence the nearer they are to the year 2000.³ The year-variable is centred at the year 2000 and the model's constant is extracted as the smoothed value for the year 2000. This procedure is repeated for each year: to estimate the value for the year 2001, another weighted regression is run for the observational window 1998 to 2004, and so forth.

The value for the bandwidth (the size of the window around the year) affects the smoothing result: a too small window makes the result too 'wiggly' or noisy, whereas a too large window produces an overly smooth estimate that ignores essential aspects of the underlying curve (Fan and Gijbels, 1996). A suitable bandwidth is chosen by graphical comparison of the raw data and the smoothed fit (Nichols, 2007). Fig. A1 in the appendix compares the chosen bandwidth with a larger and a smaller bandwidth (the bandwidth from the main analyses multiplied by 1.5 and divided by 1.5) and demonstrates that the main pattern remains stable.

4. Results

4.1. Change in the composition of the population

Fig. 1 and Table 1 show how the composition of the population shifted over time. The most remarkable change is educational expansion, manifested in the constantly growing share of people with high education. Overall, the share of highly educated people has almost

² In addition, there is no consistent information on vocational training. Such information on vocational training would be needed to rank education according to established comparable classifications (e.g. the International Standard Classification of Education, ISCED). Note that similar limitations apply to the other large-scale, nationally representative mobility survey, Mobility in Germany (Huddle, 2021).

³ The weighting follows the Epanechnikov distribution, which is widely used and is the default in Stata's `lply`-command.

doubled from 20.3 to 38.3% (+88.7%). From the beginning, residents of medium-sized and larger cities were more often highly educated than those in rural areas and smaller towns, and that gap has stayed constant in relative terms: in the cities, the share of highly educated rose from 26.7 to 49.8% (+86.6%); in the rural areas and smaller towns it rose from 17.3 to 32.5% (+88.5%). At the same time, there was slight urbanisation, as the share of people living in medium-sized and larger cities rose from 32.2 to 33.1%, a rise of 0.9 percentage points or 2.8%.

Consequently, the group of highly educated residents of medium-sized and larger cities has seen the biggest gains, almost doubling (from 8.6 to 16.5%), and the group of residents of rural areas and smaller towns with lower education has seen the biggest losses, declining by approximately one fifth (from 56.1 to 45.2%).

4.2. Change in cycling behaviour within groups

Before focusing on cycling behaviour, Fig. 2 provides an overview of overall mobility patterns and plots the modal split by group for the first and last year of observation. Over time and in all groups, the car is the most widely used means of transport, followed by walking. The car has a higher mode share in the smaller towns and rural areas and, within localities, among those with lower education. The share of walking-trips is higher in medium-sized and larger cities than in smaller towns and rural areas, and there are only relatively small changes over time. A slight tendency is an increase in walking among city residents and a decrease among those with lower education in smaller towns and rural areas. As one would expect, the use of public transport is higher in the cities. Overall, the largest observed shift is the increase in cycling and the decrease in driving among highly educated city residents. This figure also suggests that this increase in cycling has not been at the expense of walking and public transport, but at the expense of the car.

Fig. 3 shows changes in the average time spent cycling and the share of the population that spends at least 150 min per week cycling (see also Table 2). The bold dashed line shows the evolution for all groups combined. Cycling increased considerably: in 1996, people spent an average of 25.9 min per week cycling, and in 2018, an average of 36.9 min – a rise of 42.5%.

The figure also breaks down the cycling patterns by the four groups. At the beginning of the observation, there are only moderate differences in cycling – people living in cities and with high education spend around one-third more time cycling than the other groups – but confidence intervals overlap. However, the four groups show markedly different trajectories. Among city residents with high education, cycling increased by 35.0 min, which means that it doubled (+99.4%). City residents with low education increased their cycling by 16.5 min, which represents an increase of almost two-thirds (+63.7%). Rural residents with high education also increased cycling by 4.8 min or 17.7%. There is practically no change among rural residents with low education (+1.0 min; +4.1%). In 2018, those in cities and with high education spend almost three times as much time cycling than those in rural areas with low education, more than twice as much as those in rural areas with high education, and two-thirds more than their urban co-residents with low education.

Two distinct periods can be identified in these time trends. The first goes from 1996 to around 2008, the second from about 2008 to 2018. For all groups combined, the largest part of the increase in cycling happened during the first period (from 25.8 to 35.5 min; +37.6%), where cycling increased in all groups, most strongly among the educated city residents (+61.4%, compared with 22.9 to 30.0% in the other groups). During the second period, the overall increase in cycling levelled off; it only rose from 35.5 to 36.9 min (+4.0%). The novelty during the second period is that the groups are now showing opposite trends: further major increases among city residents with high (+23.6%) and low education (+26.6%), but decreases among rural residents with high (–4.2%) and low education (–19.9%).

How relevant are these changes and differences to individuals and

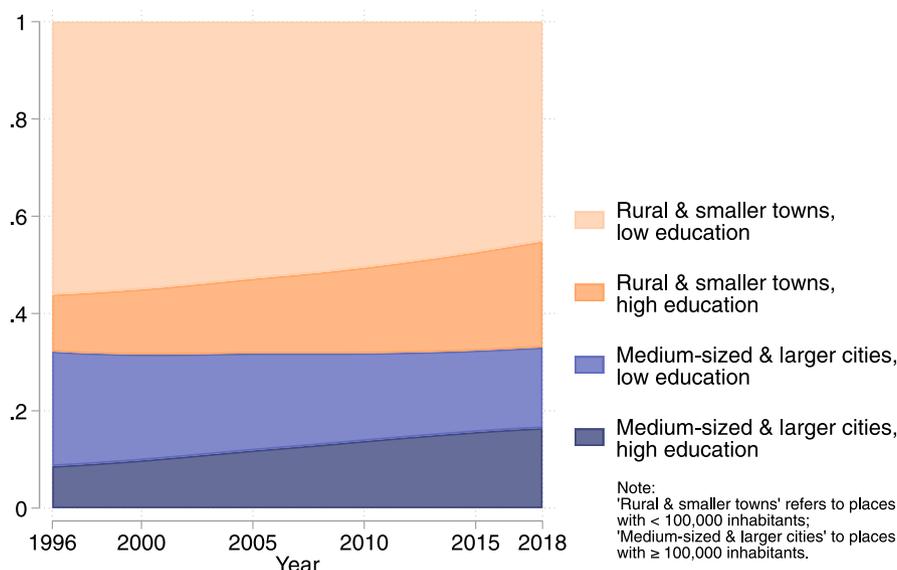


Fig. 1. Change in the composition of the population. Data is smoothed using local linear smoothing.

