The city as a driver of new mobility patterns, cycling and gender equality: Travel behaviour trends in Stockholm 1985-2015

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Abstract
We analyse changes in individual travel behaviour in Stockholm County over 30 years, using three large cross-sectional travel survey data sets. We show how travel patterns diverge over time between city, suburban and rural residents. We relate these diverging travel patterns to changes in the labour market, ICT use and the digital/knowledge economy, land-use and transport policy, increased gender equality, and population size, composition and location.

Keywords: Travel behavior, Land use policy, Urban, Agglomeration, Car use, Bicycling, ICT

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1 INTRODUCTION

There are indications that trends in travel behaviour, including car and bicycle use, are diverging between inner cities, suburban and rural areas in many parts of Europe, for instance in Sweden and England (Bastian and Börjesson, 2015; Transport for London, 2016; UK Department for Transport, 2016). It appears that similar agglomeration types across Europe - in terms of city size, density and economy - rather than national territories are experiencing similar trends in travel behaviour. In this study, we use unique travel survey data, conducted in Stockholm County in 1986, 2004 and 2015, to study how travel patterns in different socio-economic groups diverge between city, suburban and rural residents. We compare it to travel survey data conducted in Sweden as a whole.

We find that, in the core of Stockholm, bicycle and transit trip shares are increasing and car trip shares are declining. Trip distances are increasing in the rest of Sweden, but not in Stockholm County, and they are even decreasing in central Stockholm.

One reason for the divergence of travel behaviour trends could be that societal trends are strong in cities. Stockholm, in particular, is a world leader in four societal trends: increasing gender equality, ICT adoption, the related shift towards a digital/knowledge economy, and introduction of congestion charges. The literature is scarce on the long-term and aggregate effects of the latter three societal trends on travel behaviour. We explore these effects for Stockholm.

The impact of gender divisions of labour on travel behaviour is well documented, and some sociologists argue that gender roles also shape the spatial structure of urban regions (England, 1991; Markusen, 1980; Massey, 1995). Our findings suggest that the inner-city agglomeration and the increasing specialization of Stockholm's labour market reduce gender differences in commuting.

There are strong reasons to believe that ICT use (Mokhtarian and Tal, 2013; Mokhtarian et al., 2006) and a more knowledge-based economy shape travel behaviour through several, partially opposing mechanisms. Our results suggest that the main effects lie not in working from home, but in: 1) declining trip frequencies, particularly for daily leisure, service and shopping activities, and most strongly among teenagers and young adults; 2) an increase in delivery and other service traffic (also driven by congestion charge introduction); 3) an increase in long-distance travel, by train and international flight; 4) the growth and concentration of digital/knowledge economy jobs and other activities in the inner city, and consequently an increasing residential segregation by income, ethnicity, age and household structure.

In 2006, Stockholm was one of the first cities to introduce a congestion charging system, designed as a time-of-day varying toll cordon around the inner city. Before the introduction of the system there were fears that it would reduce the number of trips to the inner city and thereby its economic activity (Eliasson,

2008). And there was indeed a decline in the number of cars entering or exiting the inner city. However, we find that in the long run this was more than compensated by an increase in bicycle and transit trips to and from the city; hence it appears that the city has become more attractive. Similar trends were observed after the introduction of the London congestion charge in 2003 (Transport for London, 2015a, p. 24). We find that Stockholm County residents of all income groups made fewer and shorter car trips in 2015 as opposed to 2004. Still, car access has remained stable on average in Stockholm County (a combined effect of diverging trends between residential locations and age groups).

We present our results via descriptive statistics for the sake of simplicity. We have also explored multivariate models of trip frequencies, trip lengths, mode choice and car access, but we concluded that the models do not add sufficiently to the understanding of the changing mobility trends. We put our findings in the context of existing research throughout the paper. Since travel behaviour trends are very dependent on land use, we start the paper with a review of land-use trends in Stockholm County.

2 LAND USE AND STRUCTURAL CHANGE

Stockholm is among the fastest growing capital regions in Europe, with respect to population and economic activity (LSE Cities, 2013, p. 36). Between 1970 and 2004, most of the population increase took place in the suburban areas (Strömquist, 2005) but since 2004 the population has grown most rapidly in the regional centre, and so did the number of jobs[1]. With its growing popularity the regional centre has attracted more working-age, high-income and single residents since 2004. The socio-economic groups who tend to make fewer trips (low-income, retirees, couples) have increased primarily in the suburbs and low-income areas at the edge of the regional centre (Stockholm County, 2014). This residential segregation process is supported by a severe shortage of apartments in the centre of Stockholm and the consequent price increases[2].

Since 1999 the city of Stockholm has followed a strategy of "building the city inwards" (Pemer, 2001). This urban development focus marked a departure from the satellite town strategy, which had expanded the region with suburban transit oriented developments since the 1950s (Cervero, 1995; Stockholm City Planning Administration, 2009). The new strategy is effective: population growth is currently strongest in the central, high-income areas of Östermalm, Bromma and Hägersten-Liljeholmen (City of Stockholm, 2016). High-income residents are attracted to new residential districts at the edge of Stockholm's inner city, along simultaneously developed transit extensions, in proximity to attractive water fronts and with predominantly owner-occupied apartments. The two largest developments of this kind are Hammarby Sjöstad and Norra Djurgårdstaden.

[1] 36% of commute trips by Stockholm County residents ended in the inner city in 1986; 37% in 2004; and 40% in 2015.

[2] Apartment sales prices in the city of Stockholm have increased by 139% in real terms between 2005 and 2017, while the respective increase in the total Swedish housing market was 28%. Source: NASDAQ Valueguard's HOX Stockholm BR and Sweden indices and SCB's KPI index, 2017.

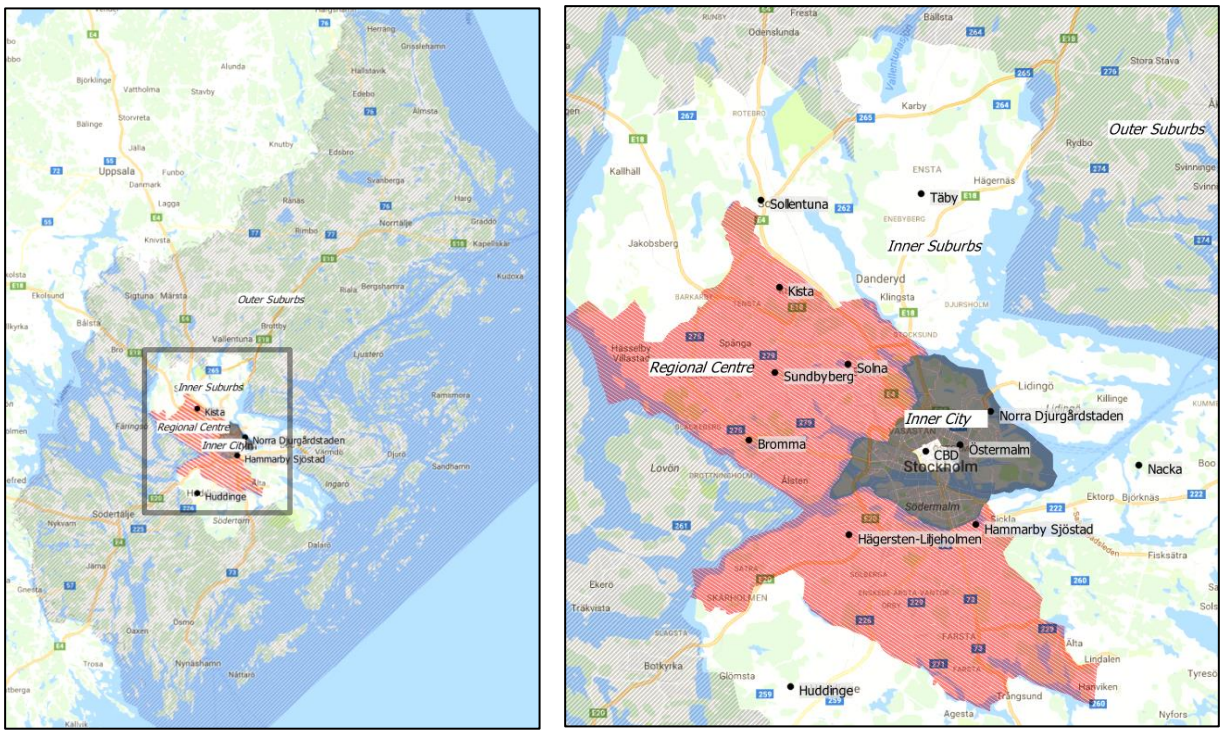

Figure 1: Maps of Stockholm County and its regional centre. Background data ©2017 Google

A similar concentration of growth in the urban core has been observed in London (Transport for London, 2015a). Both London's and Stockholm's populations grew mainly due to net foreign immigration and birth surpluses from 2004 to 2015. Meanwhile, existing inner city residents were slightly more likely to move to the suburbs than vice versa (Mayor of London, 2017; Statistics Sweden, 2017).

In Sweden, the Netherlands, Luxemburg, Austria and the United Kingdom, urban cores have grown faster than the surrounding commuter suburbs since 2001, while the dominant trend in many other OECD countries has been the opposite (Veneri, 2015). Policy is important, but the concentration of housing and job growth in the urban core may also be a sign of advanced stages of knowledge-based economic development, where face-to-face interactions, knowledge spill-overs and non-digitizable experience become relatively more important (Duranton and Puga, 2004; Glaeser, 2011; Veneri, 2015). By national and international standards, Stockholm has a knowledge-based economy, a highly specialized and educated work force, and the second highest regional employment rate in Europe (Eurostat, 2016; LSE Cities, 2013). The rapidly growing digital-, knowledge- and service-based sectors benefit more from higher densities than other industries (Ahrend and Schumann, 2014).

Stockholm County's GDP per capita has been growing faster than that of other Swedish metropolitan regions and most other European capitals since the turn of the millennium (LSE Cities, 2013, pp. 35, 37).

The Stockholm County regional planning authority supports a strategy of polycentric development, with additional jobs and housing to be located in eight rail-served sub-centres throughout Stockholm County. The stated key objective behind the polycentric development is to reduce travel and car traffic compared to further suburban sprawl (Stockholm County Growth and Regional Planning Administration, 2013, p. 8). However, what is rarely mentioned is a third alternative: concentration of growth in the regional centre, which represents a loss of investments and power for the suburban municipalities. In fact, the observed concentration of growth in the regional centre, between 2007 and 2013, was stronger than planned. This mismatch of plan and reality stems from the conflicting interests of the central versus suburban municipalities: the majority of suburban municipalities argue that the observed strong concentration of growth in the centre is "too short-sighted for long term planning". Unsurprisingly, the central municipalities, including Stockholm city, argue the opposite: a more centralized growth of buildings and infrastructure gives "better possibilities for service, transit, climate impact, economic development and social cohesion".

Interestingly, municipalities that are adjacent to but outside of Stockholm County argue more in line with Stockholm city, because they expect their travel times to be shorter with fewer larger hubs as opposed to many smaller hubs within the county (Stockholm County Growth and Regional Planning Administration, 2017, pp. 23–24).

A key argument in the public discourse about polycentric development within Stockholm County is that it would enable local employment markets, which would reduce car travel (Stockholm County, Growth and Regional Planning Administration, 2017, p. 25). However, over twenty years ago Cervero (1995) found that Stockholm's early suburban transit-oriented developments failed in keeping employment local. In section 6.1 we show that this is still the case and that the car share of commutes and the commuting distances are higher for suburban employment hubs than for inner city jobs.

3 DATA

We analyse data from three independent travel surveys conducted in 1986, 2004 and 2015[3], with representative samples of Stockholm County residents. The total county population was 1.6 million in 1986, 1.9 million in 2004, and 2.2 million in 2015.

Stockholm's inner city is the economic and social centre of Stockholm County. Its 370,000 inhabitants in 2015 made up 34% of the Stockholm municipality population and 15% of the Stockholm County population. The inner city is separated from the rest of the county by waterways, which makes its entry points prone to congestion. In 2006 a road congestion charge was introduced

3 The three survey periods are: March 1986 - March 1987; September 2004 - October 2004 and September 2015 - October 2015. For comparability across the three survey years, the summer and winter holiday periods are excluded from the 1986 data analysis. Weekdays and weekends are represented in the same proportion in all surveys. The response rate declines from 80% in 1986 to 48% in 2004 to 35% in 2015. The counts of respondents included in the analysis are: 19511 in 1986; 31348 in 2004; 40917 in 2015.

for trips entering or exiting the inner city. The regional centre is defined as the combination of the county's three most central and urban municipalities: Stockholm, Solna and Sundbyberg. It is home to half of the county's residents, and it includes the inner city. Surrounding the regional centre are the inner suburbs, which consist of the municipalities Lidingö, Haninge, Tyresö, Täby, Sollentuna, Danderyd, Nacka and Järfälla. The remainder of the county is defined as the outer suburbs.

Respondents report all trips made within a randomly assigned survey day within the study period and their socioeconomic status. Respondents are weighted to be representative with respect to age, gender and residential location. Our analysis is restricted to individuals aged 16-74, because this is the common age span of the three survey samples. The surveys are comparable: the questionnaire design is very similar across the three periods, and survey responses were mostly collected via paper mail-back. The samples of individuals responding to each survey match the corresponding census statistics of employment and driving license shares. Hence, residents with driving licences, and employed residents, have a similar response rate to others. Furthermore, the share of respondents not making any trips on their survey day is nearly constant in each survey, at 20%.