Table 1

Composition of the population. Data source: German Socio-Economic Panel (SOEP). Survey weights are applied for the population shares; 'N' refers to the unweighted sample size.

Year	Medium-sized & larger cities, high education	Medium-sized & larger cities, low education	Rural & smaller towns, high education	Rural & smaller towns, low education	N
1996	8.6%	23.6%	11.7%	56.1%	8693
1997	8.9%	23.1%	12.1%	55.9%	8596
1998	9.2%	22.6%	12.6%	55.6%	9329
1999	9.5%	22.2%	13.0%	55.3%	9167
2000	9.8%	21.8%	13.4%	55.0%	16,304
2001	10.2%	21.4%	13.8%	54.6%	14,641
2002	10.6%	21.0%	14.2%	54.2%	15,762
2003	11.0%	20.6%	14.6%	53.8%	14,633
2004	11.5%	20.3%	15.0%	53.3%	14,107
2005	11.9%	19.9%	15.4%	52.8%	13,307
2006	12.2%	19.6%	15.8%	52.4%	14,054
2007	12.6%	19.2%	16.2%	52.0%	13,050
2008	13.0%	18.8%	16.6%	51.6%	12,156
2009	13.4%	18.4%	17.1%	51.1%	12,652
2010	13.8%	18.0%	17.6%	50.6%	17,806
2011	14.2%	17.7%	18.1%	50.0%	18,745
2012	14.6%	17.4%	18.6%	49.4%	18,064
2013	15.0%	17.1%	19.1%	48.8%	18,153
2014	15.3%	16.9%	19.7%	48.1%	15,934
2015	15.6%	16.7%	20.2%	47.4%	14,973
2016	16.0%	16.6%	20.7%	46.7%	14,948
2017	16.2%	16.6%	21.3%	45.9%	17,073
2018	16.5%	16.6%	21.8%	45.2%	15,794

their health, and how many people engage in sufficient levels of physical activity, just by cycling? The WHO recommends a minimum of 150 min per week. All groups combined, the share of people that achieve the 150 min by cycling alone almost doubled (5.1% to 9.3%; right panel of Fig. 3). In 1996, there were moderate differences between the groups: 7.4% of city residents with high education reached the 150 min, compared to values between 4.5 and 5.6% in the other categories. In 2018, major inequalities emerged: one in five city residents with high education achieves 150 min of cycling (19.9%), compared to around one in twenty rural residents with low education (5.7%).

4.3. Combining change in the composition and change in behaviour

Fig. 1 shows that the composition of the population has shifted, and Fig. 3 shows that group-specific behaviour has changed. Fig. 4 brings both together for the years 1996, 2008, and 2018. Each of the bars shows the relative size of the population group (x-axis) and the average cycling behaviour of that group (y-axis). The aggregate area of all four bars represents the total cycling volume and the area of the individual bars the contribution of a population group to the aggregate. Between 1996 and 2008, there is a total increase in cycling volume and an increase in the fraction that city respondents with high education contribute to this total. Compositional changes among the three other groups – fewer people with low, and more people with high education in rural areas – have a minor impact, because these groups show similar behaviour. In sum, the increase during this first period is mainly driven by behavioural changes. The picture is different for the period between 2008 and 2018. The behaviour between groups diverges, and the composition of the population shifts to the benefit of the highest-cycling and to the detriment of the lowest-cycling group, which increases the overall cycling volume.

At all times, highly educated urban residents cycled more than the other groups. However, in 1996, that group comprised a small fraction of the population, and therefore its contribution to the overall cycling intensity was limited. In 1996, the group of highly educated urban residents contributed to 11.6% of the overall cycling volume. In 2008, that number was at 20.8% and in 2018 at 31.4%. These numbers show how group-specific changes in behaviour and educational expansion lead to a vast reshaping in the German cycling landscape.

To illustrate the relative importance of the changing group composition, here are three what-if-calculations (Das Gupta, 1993). How would overall cycling have evolved if the group-specific behaviour had changed as observed, but the group size had remained unchanged? Between 1996 and 2018, the average cycling minutes would have increased by 30.9% (from 25.9 to 33.9 min), instead of the observed 42.5% (from 25.9 to 36.9 min). During the first period (1996 to 2008), cycling increased by 36.9% and, with a constant composition of the population, would have increased by 32.7%. During the second period (2008 to 2018), cycling increased by 4.0% and would have even slightly decreased by 0.2% if it was not for compositional change. These figures show that 27% (100%–30.9%/42.5%) of the increase in cycling during the entire period, and all of the increase between 2008 and 2018 could only happen because of the shift in the population composition and

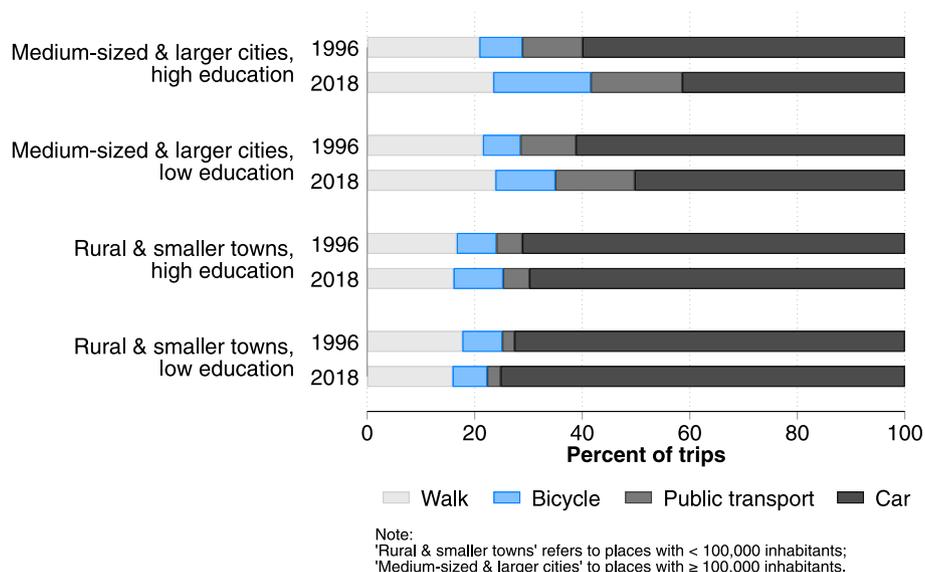


Fig. 2. Modal split, by group of residence and education in the first and last year of observation.

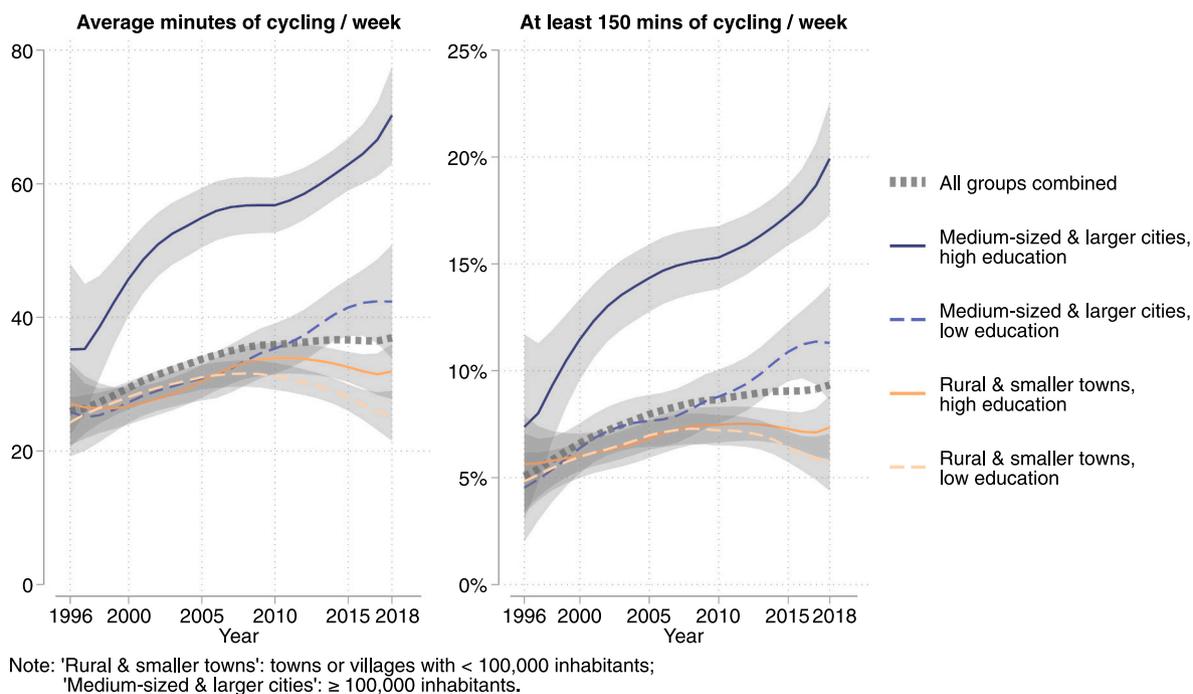


Fig. 3. Change in average minutes of cycling per week, by group of residence and education. Data is smoothed using local linear smoothing. 95% confidence intervals are displayed.

educational expansion.

5. Further analyses and robustness checks

The figures from these further analyses and robustness checks can be found in the online appendix (except for Fig. 5, which is presented here).

Cycling patterns within trip distances. The conclusions and implications from these analyses would be different if the divergence in cycling by population groups were only explained by people's trip distances, and not by changes in their decision-making. Therefore, I further analyse the groups' cycling behaviour *within* trip distances. I compare four distance categories: (a) below 1.5 km, (b) 1.5 to 4.9 km, (c) 5 to 9.9 km, and (d) 10 to 15 km. Together, these distance groups account for more than 80%

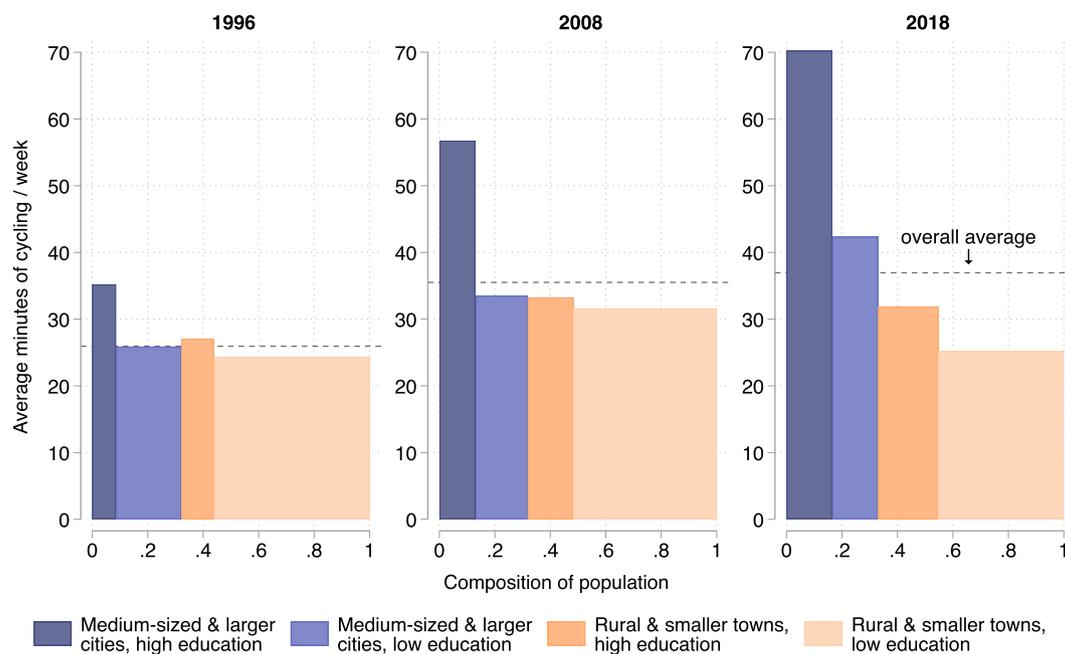
of all trips taken.