Respondents report all modes used to reach their destination, but the analysis assigns one main mode to each trip[4]. Our analysis includes trips with origin and destination in Stockholm County. Travel times are self-reported, and travel distances are calculated on the basis of adjusted Euclidian distances between the reported origins and destinations. We supplement the analysis by referencing the Swedish National Travel Surveys from 1984 to 2013, census data, car and driving licence registers and traffic counts.

4 TRENDS

4.1 Trip location and mode choice

Figure 2 shows that over time an increasing share of all trips in the county constitutes entering or exiting the inner city. This occurred for all trip purposes, among residents of all areas of Stockholm County, on work days and weekends and despite the introduction of inner-city road congestion charges in 2006. Thus, the inner city became relatively more attractive for all kinds of activities than the rest of the county.

[4] The main mode is assigned via a mode hierarchy, as follows in order of increasing dominance: walk, bicycle, motor cycle, car, bus, metro, train, car, other.

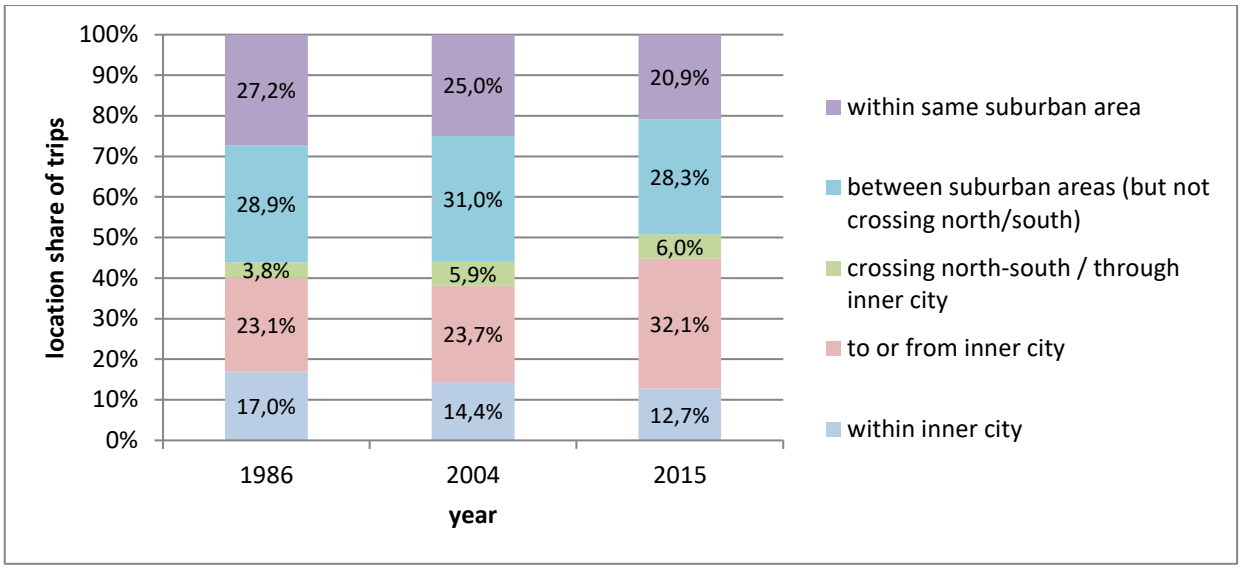

Figure 2: Location share of trips within Stockholm County, among residents aged 16-74

Figure 3 and Figure 4 show how mode shares of trips and of travel distance, respectively, have changed over time by origin-destination combination. They show that bicycles continue to gain trip shares and distance shares from cars for trips within and to/from the inner city. And since 2004, transit has gained distance shares from cars for all origin-destination combination types. Similar mode shifts have been observed for inner and outer London respectively (Transport for London, 2015).

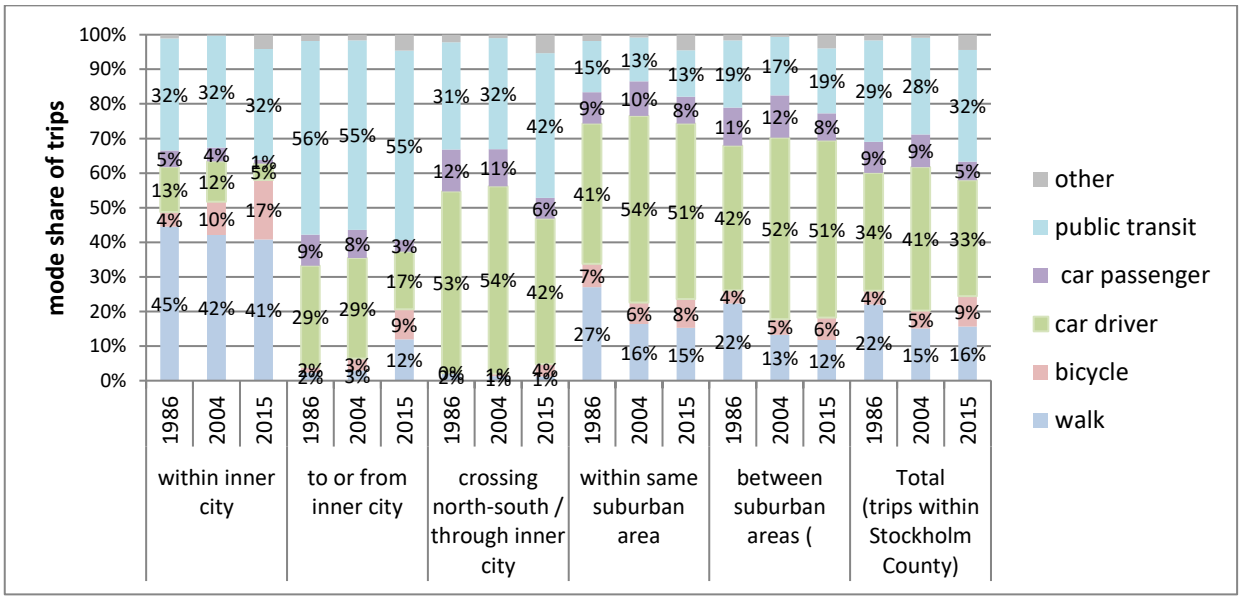

Figure 3: Trip mode share within Stockholm County, by trip location and year, among residents aged 16-74

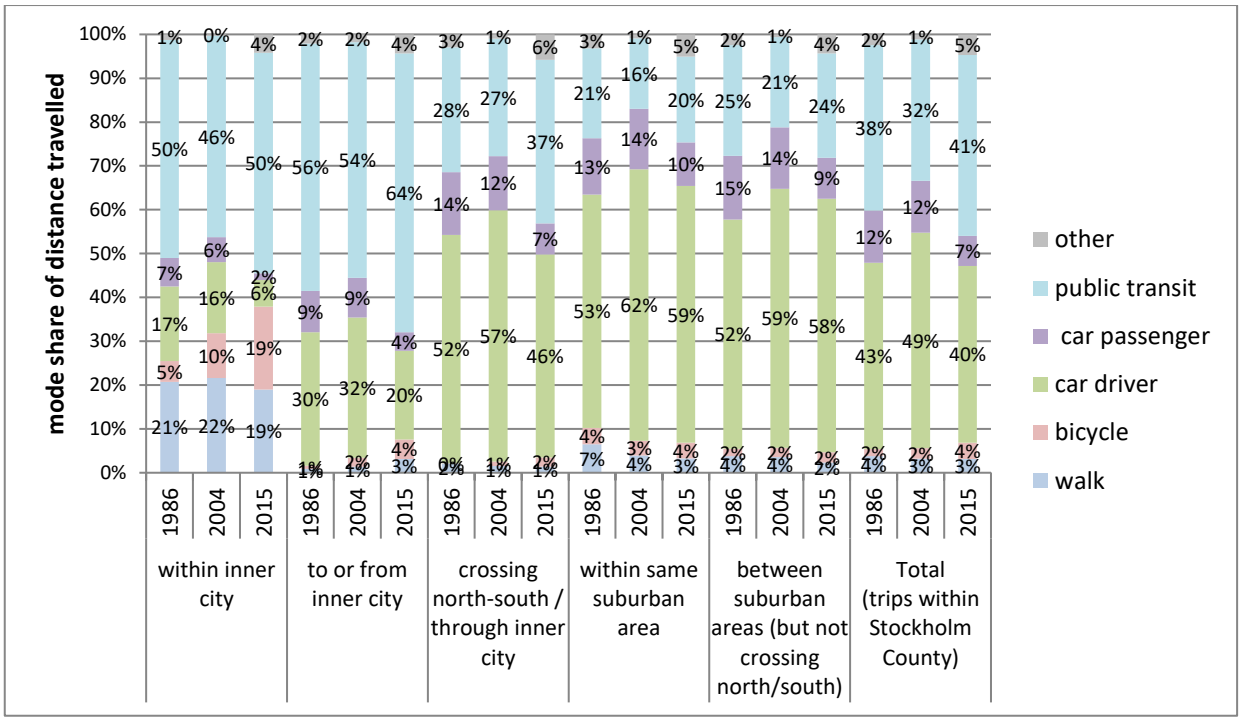

Figure 4: Distance mode share within Stockholm County, by trip location and year, among residents aged 16-74

To validate the travel survey data trends, we reference traffic count statistics in Figure 5. The traffic counts confirm that transit gains trip shares from cars for travel to/from the inner city[5]. The transit boarding counts to/from the inner city have grown at approximately the same rate as the county population since the 1990s.

Meanwhile, the motor vehicle counts to/from the inner city were roughly stable until 2004, and declined by 24% from 2004 to 2015 (see Figure 5)[6]. This decline is likely driven by a combination of the introduction of the congestion charge (Börjesson et al., 2012), increases in fuel prices (Bastian and Börjesson, 2015), parking restrictions and increased parking fees, and decreases in road travel speed in the inner city (see further discussion below). The traffic to and from the CBD declined less than traffic to/from the inner city, because that traffic is not specifically targeted by the congestion charge.

The traffic counts show that the number of motor vehicles crossing in/out of the regional centre has increased by 4% from 2004 to 2015. This is the combined effect of the following changes: 1) County residents use the car for a declining share of their total distances travelled within the county (see Figure 4). 2) The county population increased by 19%. 3) Long-distance car travel is increasing, even among city residents (see Appendix Figure 27). Remember that trips

[5] The transit boarding counts in Stockholm County have grown faster from 2004 to 2015 (28% boarding growth) than the survey transit trip counts and population increases indicate (17% growth). Half of this discrepancy is because in 2015 a larger share of transit trips combined multiple transit modes.

[6] The survey data and population changes combined would even suggest a 39% decline of car trips to/from the inner city from 2004 to 2015. Possible reasons for the discrepancy between survey and traffic count data are outlined in the next paragraph.

beyond county boundaries are not considered in our Stockholm survey analysis. 4) Professional traffic, for example delivery vans and taxis, is increasing, and this is not included in the survey data. 5) It is plausible that the car traffic by drivers who are not residents of Stockholm County is increasing, given the tendency towards longer car trips among residents of other parts of Sweden (see Appendix Figure 27). 6) There might be reporting errors in the travel surveys. Yet, travel surveys from metropolitan regions in England, Germany, Austria and Switzerland show similar trends (Buehler et al., 2017; UK Department for Transport, 2016), which makes it plausible that broader societal trends and policy trends are also involved.

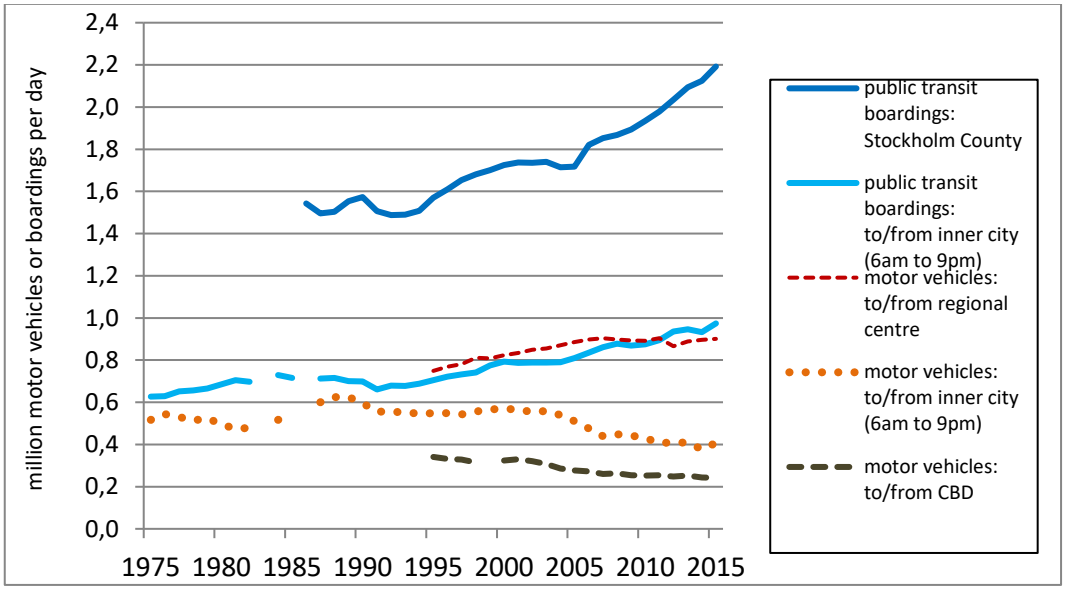

Figure 5: Traffic counts for motor vehicles and transit boardings Source: 2015 AB Storstockholms Lokaltrafik, and City of Stockholm. Excluding motorways. For spatial definitions, see Figure 1.