Fig. 5 plots these analyses. Results for all trip distances of at least 1.5 km are similar to the main results from this article, as described in section 3.2. For trips below 1.5 km, where walking is the most common means of transport, the groups show relatively similar cycling levels and trends. Interestingly, cycling among those with high education living in medium-sized and larger cities has particularly increased for trip distances between 5 and 15 km over the last ten years. In the three higher categories, those with high education living in medium-sized and larger cities are now 2.5 to 4 times more likely to cycle than those with lower education in smaller towns and rural areas. Overall, these results show that the divergence in cycling behaviour also holds when analysing changes within given trip distances.

Table 2

Average minutes of cycling by years and group. Data source: German Mobility Panel. ‘Cycling minutes’ refers to the average minutes of cycling per week; 95%-confidence intervals are displayed in brackets; ‘N’ refers to the unweighted number of observations in the data.

Year	All groups		Medium-sized & larger cities, high education		Medium-sized & larger cities, low education		Rural & smaller towns, high education		Rural & smaller towns, low education	
	cycling minutes	N	cycling minutes	N	cycling minutes	N	cycling minutes	N	cycling minutes	N
1996	25.9 [23.1;28.8]	1015	35.2 [22.3;48.1]	96	25.9 [19.2;32.6]	186	27.1 [20.9;33.3]	198	24.3 [20.6;28.0]	535
1997	26.4 [24.2;28.5]	1033	35.3 [25.6;45.0]	110	25.1 [20.0;30.1]	205	26.5 [21.9;31.2]	199	25.5 [22.6;28.3]	519
1998	27.3 [25.5;29.0]	994	38.5 [30.9;46.2]	114	25.3 [21.3;29.3]	209	26.4 [22.7;30.1]	189	26.4 [24.1;28.7]	482
1999	28.3 [26.8;29.8]	1252	42.3 [35.9;48.6]	140	26.2 [22.8;29.6]	272	26.4 [23.3;29.5]	244	27.3 [25.3;29.3]	596
2000	29.5 [28.1;30.8]	1027	45.8 [40.3;51.2]	122	27.3 [24.2;30.4]	209	26.7 [24.0;29.4]	183	28.1 [26.3;29.9]	513
2001	30.5 [29.2;31.8]	1286	48.7 [43.7;53.7]	155	28.3 [25.3;31.3]	245	27.2 [24.7;29.8]	247	28.8 [27.1;30.6]	639
2002	31.4 [30.1;32.7]	1125	50.9 [46.2;55.7]	159	29.0 [26.1;32.0]	207	27.8 [25.4;30.3]	217	29.5 [27.7;31.2]	542
2003	32.2 [30.9;33.5]	1278	52.6 [47.9;57.2]	196	29.7 [26.6;32.7]	191	28.5 [26.1;31.0]	312	30.0 [28.2;31.8]	579
2004	33.0 [31.6;34.3]	1194	53.7 [49.2;58.2]	182	30.3 [27.2;33.5]	188	29.4 [27.0;31.8]	296	30.5 [28.7;32.3]	528
2005	33.8 [32.4;35.1]	1123	54.9 [50.5;59.4]	168	30.9 [27.6;34.2]	177	30.4 [28.0;32.8]	304	31.1 [29.2;32.9]	474
2006	34.4 [33.0;35.8]	1009	56.0 [51.6;60.3]	167	31.4 [27.9;34.9]	153	31.5 [29.0;33.9]	265	31.3 [29.4;33.2]	424
2007	35.0 [33.6;36.4]	989	56.5 [52.2;60.8]	177	32.4 [28.8;35.9]	138	32.5 [30.1;35.0]	280	31.5 [29.6;33.5]	394
2008	35.5 [34.1;36.9]	1086	56.8 [52.5;61.0]	169	33.5 [29.8;37.2]	173	33.3 [30.8;35.7]	320	31.6 [29.6;33.6]	424
2009	35.8 [34.5;37.2]	979	56.8 [52.6;61.0]	184	34.6 [30.9;38.3]	145	33.7 [31.3;36.1]	271	31.5 [29.5;33.5]	379
2010	35.9 [34.6;37.3]	1034	56.8 [52.7;60.9]	208	35.3 [31.6;39.1]	135	33.9 [31.5;36.3]	304	31.2 [29.2;33.2]	387
2011	36.1 [34.8;37.5]	1016	57.5 [53.5;61.5]	210	36.2 [32.4;40.0]	116	33.9 [31.6;36.3]	309	30.8 [28.8;32.8]	381
2012	36.3 [34.9;37.6]	1089	58.5 [54.6;62.4]	201	37.3 [33.5;41.1]	138	33.8 [31.5;36.0]	322	30.3 [28.4;32.2]	428
2013	36.5 [35.2;37.8]	1450	59.8 [56.1;63.6]	304	38.9 [35.0;42.7]	189	33.5 [31.3;35.7]	418	29.7 [27.8;31.6]	539
2014	36.7 [35.3;38.0]	1665	61.3 [57.6;65.1]	321	40.4 [36.4;44.3]	225	33.1 [30.9;35.3]	505	29.0 [27.1;30.9]	614
2015	36.6 [35.2;38.1]	1695	62.9 [59.0;66.8]	354	41.5 [37.2;45.7]	226	32.6 [30.3;34.8]	520	28.0 [26.0;30.0]	595
2016	36.5 [34.9;38.1]	1762	64.5 [60.1;68.9]	328	42.2 [37.3;47.1]	235	31.9 [29.4;34.5]	560	27.0 [24.7;29.2]	639
2017	36.5 [34.4;38.5]	1887	66.6 [61.1;72.1]	385	42.4 [36.1;48.7]	241	31.5 [28.4;34.6]	583	26.0 [23.1;28.8]	678
2018	36.9 [34.2;39.7]	1858	70.2 [63.0;77.5]	440	42.4 [33.9;50.9]	210	31.9 [27.8;36.0]	618	25.3 [21.5;29.0]	590



Note: ‘Rural & smaller towns’: towns or villages with < 100,000 inhabitants; ‘Medium-sized & larger cities’: ≥ 100,000 inhabitants.

Fig. 4. Composition of the population and group-specific cycling behaviour.