According to the self-reported travel times in the travel survey, average travel speeds in Stockholm County have slightly decreased between 2004 and 2015 for car, bus and bicycle, but not for rail. This simultaneous decrease in road travel speeds and traffic counts might seem like a paradox. However, such trends have also been found in central London. The London Transport Authority attributes this to a reduction in effective road network capacity (Transport for London, 2015a, p. 24). In Stockholm, a more likely reason for the decreasing speeds (according to planners at the city of Stockholm) is the large number of roadworks in the inner road network, propagating out in the region.

Additionally, the share of professional/delivery/taxi vehicles among motor vehicle trips to/from the inner city is growing (Swedish Transport Administration, 2016), and the number of registered trucks[7] and taxis in Stockholm city has increased by over 30% each between 2005 and 2014 (City of Stockholm, 2016). The increase in professional/delivery/taxi traffic, which was intended by the congestion charge, probably contributes to the decrease in traffic speeds for bus and passenger cars, because the loading of goods causes disruptions in the traffic.

[7] This combines light and heavy trucks, so it includes vans.

4.2 Trip distances

Table 1: Mean distance per trip within Stockholm County, by residence location, main mode and year. Two-sided significance tests between survey years, assuming equal variances with significance level .05. Significantly larger values are indicated by the label of the smaller value.

	inner city residents			regional center excl. inner city residents			inner suburb residents			outer suburb residents			Total Stockholm County residents		
	1986	2004	2015	1986	2004	2015	1986	2004	2015	1986	2004	2015	1986	2004	2015
	(A)	(B)	(C)	(A)	(B)	(C)	(A)	(B)	(C)	(A)	(B)	(C)	(A)	(B)	(C)
walk	1.3	1.8 (A)	1.7 (A)	1.4	2.2 (A)	2.5 (A B)	1.4	3.2 (A C)	2.7 (A)	1.5	4.4 (A)	4.8 (A)	1.4	2.6 (A)	2.5 (A)
bicycle	3.1	3.9	4	3.5	5.7 (A C)	5.0 (A)	3.2	5.2 (A)	5.9 (A B)	3.3	7.7 (A C)	5.0 (A)	3.3	5.4 (A C)	4.9 (A)
car driver	9	13.4 (A)	13.5 (A)	8.8	12.1 (A C)	11.0 (A)	10	12.6 (A C)	10.8 (A)	12.3	17.1 (A C)	16.3 (A)	10.7	13.9 (A C)	13.0 (A)
car passenger	8.9	14.2 (A)	13.7 (A)	10.4	12.9 (A)	12.3 (A)	11	14.5 (A C)	11.8	12.5	17.5 (A)	16.7 (A)	11.3	14.8 (A C)	13.7 (A)
public transit	6.4	7.8 (A)	8.7 (A B)	8.6	10.5 (A)	10.5 (A)	12.7	15.9 (A C)	14.6 (A)	18.1	24.9 (A)	26.7 (A B)	12.4	13.6 (A)	14 (A B)
Total	5.2	7.3 (A C)	6.8 (A)	7	9.9 (A C)	9.1 (A)	9.1	12.4 (A C)	11.1 (A)	11.1	17 (A)	17.7 (A B)	9.1	11.9 (A C)	11.3 (A)

The average length of trips within Stockholm County increased from 1986 to 2004 for all modes, especially for residents in the outer suburbs (Table 1). Such trends have been seen in many countries over a long period[8]. However, among more central residents average trip lengths decreased between 2004 and 2015. Among outer suburban residents trip lengths continued to increase. This increase is caused by increasing transit trip length and mode share – the average trip length for car decreased.

The average lengths of bicycle trips decreased among outer suburban and regional centre residents between 2004 and 2015. However, bicycle trip lengths increased among inner suburban residents, because the commute share of bicycle trips increased most strongly among this group, and their commute trips are longer than trips for other purposes.

Walking trip length at the county average remained stable between 2004 and 2015, but it increased among regional centre residents. This could be because of the population growth just outside of the inner city boundaries.

The NTS data, in Figure 6, is consistent with the Stockholm survey data, showing that trip distances in the cores of the metropolitan areas have fallen approximately since the turn of the millennium. It also reveals the interesting pattern that trip distances continue to increase outside the metropolitan areas (as they did in Stockholm 1986-2004). Thus, with respect to trip lengths, travel behaviour diverges between urban, suburban and rural areas.

[8] See for example (Metz, 2010) arguing that higher incomes historically enabled faster and longer trips, (Frändberg and Vilhelmson, 2011) finding a long-term expansion of everyday mobility spaces, and (Banister and Berechman, 2003, p. 103) arguing for specialization as a driver of increasing trip lengths.

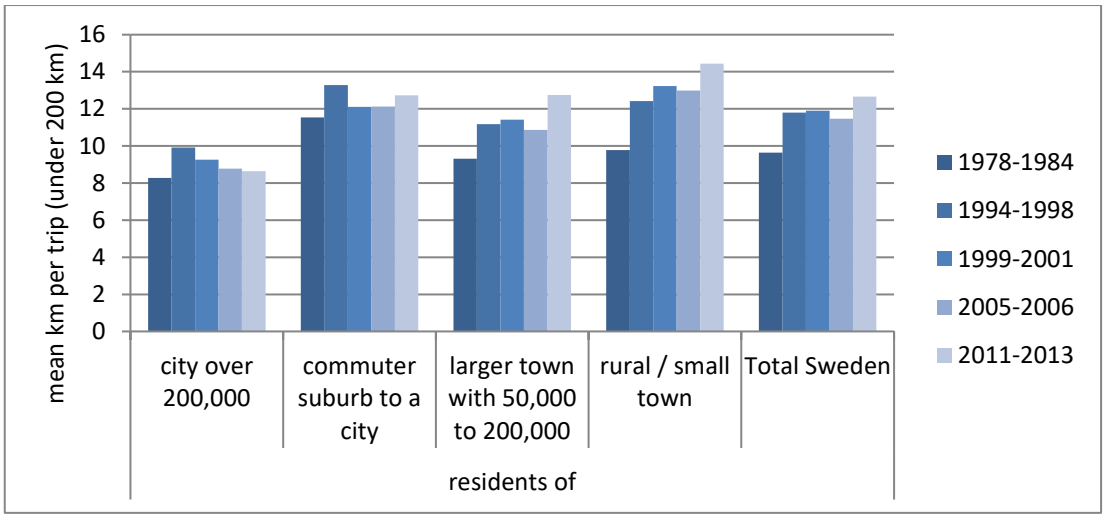

Figure 6: Mean distance per trip among adults, by residential location and year. Only trips under 200 km considered. Here city residents are defined as residents of the core city municipalities of Stockholm, Göteborg or Malmö. Source: Swedish National Travel Survey.

4.3 Trip frequencies by gender and purpose

Trip frequencies have declined from 2004 to 2015 for all purposes and among all socioeconomic groups in Stockholm County. This trend is not unique to Stockholm: trip frequencies have declined in Sweden as a whole since the 1990s[9] and in England (UK Department for Transport, 2016). In both countries, the frequency decline is strongest for shopping, business trips and hobby/visiting friends. In England, the commuting frequency also declined strongly, but in Sweden it declined only slightly. Employment rate trends cannot explain this country difference. Instead, it might be due to differences in the survey sample (only the English survey sample also includes children), or due to actual differences in commuting trends between the two countries.

Trip-chaining cannot explain the declining trip frequencies in Stockholm County: home-bound trip frequencies decline less than other trip frequencies, indicating that trip-chaining in fact decreased.

The slight decline in commute trip frequency is not explained by working from home: In 2004 and 2015, only 3-4% of people working on the survey day worked entirely from home (did not make any commuting trip)[10]. Older people and men have a greater propensity to work from home.

Trip frequencies declined between 2004 and 2015 for all purposes and in all socio-economic groups, but most strongly for non-food shopping, visiting family/friends, free time activities and business (Table 2). The groups with previously high trip frequencies experienced the strongest decline: men, working-age, young adults and car owners. People residing in the outer suburbs

[9] Between 1996 and 2011 trip rates declined by 12% in Sweden's cities and by 14% in the whole of Sweden. Source: Swedish National Travel Survey

[10] Earlier, from 1986 to 2004, in Stockholm County there was a strong decline in men's commute trip frequencies, but more than 50% of this decline can be explained by fewer workers making more than one commute trip per day. An additional 5% of this decline can be explained by higher unemployment in 2004 than 1986, particularly among men.

and those without children reduced their trip frequencies more than inner city residents and parents[11]. Trip frequencies for commuting, business, transporting children/others and shopping became more gender equal between 2004 and 2015.

Table 2: Mean distances, travel times and frequencies among Stockholm County residents, by trip purpose, year and gender[12].

		km per trip		minutes per trip		trips per person per day		km per person per day		minutes per person per day	
trip purpose	**gender**	**2004**	**2015**	**2004**	**2015**	**2004**	**2015**	**2004**	**2015**	**2004**	**2015**
home	women	11.2	10.7	27.5	30.6	0.96	0.94	10.8	10.1	26.5	28.7
	men	13.5	12.3	28.5	31.4	0.95	0.90	12.8	11.1	27.0	28.2
work/school	women	12.7	12.7	31.2	36.1	0.51	0.48	6.4	6.1	15.8	17.3
	men	15.3	14.2	30.7	36.0	0.56	0.50	8.7	7.1	17.3	18.0
business	women	12.3	11.6	28.0	41.6	0.08	0.05	1.0	0.6	2.2	2.1
	men	15.2	15.6	28.4	56.8	0.18	0.08	2.8	1.3	5.1	4.7
visit friends/family	women	12.6	13.0	29.4	34.9	0.16	0.10	2.1	1.3	4.8	3.5
	men	13.6	12.6	27.8	32.1	0.14	0.08	1.8	1.0	3.8	2.4
transport children/others	women	7.7	7.5	16.8	22.6	0.20	0.16	1.6	1.2	3.4	3.5
	men	9.1	8.6	17.6	22.4	0.16	0.14	1.5	1.2	2.9	3.2
leisure activities	women	11.5	10.1	27.4	35.4	0.27	0.21	3.1	2.1	7.3	7.3
	men	13.8	10.9	28.7	33.0	0.26	0.17	3.6	1.9	7.5	5.6
shopping food/daily	women	7.0	6.4	16.2	19.0	0.17	0.15	1.2	1.0	2.8	2.8
	men	7.3	6.4	16.0	18.1	0.15	0.13	1.1	0.8	2.4	2.4
shopping non-food/infrequent	women	8.1	8.1	20.6	27.3	0.15	0.08	1.2	0.6	3.2	2.1
	men	9.8	9.0	20.4	27.4	0.12	0.06	1.2	0.5	2.4	1.5
service and other	women	8.5	9.2	23.4	29.7	0.15	0.17	1.3	1.6	3.5	5.1
	men	9.2	10.1	21.6	29.1	0.14	0.14	1.3	1.4	3.0	4.0
Total	women	10.8	10.6	26.2	31.4	2.66	2.33	28.7	24.6	69.7	73.1
	men	13.0	12.0	26.8	32.0	2.66	2.19	34.7	26.4	71.4	70.2

The decline in everyday trip frequencies is accompanied by an increasing frequency of long-distance trips among residents all over Sweden. Thus, in terms of total travel distance, the decrease in everyday travel is partly compensated by more long-distance trips (Figure 7).

[11] These descriptive results were also confirmed by a linear regression model with trip frequency per person as the dependent variable.

[12] For 1986 only a less detailed categorization of trip purposes is available, see Appendix Figure 30.