5.1. Different cut-off value for city size

Cities with a population between 50,000 and 100,000 are diverse in their degree of urbanity and mobility behaviour. Therefore, I perform a robustness check that moves the cut-off value to distinguish between ‘medium-sized and larger cities’ and ‘smaller towns and rural areas’ from 100,000 to 50,000 inhabitants. Empirically, cycling behaviour in cities with 50,000 to 100,000 inhabitants lies between the behaviour in smaller and larger places. With this change, the broader results of

growing behavioural gaps by residence and education remain unchanged. When looking at this re-categorisation in more detail, the urban-rural divide is already visible in 1996 and the decline in cycling among those with low education in the smaller towns and rural areas shows even more drastically.

5.2. Adjusting for changes in the gender- and age-composition

The age- and gender-composition of the location- and education-

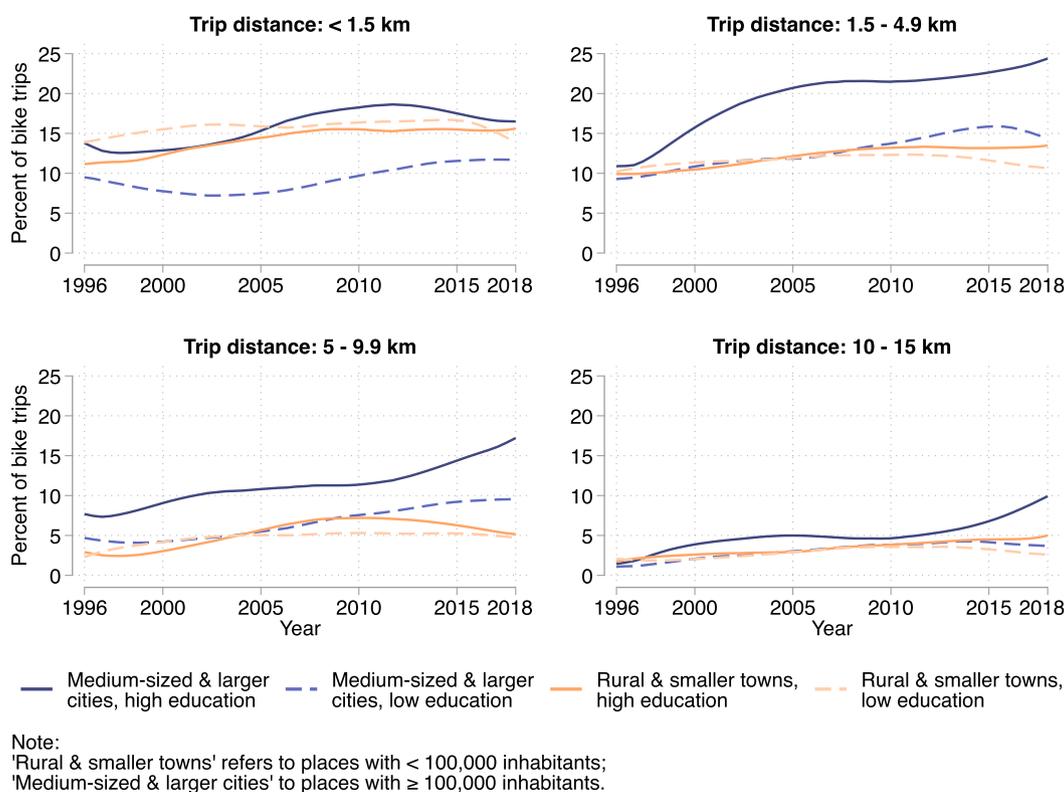


Fig. 5. Group-specific cycling behaviour, by trip distance.

groups have changed over time (see Table A1 in the Online Appendix) and these changes may confound observed behavioural trends in the groups (Aldred et al., 2016). Gender and age affect the likelihood of being highly educated and living in a large city; and these variables could also affect cycling behaviour (even though previous findings from Germany suggest little difference in cycling by age and gender groups, Buehler and Pucher, 2021; Goel et al., 2021; Nobis, 2019). To rule out that this paper's key findings are simply driven by such compositional changes, I conduct analyses in which gender and age are held constant over time within education and location groups.

Here are the three technical steps of this procedure. First, I run linear regression models that control for gender and age. These models are run separately for the four location- and education-groups, and age enters with dummy variables for ten-year age groups. Second, to attain the age- and gender-adjusted values, I compute predicted values of cycling minutes for the age- and gender-composition of the year 1996 and add individuals' residual values to this. Third, I compare these counterfactual age- and gender-adjusted values to the unadjusted, observed values (see Fig. A4). The adjusted curves can be interpreted in the following way: if the age- and gender-composition had remained unchanged at the levels of 1996, this is how cycling patterns would have evolved.

The adjusted and unadjusted values produce similar curves and lead to the same broader conclusions. In more detail, results suggest that, if age- and gender-composition had remained constant, overall contemporary cycling rates would be marginally lower than the actual observed rates. Furthermore, if the age- and gender-composition had remained unchanged, the gap between the highly educated in the cities and those that live in more rural areas would be even larger. In sum, this shows that the main findings of this paper are robust against controlling for the age- and gender-composition of the population. It would further be interesting to hold ethnicity/migration background constant, but such information is not available in the data.

5.3. Analysing Eastern and Western Germany separately

As noted in the main text, the Eastern German federal states are only covered by MOP starting in 1999. The main analysis combines data from all German regions and Fig. A2 shows separate analyses for Eastern and Western Germany. In broad terms, patterns are similar in Eastern and Western Germany. Given that four out of five Germans live in the Western federal states, the overall picture is largely driven by the patterns in Western Germany. With a more detailed look, the regions show two relevant differences. First and foremost, in Eastern Germany cycling declined in all groups between 2008 and 2018. However, the relative evolution between the groups is the same as in the Western federal states; that is, the decline was most pronounced among people with low education in rural areas (-32.3%) and least pronounced among people with high education in cities (-6.1%). Therefore, cycling patterns diverge by education and residency in both regions. The second difference is that, in 2018, the group differences are somewhat more moderate in Eastern than in Western Germany.

6. Discussion

This paper offers a brief overview of group-specific cycling trends and compositional change in the German population over the last two decades, using representative data from 23 waves of the German Mobility Panel. Overall, cycling has increased by more than 40% between 1996 and 2018, but this 'boom' is highly unequal. Group differences were relatively minor in the 1990s, but today, well-educated people in medium-sized and larger cities cycle two-thirds more than people in the second highest group, those with lower education in cities, and almost three times as much as people with lower education in rural areas and smaller towns. The overall increase in cycling is not only driven by altered behaviour of group members, but also by changes in the composition of the population, most notably, educational expansion. In fact, the increase in cycling during the last decade would not have

occurred without educational expansion – a factor that should be on the radar of mobility research.

These brief analyses have limitations. The data source, the German Mobility Panel, is a unique resource because it collects detailed and reliable information about respondents' mobility behaviour and allows to trace mobility patterns over more than two decades with one coherent source. However, this contrasts with limited information on socio-demographic aspects, including education. The school leaving certificate is reported in all waves, but vocational training involvement is not – a limitation that these data share with the other major mobility survey, Mobility in Germany. This paper takes a macro-level perspective; that is, it focuses on societal groups rather than individuals. Inevitably, this leaves interesting questions and details untouched. For instance, future research could trace individuals from a life course perspective and study at what point people with high and low education in rural and urban settings start to differ in their mobility behaviour (see e.g., Elder et al., 2003; Janke and Handy, 2019; Scheiner, 2014; Scheiner et al., 2016). Another interesting avenue would be to compare small-scale regional entities over time and test to what degree their level and trend in cycling is driven by the educational composition of their population and changes therein. Mobility behaviour, and cycling in particular, is highly context-dependent. Future research could therefore assess whether the patterns identified here replicate in different societies. Is the divergence in cycling by residence and education observable in other countries? Is educational expansion similarly important for changes in cycling around the world?

Cycling is a healthy and inexpensive means of transport that

contributes to environmental sustainability; hence Germany's cycling 'boom' is applauded. The finding that this boom is unbalanced has relevant implications. First, people with less education have poorer health and fewer financial resources, and cycling could help with both, but the opposite is taking place, because the educational gap in cycling is large and increasing (Hendi, 2017; Mäki et al., 2013; Zajacova et al., 2021). Second, governments at different levels around the world are investing heavily in cycling-related infrastructure, in many cases redistributing resources to the detriment of drivers and in favour of cyclists (Sheldrick et al., 2017; Wang, 2018). If the well-educated benefit disproportionately from such changes, these policies have the unintended side-effect of reinforcing social inequalities. Third, the cycling boom is bypassing relevant parts of the population, which represents untapped potential for the contribution to sustainability goals. Suppose policy makers want to reduce such inequalities and realise the full potential of cycling for health and sustainability. In that case, they need targeted policies that reach those who stand aside from the current cycling boom: people outside the bigger cities and with less education (Braun et al., 2019; Parra et al., 2018). Finally, the shift of the population towards higher education, which can be observed in all modern societies, is a driver behind the increase in cycling. This is good news for the future of cycling: the educational expansion will by all expectations continue and thus further boost cycling.

Author statement

Not applicable, because the paper is single-authored.

Appendix A. Appendix

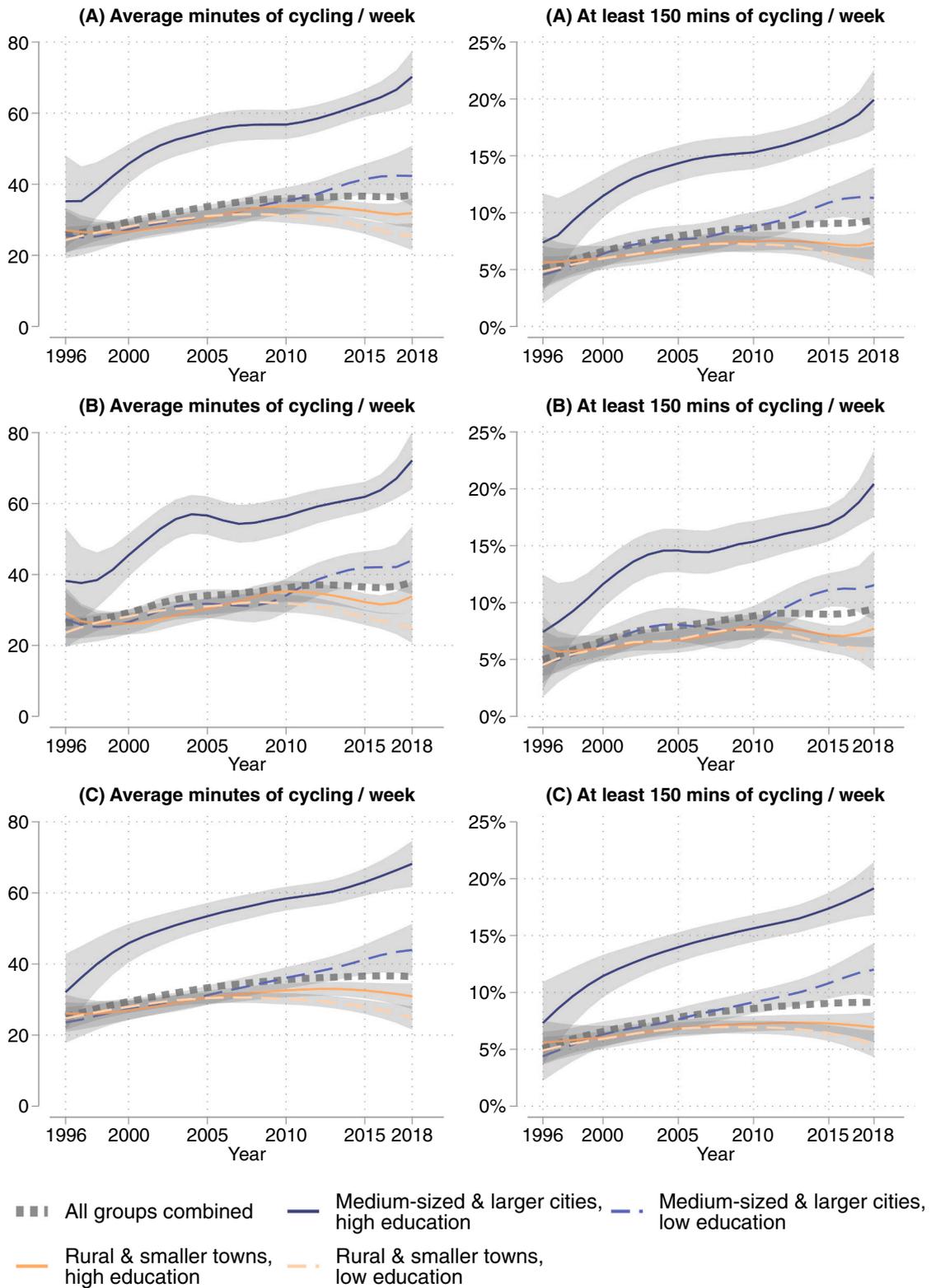


Fig. A1. Comparing different bandwidths for smoothing the data. (A) denotes the bandwidth of the main analyses, (B) a smaller bandwidth, and (C) a larger bandwidth.