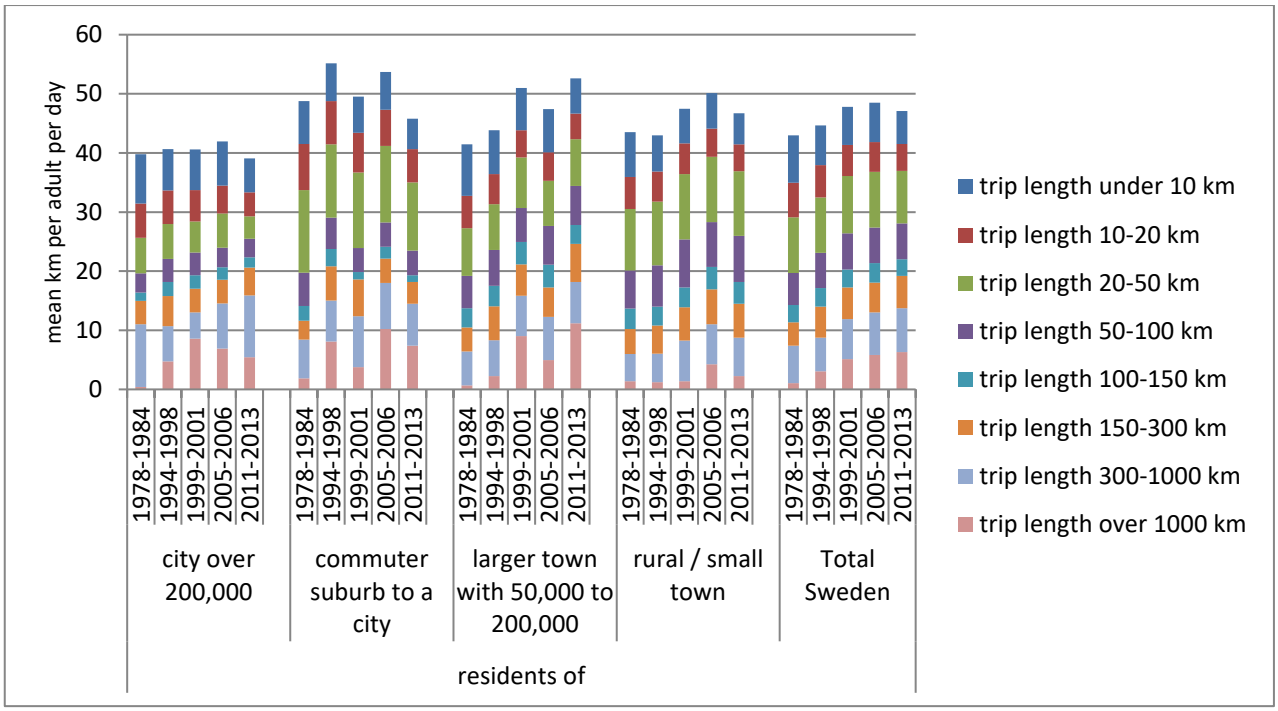

Figure 7: Mean km per adult per day, <u>all modes</u> (including flights), by trip length category, year and residential location. City residents are residents of the core city municipalities of Stockholm, Göteborg or Malmö. Source: Swedish National Travel Survey.

Frändberg and Vilhelmson (2011) found a trend towards more international flights for leisure purposes but a decrease in everyday leisure trips among Sweden's residents. At Stockholm County's airports, the number of international passengers grew by approximately 6% annually between 2010 and 2014, while domestic passenger counts remained stable (City of Stockholm, 2016). Much of the growth in domestic long-distance travel is by rail, in particular among residents of cities and large-towns (Appendix Figure 28).

4.4 Discussion

The spatial concentration in the regional centre since 2004 has improved accessibility[13] without increasing trip lengths. Trip lengths have also declined because the socio-economic groups who have a high trip frequency have been more likely than others to move to the regional centre, where average distances are shorter.

Inner city road congestion appears to be increasing, although the motor vehicle traffic volume has not increased. The increased congestion seems to stem from several large roadworks, and possibly also from more loading activities of delivery and taxi vehicles disrupting the traffic.

Average commute times in the county increased from 30 to 35 minutes from 2004 to 2015 and the time spent at work per day increased by 28 minutes on average per person who went to work. This is one of the reasons that the available leisure time has decreased among workers. Additionally travel times are increasing due to congestion, and it is likely that employed and other people

[13] The number of services/activities/work places that can be reached at a given generalized travel cost.

spend more time online. To save time, people appear to have adopted different travel behaviour strategies: among residents of the regional centre and the inner suburbs, shorter trips and commuting by bicycle are becoming more common. Outer suburban residents have fewer destinations available nearby, and they have instead reduced their trip frequencies most.

The strong trend decline in shopping, service and leisure trip frequencies over time matches the growing popularity of the corresponding online activities. Yet, while these everyday trip frequencies are declining, this is partly compensated by an increase in long-distance travel. Among city residents, this increase in long-distance travel occurs by car, rail and international flights.

Road travel speeds have declined in all parts of Stockholm County between 2004 and 2015. Car trip frequencies declined among all income groups, suggesting that this is also an effect of congestion, parking limitations and spatial activity concentration, in addition to congestion charges and fuel price increases. The trend declines in car trip and distance shares and increases in bicycle trip shares are predominantly an urban phenomenon. See further discussion in section 5.

Several studies have found a positive link between car mode choice and more complex trip chains, for example (Yun et al., 2011) and (Xianyu, 2013). Hence, the declining car use may also have contributed to people making fewer stops within the same trip chains.

5 TRENDS BY MODE

5.1 Bicycling

Remember from section 4.1 that bicycling is gaining trip shares from cars for trips within, to and from the inner city. Bicycles are increasingly used for commuting, particularly to reach jobs in the inner city. Of the total bicycle distance travelled in Stockholm County nearly 63% was for commuting to work or school in 2015. Bicycles accounted for 11% of commuting trips and 5% of commuting distances in Stockholm County in 2015.

While bicycling used to be dominated by teenagers, it is now most popular among middle-agers and high income groups (Figure 8). The income and gender gaps in daily bicycle distances at the county level have widened between 2004 and 2015, because high income groups have increased their bicycle share of trips more than low income groups (Figure 9), because men have increased their bicycle distances more than women, and because central residents have increased their bicycle distance but not outer suburban residents (Figure 10). Still, bicycles are almost exclusively used for trips under 10 km length, and more among people who can afford and want to live in the regional centre than among outer suburban residents.

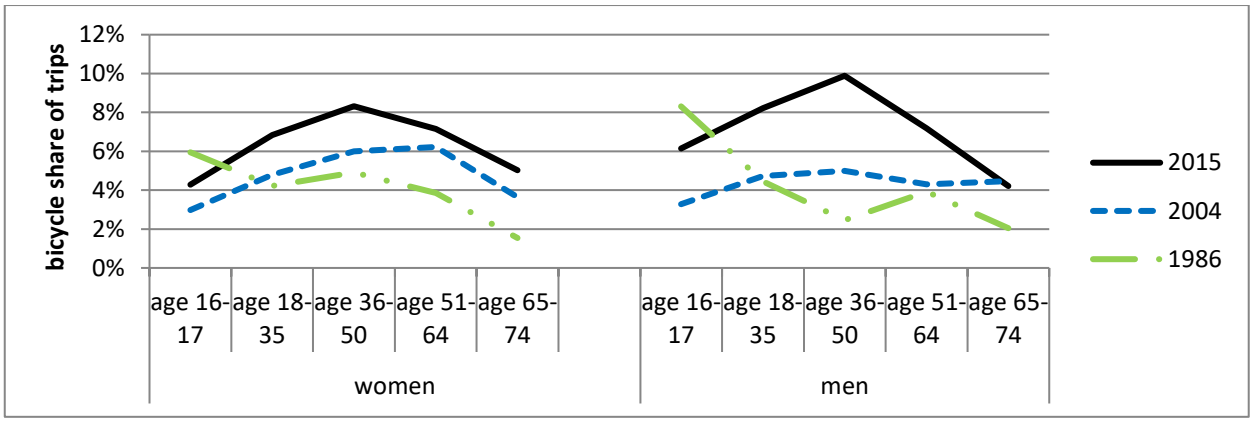

Figure 8: Bicycle share of trips within Stockholm County, by age and gender

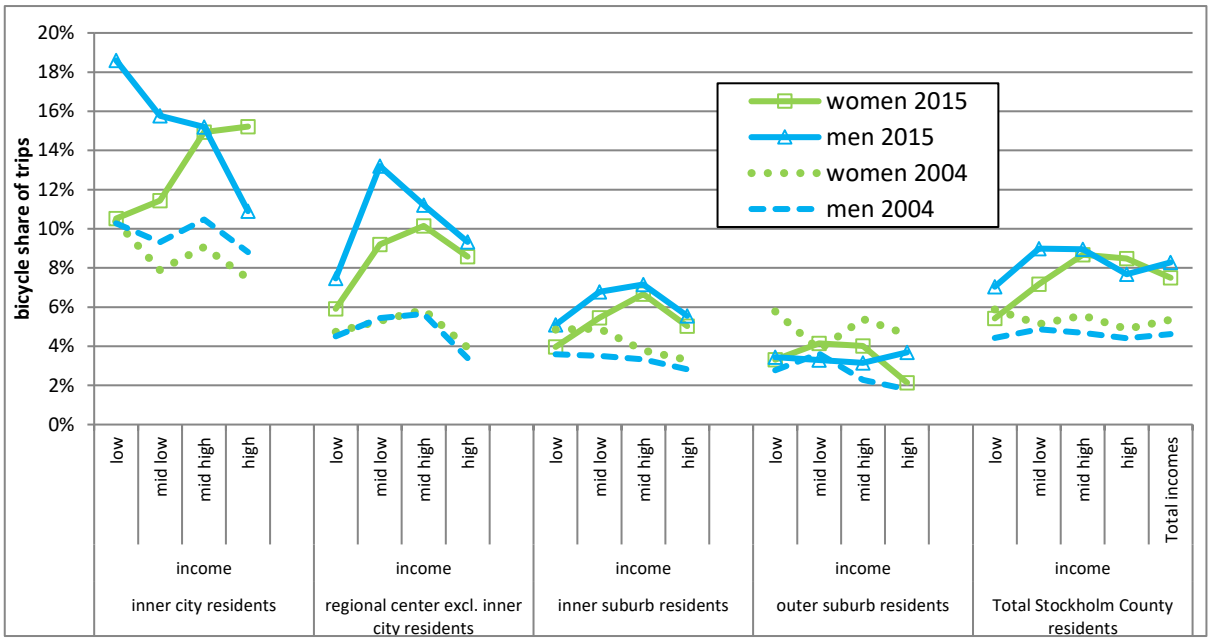

Figure 9: Bicycle share of trips within Stockholm County, by residential location, equalized household income and gender[14]

[14] Household income per consumption unit, quartiles for the Stockholm County population in the respective year. Household income data is only available for the survey years 2004 and 2015.

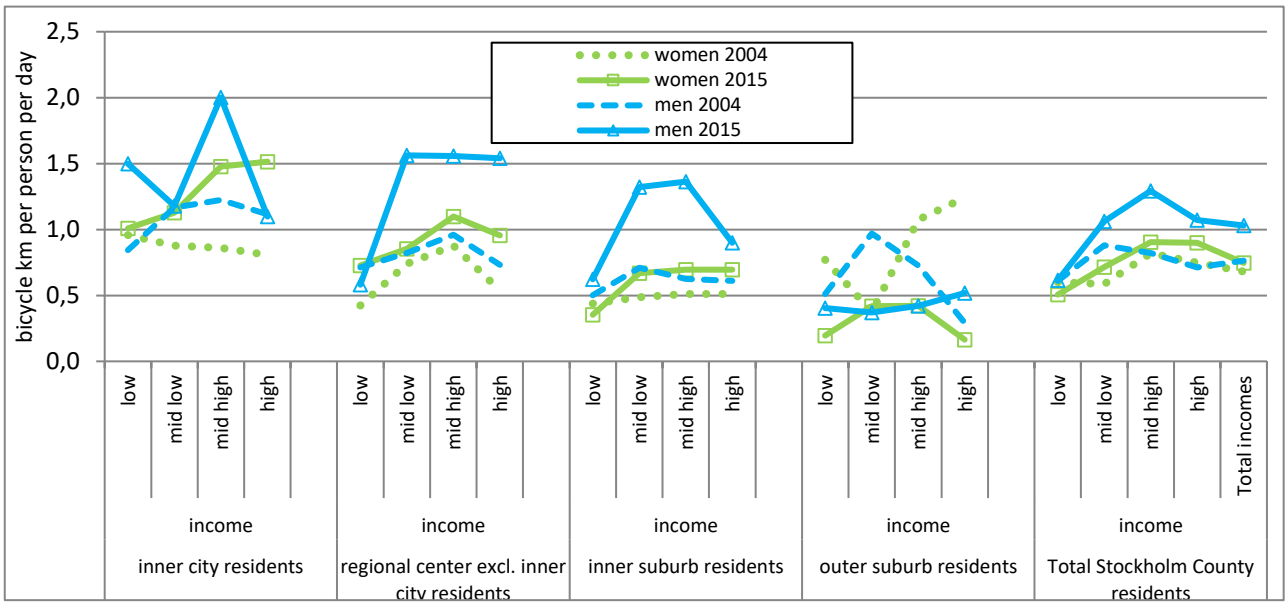

Figure 10: Mean bicycle km per person per day, within Stockholm County, by residential location, equalized household income and gender.

At the Swedish national level, the average bicycle share of trips has remained constant over time, which is the combined effect of increased bicycling in large and medium sized cities and decreases in rural areas since the turn of the century (Traffic Analysis Sweden, 2015). The Stockholm pattern of increasing bicycle use in the regional centre, stability in suburbs and decline in rural areas is also found in the Berlin and Copenhagen capital regions over the past decade (Berlin Senate, 2014), (Capital Region of Denmark, 2014).

5.2 Discussion of bicycling

The growth of bicycling in the inner city and concurrent decline in car use demonstrate that car use can be reduced without increasing per capita transit use. It is one of several indicators of increasing road congestion and parking constraints in the inner city.