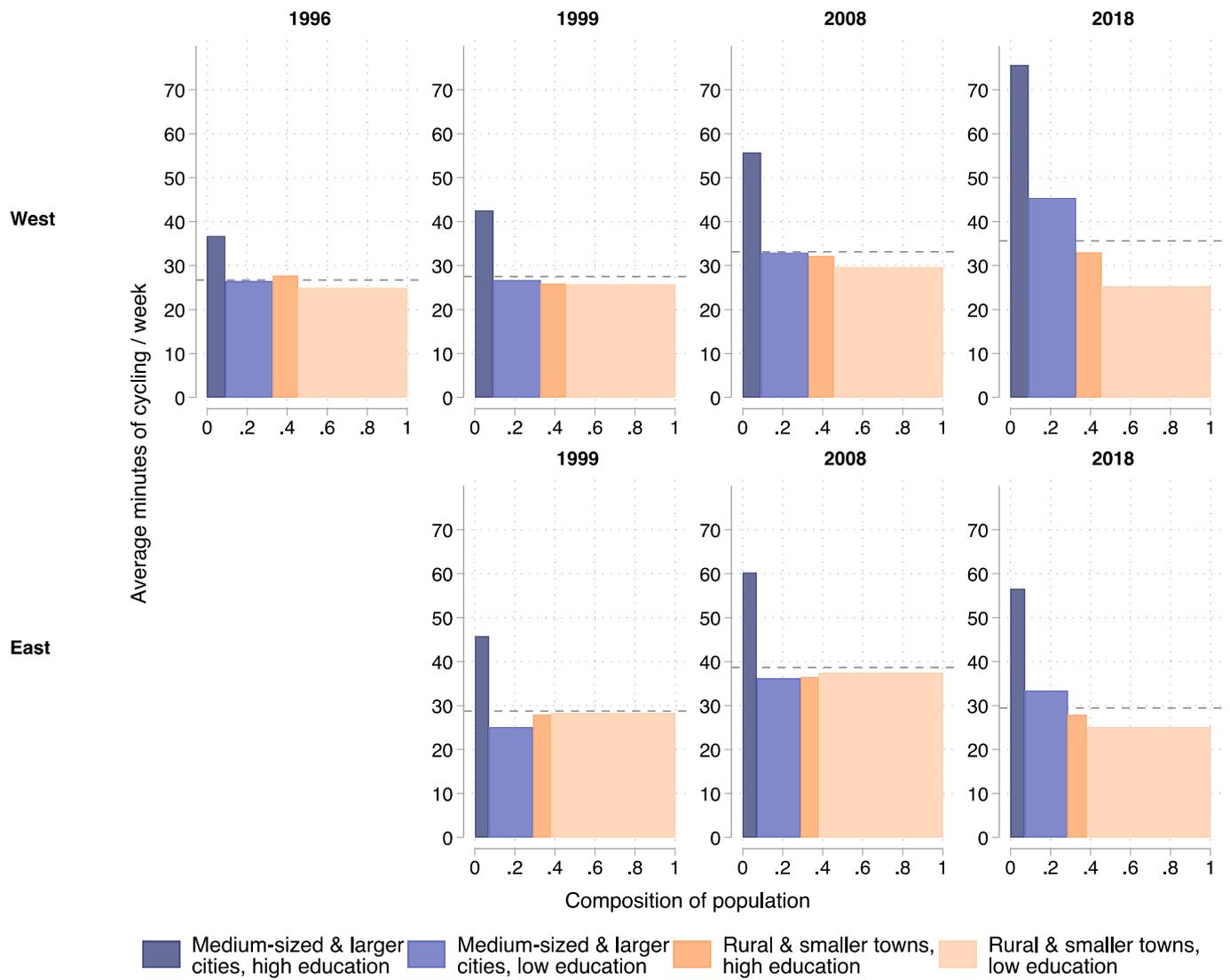
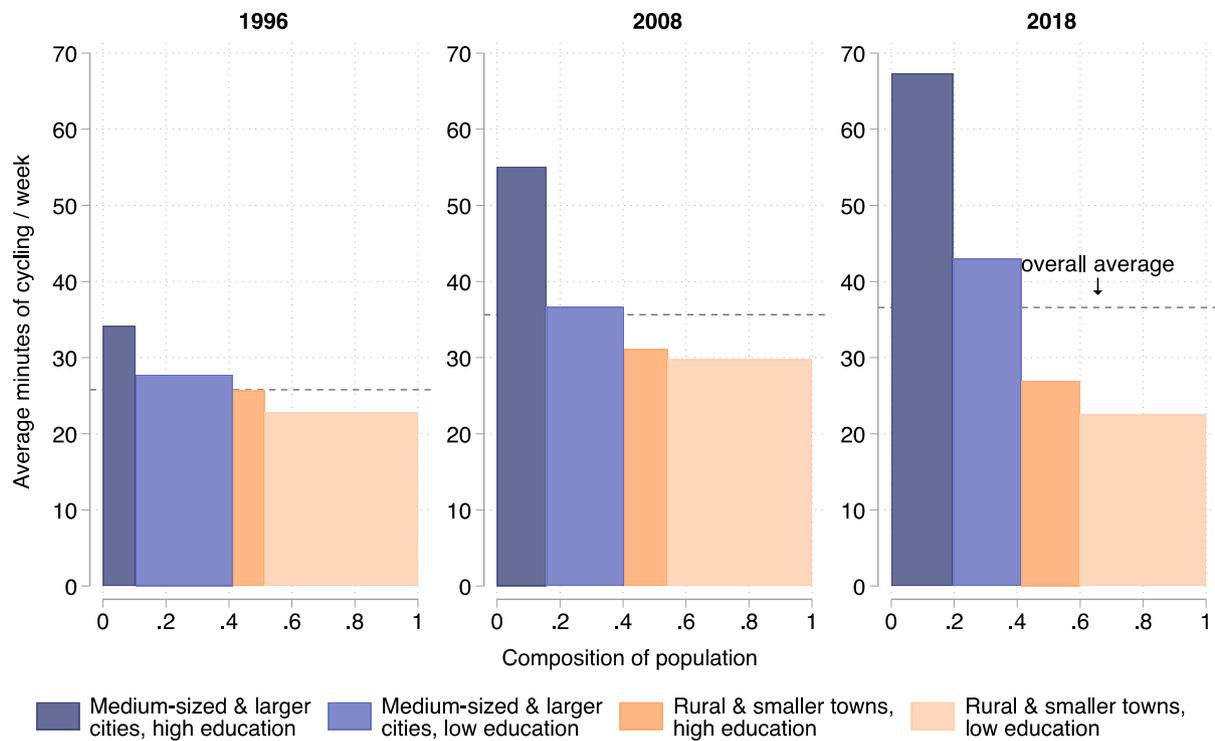