In addition to the time savings themselves, time saving by exercising while travelling is also an important driver of the growth in bicycling. Travel time savings and exercise are the most commonly claimed reasons for bicycle commuting in Sweden (SIFO, 2012) and Stockholm (Börjesson and Eliasson, 2012), especially among middle-aged people and men, which are also the groups who increased their bicycle use the most in Stockholm County.

The above bicycling data does not consider trips in which a bicycle is used to connect to transit, but this has remained stable over time: of all commuter train trips in Stockholm County, 8% also involved a bicycle in the same trip in 2004, and 9% in 2015, while in the Netherlands 40% of transit trips are combined with a bicycle (Ministry of Transport Netherlands, 2009). Both the Netherlands and Stockholm County have a large share of their population living within cycling distance of a rail station (Ministry of Transport Netherlands, 2009), (LSE Cities, 2013). However, the Netherlands have more sheltered and secure bicycle

parking at train stations, wider and more extensive bicycle paths (Pucher and Buehler, 2008) and a distance-based transit pricing, as opposed to the period tickets that are used by 70% of Stockholm County transit users.

Copenhagen has a similar size and car share of trips to Stockholm, but more cycling and less transit. In, to and from the inner city of Copenhagen, bicycling is the most popular mode for commuting, making up 45% in 2014 (Copenhagen Municipality, 2014). To and from the inner city of Stockholm, transit is the most popular mode, making up 65% of commute trips to in 2015. The higher transit share and lower cycling shares are a result of a different infrastructure and a more spread-out land use along transit corridors (LSE Cities, 2013). Moreover, it appears that both cities are on a path to reinforcing their dominant commute mode: Copenhagen city has expanded its bicycle infrastructure extensively (LSE Cities, 2014) and deprioritized road space for cars, busses and delivery vehicles (City of Copenhagen, 2011). In contrast, Stockholm city's mobility strategy puts more emphasis on expansion of the transit infrastructure, and it refers to bicycling mainly in conjunction with walking and transit (City of Stockholm Traffic Administration, 2012), thus not awarding bicycling the hero status it receives in Copenhagen.

5.3 Transit

Remember from section 4.1 that transit gained trip and distance shares between 2004 and 2015 in suburban areas, in particular for trips between the northern and southern suburbs. However, the increase in transit trip shares is a result of declining car trip frequency, and not an increased transit trip frequency. The daily transit distance has, however, increased (Figure 12).

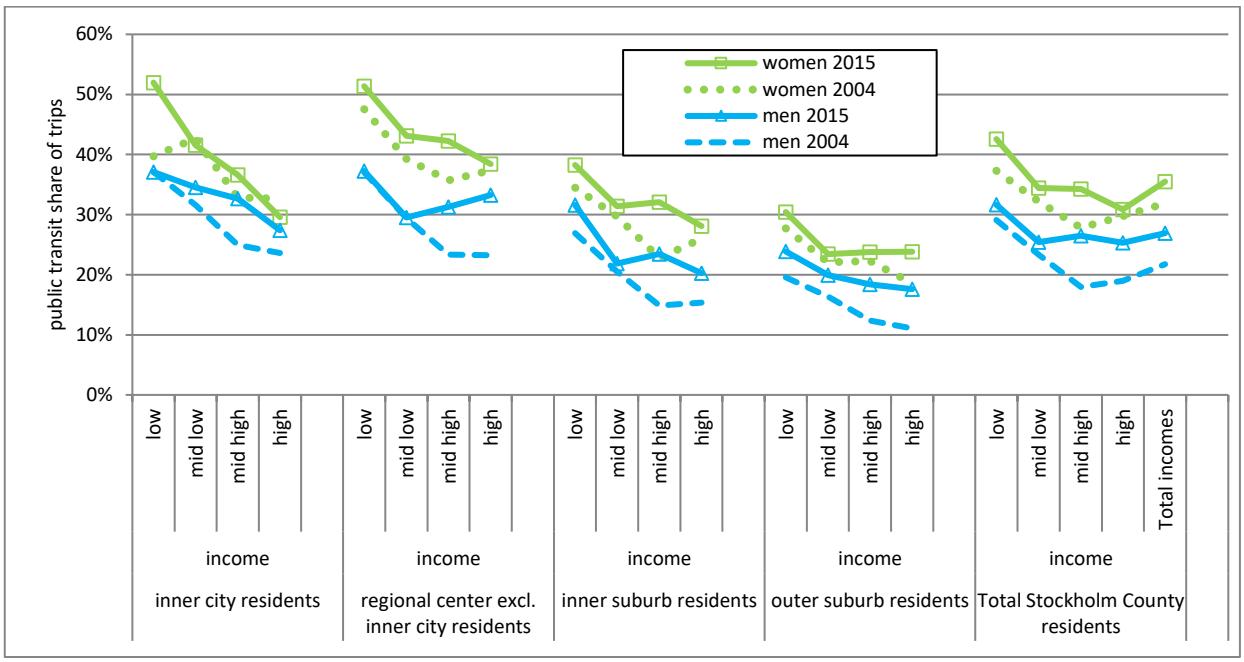

Figure 11: <u>Transit share of trips</u> within Stockholm County, by residential location, equalized household income and gender

As expected, transit trip shares (Figure 11) and distances are higher among low income groups and women. However, between 2004 and 2015 the gap in transit distance between the genders and income groups was reduced. This is because high income suburban residents, particularly men, increased their transit distances, while women in the regional centre nearly maintained their transit distances.

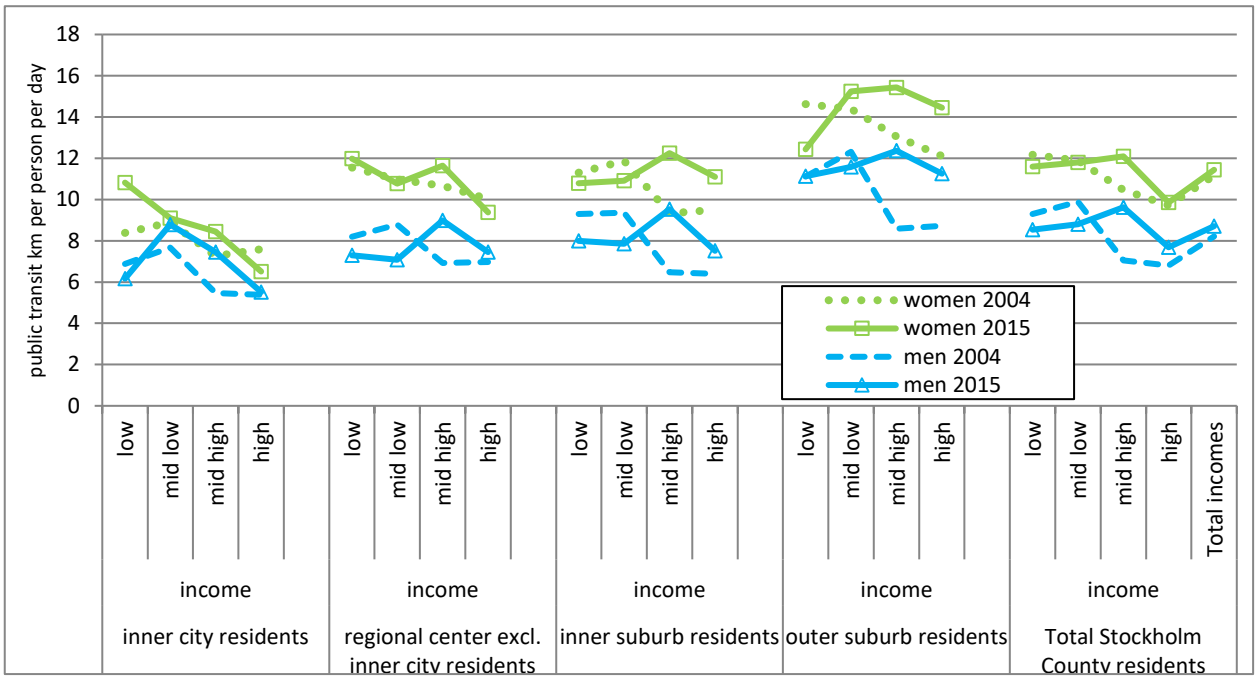

Figure 12: Mean transit km per person per day, within Stockholm County, by residential location, equalized household income and gender

5.4 Discussion of transit

The transit trip frequency per person remained stable between 2004 and 2015, despite improvements in transit accessibility, increased road congestion, and the introduction of congestion charges. The transit distance per person grew, however, due to longer trips. The stable transit trip frequencies are partly explained by the decline in overall trip frequencies. Moreover, in the suburbs the transit distance per person grew and the car distance per person fell (see Figure 17), in particular for mid-high and high income groups, suggesting that transit has replaced some car use for these groups.

The Swedish Government and transit industry communicate a goal of doubling transit travel between 2008 and 2020, in order to reduce greenhouse gas emissions (Swedish Parliament, Traffic Council, 2015). While such a goal is simple to communicate, it assumes that an increase in transit use implies lower car travel distances, which does not hold. Therefore, a direct goal of reducing emissions from (car) travel would appear more relevant for policy development.

5.5 Car use

As shown in section 4.1, car trip and distance shares in Stockholm County increased from 1986 and 2004, but they decreased again, such that the 2015 level is below the 1986 level. Nevertheless, the spatial distribution of car travel is different: car trip and distance shares have decreased markedly in the inner city. However, car use has increased in the suburban areas: trips within the

southern or northern suburban areas have a higher car share in 2015 than in 1986 (Figure 3).

Figure 13: Car share (driver or passenger) of trips within Stockholm County, by residential location, equalized household income and gender

From 2004 to 2015 the car trip share (Figure 13), car trip lengths (Table 1) and daily car distances (Figure 14) have significantly decreased among all income groups, but especially among men, and high-income women. Daily car distances decreased most among high-income outer-suburban men, which is also the group who increased their transit distances the most and initially had the longest car travel distance.

Outside of Sweden's metropolitan areas the mode shares of trips have changed less, with the car driver share of trips only changing from 54% to 53% from 1994 to 2013, but due to population increases total car distances driven are increasing in Sweden.

Figure 14: Mean car (driver or passenger) km per person per day within Stockholm County, by residential location, equalized household income and gender

Figure 15 suggests that single parents of both genders are more car-dependent than other groups, possibly due to a tighter time budget, since their car distance is high and barely decreased between 2004 and 2015.

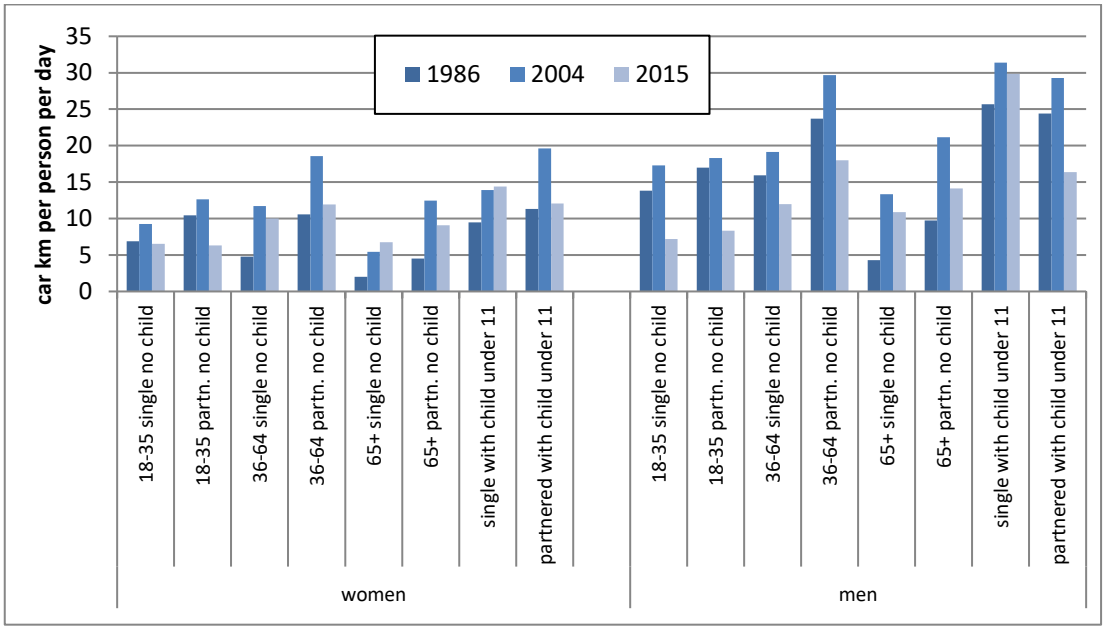

Figure 15: Mean car (driver or passenger) km per person per day within Stockholm County, by gender, year, age, partnership and children in the household

5.6 Car Access

We define car access as owning a private car, leasing a car or having a company car in the household. In 2015 only 1% of the adult residents of the county were

registered for a car sharing service, and we do not include this in the definition of car access.

The average car access in Stockholm County remained stable between 2004 and 2014 at 0.44 cars per capita. Meanwhile, the car access has increased in the rural parts of Sweden, mainly by more households adding a second car. However, the stability in Stockholm County is a result of decreasing car access among young adults and increasing car access among middle-aged and older people (Figure 16). Among the possible explanations is that the real income gains since 2004 have accrued mainly to middle-aged and older adults, and that younger adults have become more likely to reside in the regional centre. Older people have also become healthier and more mobile, and the driving licence frequency has increased substantially among older women. Since 2004 the income and location gaps in car access have also widened: car access increased among residents of high-income and outer suburban municipalities and decreased among residents of the regional centre and low income households.