Fig. A2. Comparing Eastern and Western Germany. Data for Eastern Germany is only available for 1999 onwards.



Note: 'Rural & smaller towns': towns or villages with < 50,000 inhabitants; 'Medium-sized & larger cities': ≥ 50,000 inhabitants.

Fig. A3. Changing the cut-off value for the distinction between 'medium-sized and larger cities' and 'rural areas and smaller towns' from 100,000 to 50,000 inhabitants.

Table A1

Average age and share of women by location and education. Data source: German Socio-Economic Panel (SOEP). Survey weights are applied.

Year	All groups		Medium-sized & larger cities, high education		Medium-sized & larger cities, low education		Rural & smaller towns, high education		Rural & smaller towns, low education	
	Ø age	% women	Ø age	% women	Ø age	% women	Ø age	% women	Ø age	% women
1996	43.8	49.9%	39.9	43.3%	45.5	52.7%	39.8	39.3%	44.5	51.8%
1997	43.9	49.6%	39.5	42.8%	46.0	52.4%	39.8	39.0%	44.6	51.7%
1998	44.2	49.7%	40.4	44.6%	46.2	52.1%	40.2	40.8%	44.9	51.5%
1999	44.4	49.5%	40.0	44.7%	46.6	51.4%	40.9	41.1%	45.1	51.5%
2000	44.4	49.6%	40.4	45.1%	46.2	51.9%	41.6	41.6%	45.2	51.6%
2001	44.5	49.5%	40.6	46.2%	46.4	51.3%	42.0	41.6%	45.2	51.5%
2002	44.7	49.3%	40.9	45.4%	46.4	51.1%	42.1	42.5%	45.4	51.2%
2003	44.6	49.5%	40.9	46.3%	46.2	51.0%	41.9	44.1%	45.4	51.1%
2004	44.6	49.2%	40.6	45.0%	46.4	50.6%	42.1	44.9%	45.5	50.8%
2005	44.1	49.6%	40.0	46.5%	46.2	49.5%	42.0	47.2%	44.9	51.1%
2006	44.3	49.3%	40.0	46.5%	46.3	49.5%	42.3	46.8%	45.1	50.6%
2007	44.3	49.6%	40.2	47.9%	46.3	49.1%	42.3	46.9%	45.3	51.0%
2008	44.5	49.4%	40.2	47.0%	46.3	49.0%	42.4	45.9%	45.5	51.1%
2009	44.6	49.3%	40.3	47.8%	46.6	48.6%	42.4	46.7%	45.8	50.9%
2010	45.0	49.2%	40.9	46.1%	46.8	50.2%	42.7	48.6%	46.4	50.0%
2011	45.2	49.7%	40.8	47.6%	46.8	50.2%	43.0	48.6%	46.6	50.5%
2012	45.3	49.6%	40.9	47.5%	46.7	50.7%	43.2	49.0%	46.8	50.0%
2013	45.4	50.0%	41.0	48.7%	46.6	50.4%	43.3	48.1%	47.2	50.9%
2014	45.5	50.0%	41.2	49.1%	46.9	49.2%	43.2	49.2%	47.4	51.0%
2015	45.6	49.8%	41.3	48.4%	47.0	48.6%	43.4	49.9%	47.5	50.6%
2016	45.6	49.4%	41.0	49.2%	46.7	46.1%	43.7	49.3%	47.6	50.6%
2017	45.6	49.1%	41.2	48.5%	46.7	48.4%	43.9	48.9%	47.5	49.6%
2018	46.0	49.0%	41.7	46.6%	46.9	48.8%	44.3	49.0%	47.9	50.0%

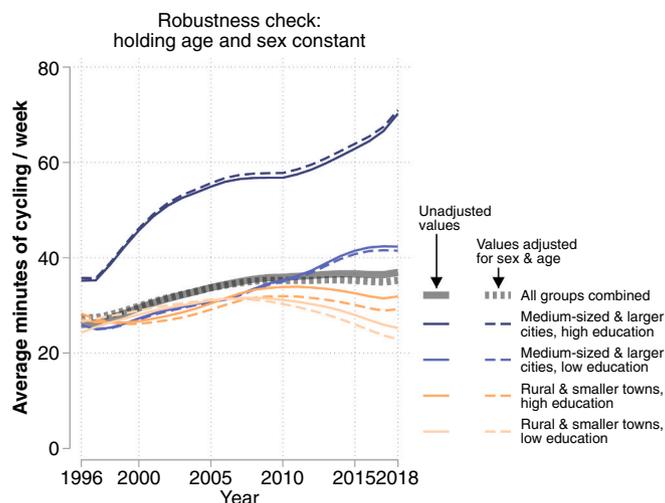


Fig. A4. Adjusting for changes in the gender- and age-composition (comparing observed or unadjusted behavioural changes to the counterfactual of a gender- and age-composition that remains constant at the values of 1996 [adjusted values]).

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