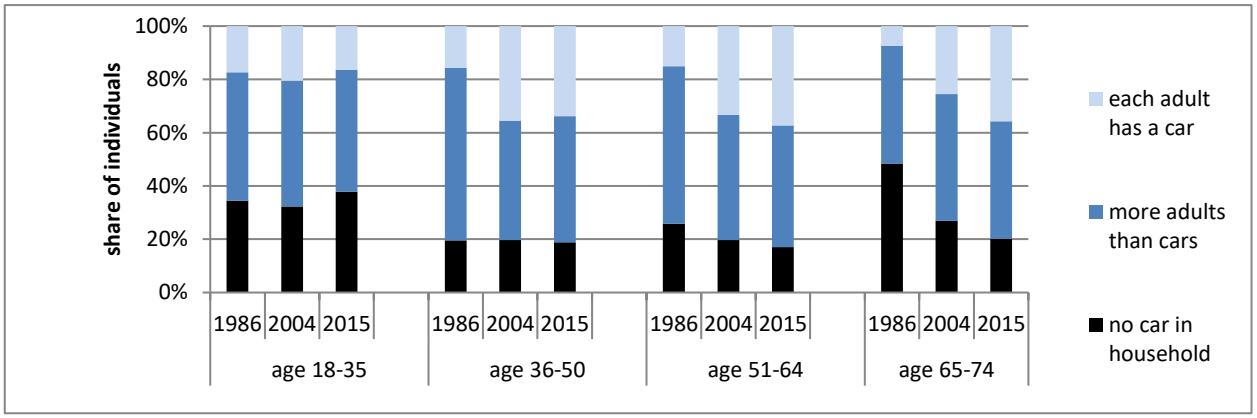

Figure 16: household car access by age and survey year, share of individuals aged 18-74 in Stockholm County

Among singles, men are more likely than women to have a car in the household, although the gender gap in car access has narrowed over time. The gender gap remains largest among parents and retirees.

For company cars, the gender differences remain even more pronounced: among full-time employed singles, men are three times more likely to have a company car than women (Appendix Figure 25). Even after controlling for income, household composition and residential location, this gender gap remains large and statistically significant. Between 2004 and 2015, company car access has also become more concentrated on high income households and outer suburban households, as opposed to households in the regional centre and lower income households.

Cars that are owned by a juridical entity (of which roughly half are company cars) make up an increasing share of registered cars and distances driven in Stockholm County since 2004 (Figure 17). The trend in the rest of Sweden has been more stable, except for the dip during the 2008-2010 recession. The recession affected the economic activity and the number of company/professional cars more outside than inside Stockholm County.

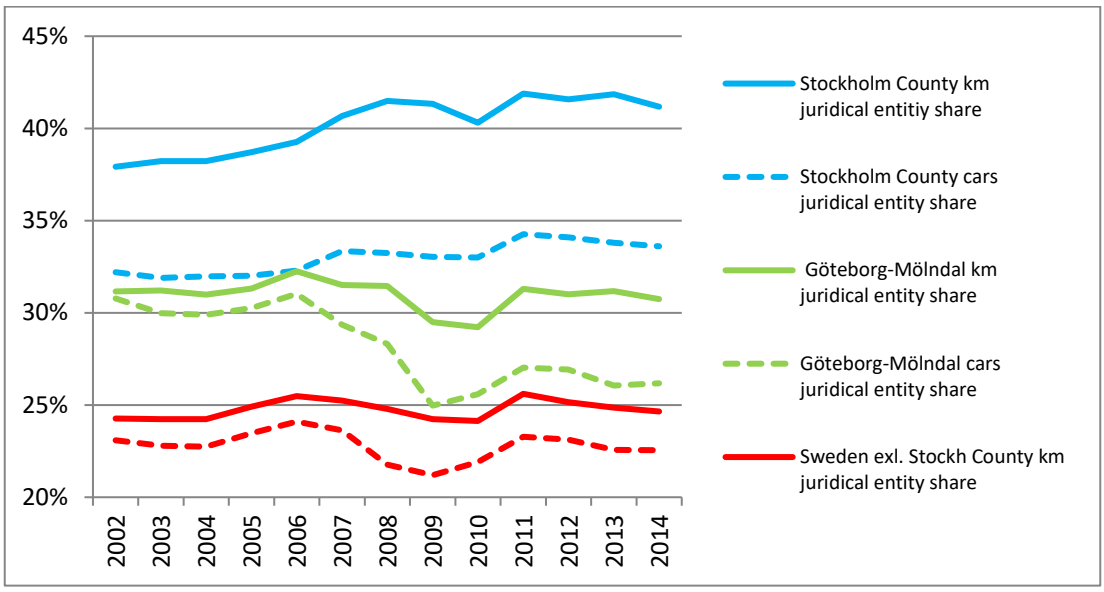

Figure 17: Share of cars that are owned by a juridical entity among total car distances driven, and among all registered cars[15]. Source: Swedish car register and inspection data.

5.7 Discussion of car use and access

On average, car access was stable between 2004 and 2015 in Stockholm County, but it has become more segregated with respect to residential location and income, and has shifted from younger to older. Meanwhile, car use has declined among all groups in Stockholm, except retired women and single parents. The former is a well-known generation shift towards older women having higher incomes, driving licences and car access. The latter suggests that single parents are more car-dependent than other groups of society, likely because of their high value of time and complex trip chains.

It is important to consider cars that are owned by a juridical entity (including company cars) in any policy planning for car use in Stockholm, because they already account for over 40% of the distances driven by cars registered in Stockholm County. The distances driven by these cars are less elastic to fuel price changes than privately owned cars and insensitive to congestion charges and parking charges[16]. Furthermore, the distances driven by company cars and professional traffic are more elastic to economic growth than private cars. Therefore, it will take different instruments to steer, time and differentiate the growing professional urban road traffic than it took to reduce the private car traffic.

[15] Cars and distances are assigned to the residence of their owner. Cars owned by a juridical entity are all cars that are not owned by a natural person. About half of juridical entity-owned cars are company cars, thus provided by an employer to an employee for the use of their household.

[16] With an increase in the congestion charge in 2016, the number of cars entering or exiting the inner city increased by 1% for cars owned by a juridical entity and decreased by 10% for privately owned cars (Swedish Transport Administration, 2016).

6 COMMUTING

6.1 Descriptives

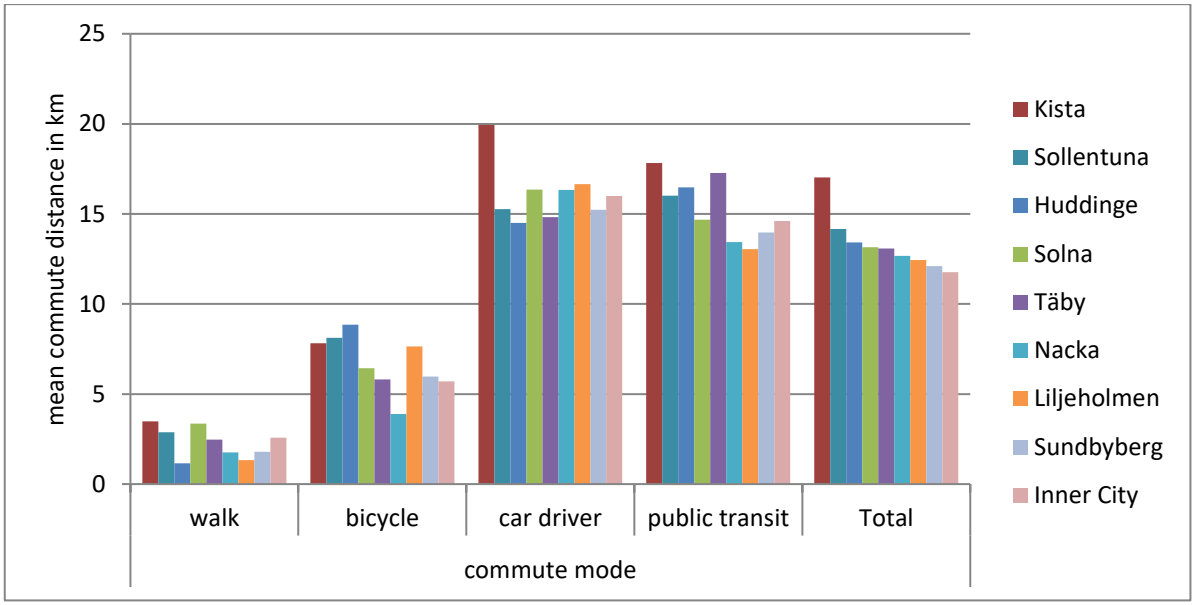

Figure 18: Mean commute distance by job location and mode in 2015. Inner city job location versus the largest other employment centres in Stockholm County.

As discussed in section 2, the inner city is becoming increasingly attractive as an employment location. Employees working in the inner city, and in the clusters adjacent to the inner city (Liljeholmen, Solna, and Sundbyberg), have shorter commutes than employees in more remote employment clusters; see Figure 18. Moreover, the car share is much lower for workers in or adjacent to the inner city (Figure 19).

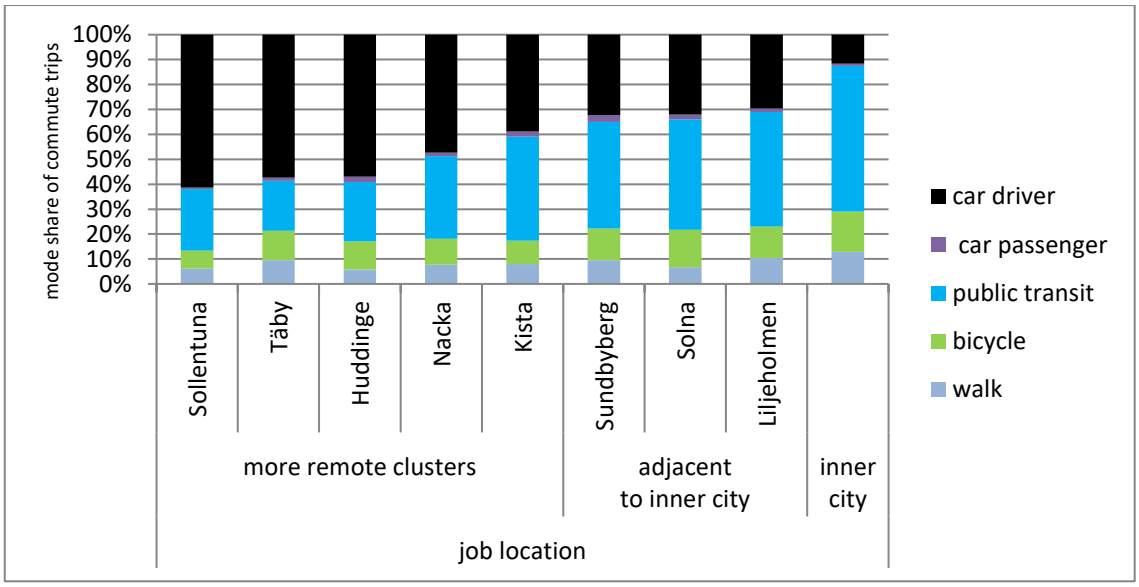

Figure 19: Mode share of commute trips by job location in 2015. Inner city job location versus the largest other employment centres in Stockholm County.

Among employees who work in the inner city and the regional centre, the commute distances and travel times are similar across income groups and genders (Figure 21). The same holds for employees residing in the inner city and the regional centre (Figure 20). However, to reach suburban job locations (and among suburban residents) men travel still farther than women, though this gap has reduced since 2004, in particular in the highest income group. Meanwhile, in rural areas of Sweden the gender gap in commute distances is not narrowing, and rural commute distances are increasing from their already high levels (Appendix Figure 26).

Figure 20: Mean commute distance among employed adults, by residence location, equalised household income, gender and year, for trips within Stockholm County

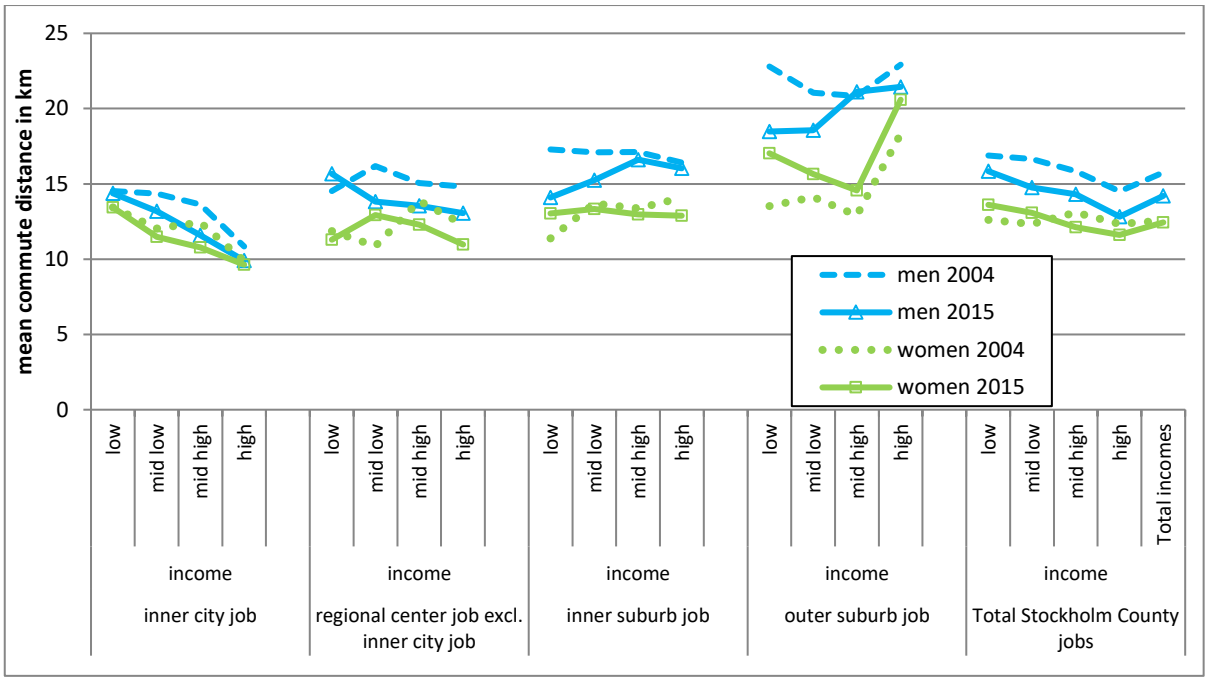

Figure 21: Mean commute distance among employees, by job location, equalized household income, gender and year, for trips within Stockholm County

Figure 22 shows that commute times in 2015 are relatively stable across job locations, genders and income groups. Commute times have increased between 2004 and 2015, more so for jobs outside of the inner city, thus for locations with a high car share of commutes.

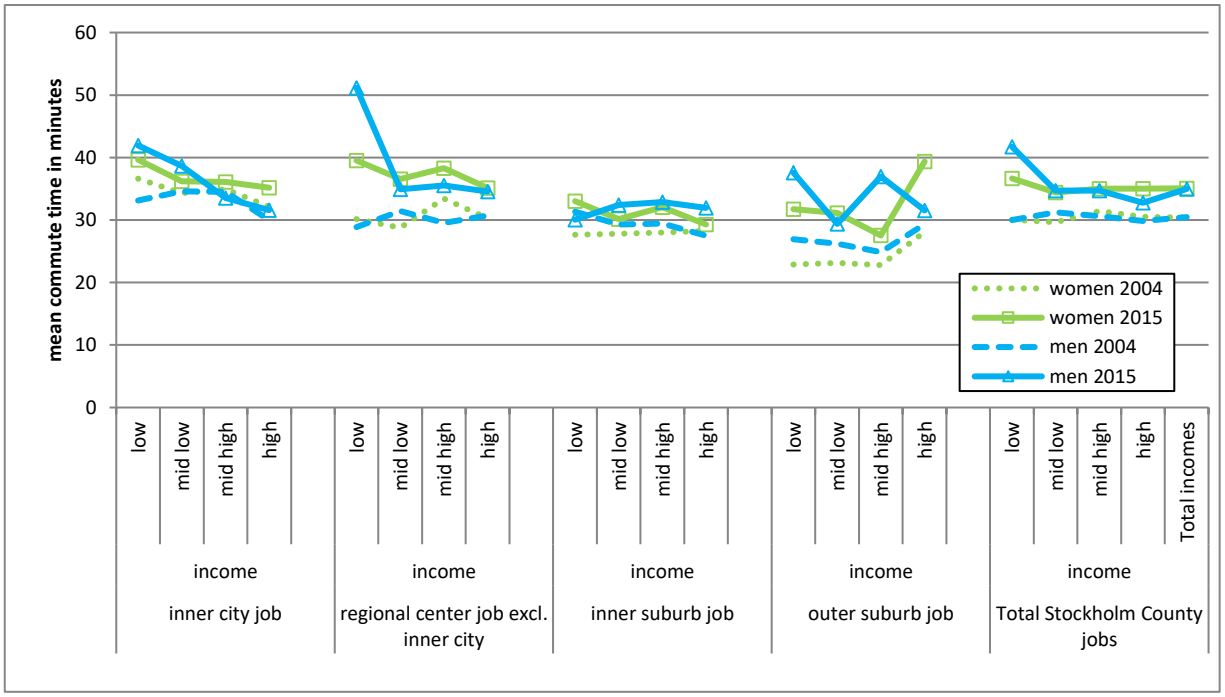

Figure 22: Mean commute time among employees, by job location, equalized household income, gender and year, for trips within Stockholm County

Table 3 shows that 1) working men and women in Stockholm County spend equal time commuting on average; 2) men in 2015 still have slightly longer average commute distances than women; 3) this remaining gender gap in commute distances exists only for car commuters. Among transit commuters, men and women in 2015 have nearly equal commute distances.

Table 3: Commute trips within Stockholm County, statistics by gender, year and mode

	car driver		public transit		All modes	
	women	men	women	men	women	men
mean commute trip distance (km)						
1986	9.4	12.3	11.3	12.9	8.8	11.1
2004	14.7	17.9	14.6	16.8	12.6	15.8
2015	14.8	17.7	14.9	15.8	12.5	14.3
mean commute trip time (min)						
1986	20.1	25.9	40.6	43.5	28.9	29.5
2004	22.7	26.6	41.4	43.0	30.3	30.5
2015	27.3	31.0	44.1	44.9	35.1	35.2

6.2 Commuting Discussion

Jane Jacobs (1961, p. 70) was among the first to warn of issues in satellite town planning. Our results suggest that a strategy towards more suburban employment clusters is not reducing commuting distances or the car share, compared to more central job locations. Additionally, even to reach the suburban employment clusters by transit, many travellers need to pass through Stockholm's crowded inner city stations, because of the radial design of the metro and commuter rail system. The key issues with the suburban employment clusters as opposed to the central clusters appear to be 1) that there is high accessibility to the inner city from most parts of the county, whereas the accessibility to suburban employment clusters is limited from many parts of the county; 2) the high specialization of the labour markets; 3) the increasing attractiveness of activities in the urban core to employees, employers (JLL, 2015; Savills, 2016) and residents; 4) that people change jobs more often than residential locations and many households have two specialized employees.

The gender gap in commute distances has nearly vanished for job (and residence) locations in the regional core. Yet the gap remains large for suburban and rural commutes in Sweden, and in particular for commutes by car. This spatial difference and the gender gap in urban commuting line up with earlier studies: women in Montreal were found to travel farther (Shearmur, 2006) and women in the San Francisco Bay Area to travel for a longer time (Chapple and Weinberger, 2000) than men to the central business district, when controlling for socio-economics and industry type. The opposite was found for suburban job locations.

There could be a range of different reasons for the lack of gender gap in central and dense locations: 1) societal changes beyond the transport system, for example, the faster increases in gender equality, women's education levels and employment levels in cities, and self-selection of more gender equal people to cities; 2) inner city jobs enable short commute distances for both men and women; 3) other aspects of inner cities might make city job locations more attractive to women and justify their travelling as far as men do to reach inner city jobs, for example services and transit accessibility. Women have a higher preference for transit versus car travel than men, while controlling for all other socio-economic variables. However, this preference gap has narrowed over time. It appears that women have a lower tolerance for long car commute distances than men. And women are less likely than men to have access to company cars and the free fuel, free congestion charge, and free job parking benefits that often come with them.

7 POLICY RECOMMENDATIONS

This study showed that the differences in travel behaviour between urban, suburban and rural populations are widening over time. A dense urban core corresponds to more gender-equal, income-equal and greener daily travel behaviour. We showed that car use declines and bicycling increases where economic, housing and activity densities are growing and road space is limited, even without substantial transit expansion. Thus, congestion (and housing shortages) in the urban core might be viewed as unavoidable in an attractive growing city. It needs to be managed by policies that allow for the accessibility (and housing) of more people in a small space, therefore allocating more space and priority to pedestrians, cyclists and transit users.

Conversely, we found that suburban employment and housing corresponds to much higher car travel distances and less gender-equal travel behaviour than for inner city locations in Stockholm County. This suggests that, to reduce car use and promote gender equality, housing and job growth would need to continue to be concentrated in the regional centre rather than suburban municipalities. This conflicts with the interests of suburban municipalities. Thus, the planning and decision authority for land use and transportation would need to be at a regional level rather than a municipal level. Apart from land-use and transportation planning, Stockholm's densification process may also benefit from (and fuel) the city's leading role as a technology, innovation and research hub.

Any policy aimed at reducing urban motor vehicle use would be wise to consider the incentive structure of access and use of company cars, delivery vans, and other professional vehicles. Cars that are owned by a juridical entity already account for over 40% of the distances driven by cars registered in Stockholm County. The congestion charges in Stockholm and London have been effective in keeping the highest valued trips on the road and thus increasing the share of professional traffic. Now, to manage the growing professional traffic and company cars, new instruments are needed, because professional traffic is very inelastic to pricing (and more elastic to GDP).

A possible path towards increasing bicycle accessibility for longer trips and among teenagers, women and retirees may be to improve the integration of transit and bicycles and safety for cyclists, following examples set by the Netherlands and Copenhagen. The spread of electric bicycles may also help in making bicycle use more attractive for longer trips and therefore more age- and gender-equal.

Urban car use is the predominant source of congestion, traffic accidents (European Commission, 2011) and urban air pollution (European Commission, 2016), but not of greenhouse gas emissions from high-income countries. European urban transport only directly causes roughly 6% of European greenhouse gas emissions[17], and this includes a growing share of professional transport[18]. A greater potential may lie in the indirect impact of European urban transport and land-use policy, via prototyping and demonstrating solutions that eventually help mitigate emissions from the rapidly growing cities in emerging economies. At a global level, urban transport already accounts for 40% of transport energy use (IEA, 2013), and cities in emerging economies are experiencing a rapid growth in population, motorization, and rapid changes to their land-use and transport systems (IEA, 2013). Hence, the climate issue will not be solved directly by changing transportation in European cities. Policy and technology would need to address long-distance travel, travel in rural areas and smaller cities, and to steer population and economic growth towards denser areas.

[17] European Union urban transport accounts for approximately one fourth of all transport related CO_2 emissions (European Commission, 2011). And the transport sector accounts for approximately one fourth of European greenhouse gas emissions (European Commission, 2016).

[18] In 2012 professional goods transport accounted for one third of road transport related greenhouse gas emissions in Stockholm city, and its share is expected to grow (Riedel, 2012).

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9 APPENDIX

Table 4: trips within Stockholm County, statistics by year and home location

	residential location				
	inner city	regional center excl. inner city	inner suburbs	outer suburbs	Total (Stockholm County)
mean trip distance (km)					
1986	5.2	7.0	9.1	11.0	8.2
2004	7.3	9.9	12.4	17.0	11.9
2015	6.8	9.1	11.1	17.7	11.3
mean trip duration (min)					
1986	30.1	30.3	30.9	31.0	30.6
2004	24.5	26.9	26.1	27.9	26.5
2015	27.1	30.5	31.1	37.1	31.7
mean trip speed (km/h)					
1986	10.3	13.9	17.6	21.4	16.1
2004	17.9	22.1	28.6	36.6	26.8
2015	15.0	17.8	21.3	28.7	21.3
mean trip frequency (trips per person per day)					
1986	3.1	2.8	3.0	2.9	2.9
2004	2.8	2.6	2.8	2.6	2.7
2015	2.5	2.3	2.4	2.1	2.3
mean daily travel distance (km per person per day)					
1986	15.8	19.6	26.9	31.6	23.8
2004	20.7	26.2	34.2	43.8	31.8
2015	17.0	20.9	26.1	37.2	25.8
mean daily travel time (min per person per day)					
1986	92.5	84.3	91.7	88.6	88.4
2004	69.4	71.1	71.8	71.9	71.2
2015	68.1	70.4	73.6	77.6	72.6

Figure 23: hours spent at each activity, mean among Stockholm County residents

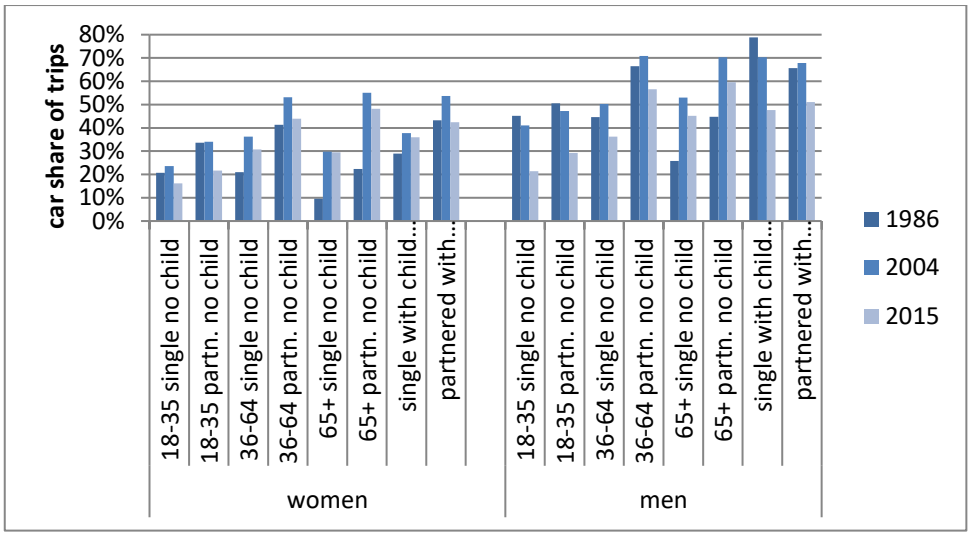

Figure 24: car share of trips within Stockholm County, by gender, year, age, partnership status and children in the household

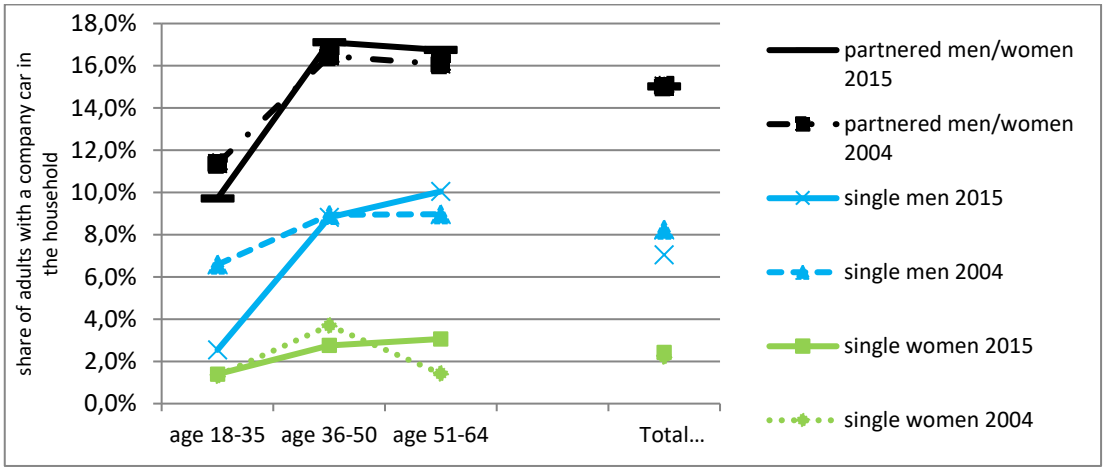

Figure 25: share of full-time employed adults aged 18-64, who have a company car in the household

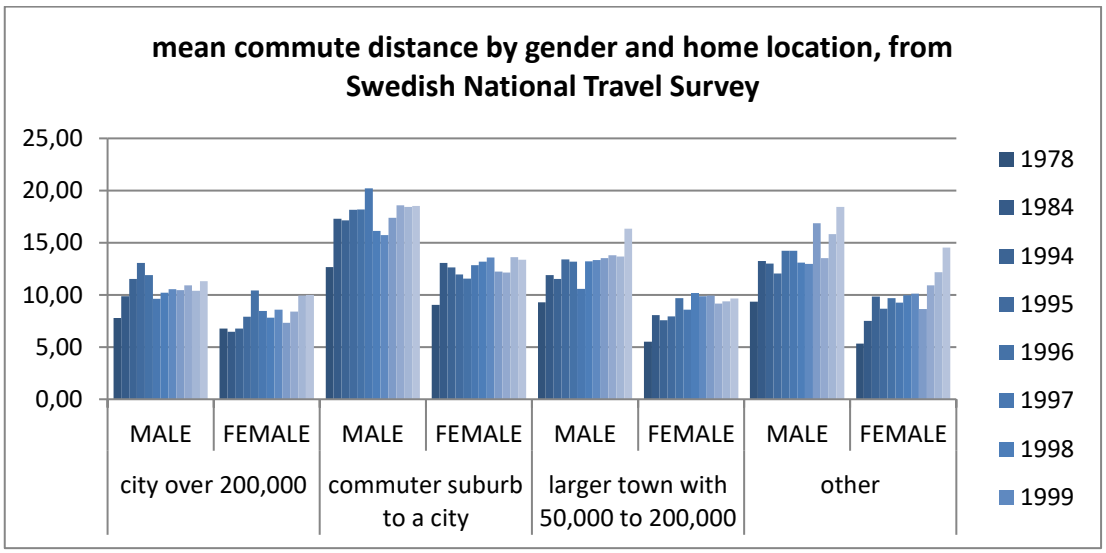

Figure 26: mean commute distance by gender and home location. Source: Swedish National Travel Survey. City residents are residents of the core city municipalities of Stockholm, Göteborg or Malmö.

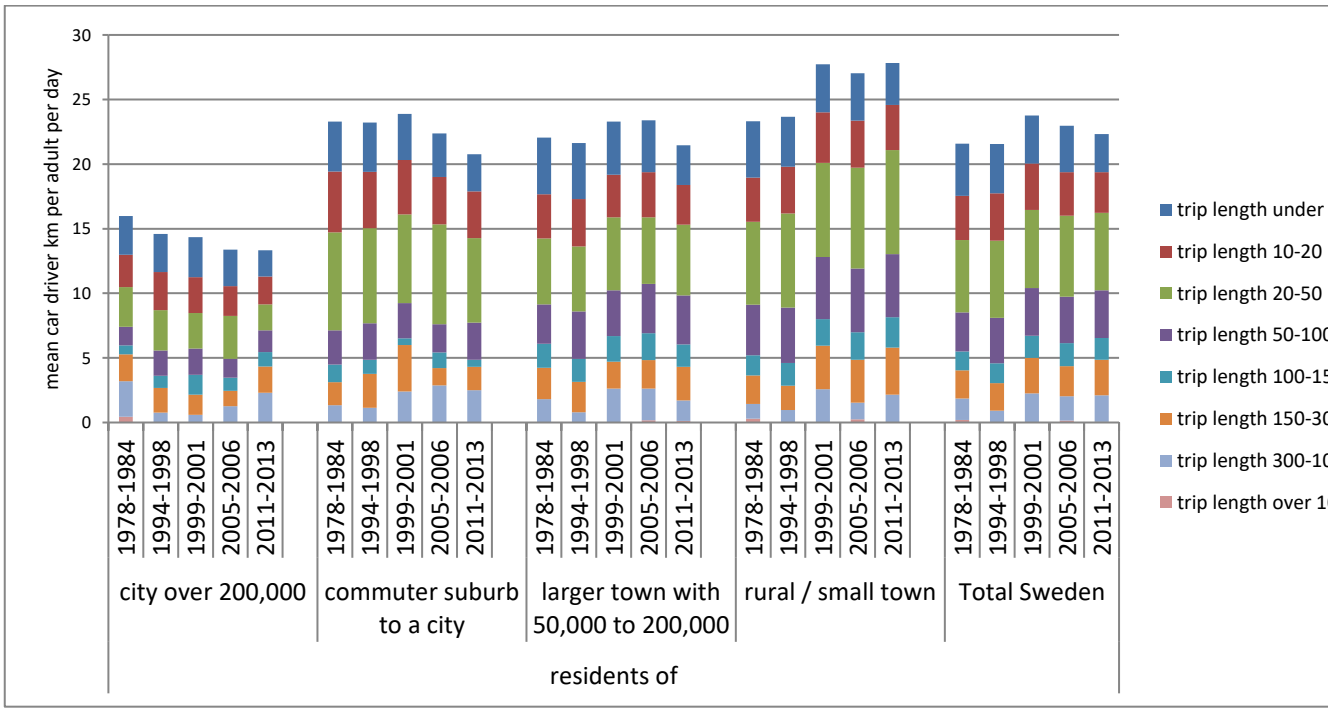

Figure 27: mean <u>car driver</u> km per adult per day, by trip length category, year and residential location. Source: Swedish National Travel Survey. City residents are residents of the core city municipalities of Stockholm, Göteborg or Malmö.

Figure 28: mean <u>rail</u> km per adult per day, by trip length category, year and residential location. Source: Swedish National Travel Survey. City residents are residents of the core city municipalities of Stockholm, Göteborg or Malmö.

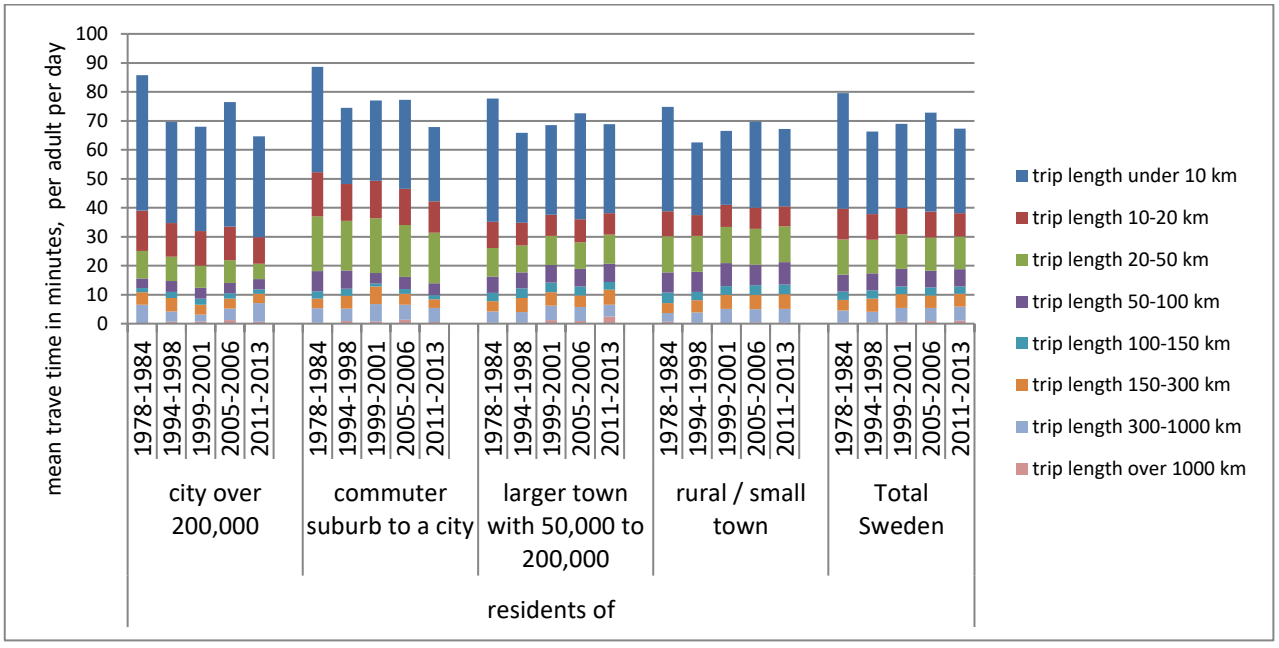

Figure 29: <u>mean travel time</u> in minutes, per adult per day, <u>all modes</u> (including flights), by trip length category, year and residential location. Source: Swedish National Travel Survey. City residents are residents of the core city municipalities of Stockholm, Göteborg or Malmö.

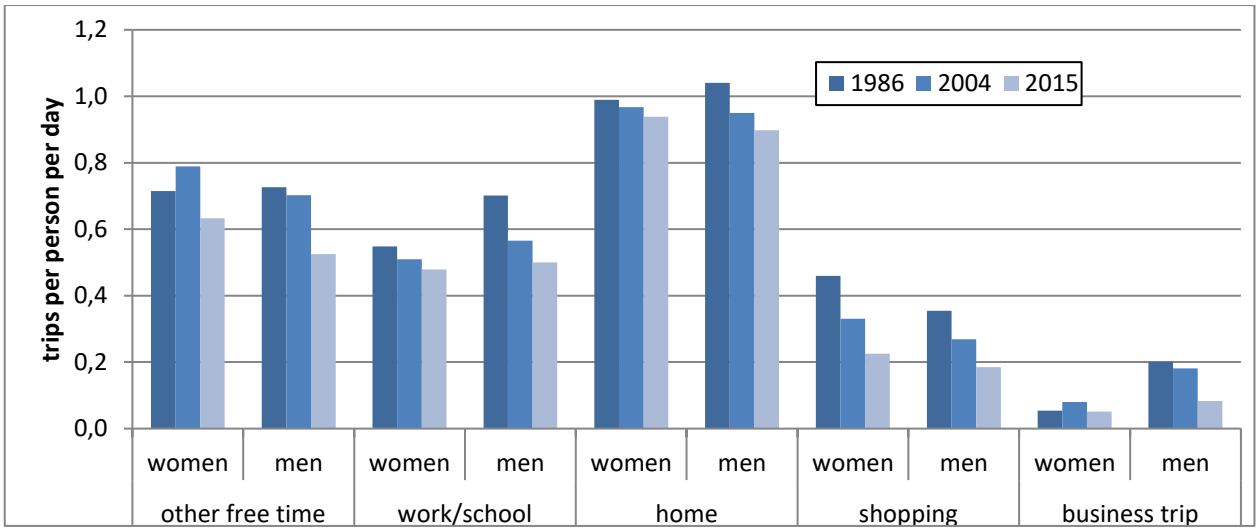

Figure 30: trips per person per day, by gender, trip purpose and year, among ages 16-74 in Stockholm County. For 1986 only this less detailed categorization of trip purposes is available.