

Bergen Light Rail – effects on travel behaviour

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Abstract

Bergen is the second most populous city in Norway (280,000 inhabitants) and is situated along the west coast of the country. In 2010, the city reintroduced tram service with the opening of a new light rail line, after a gap of 45 years. This study documents the increase in public transit use in Bergen, both in terms of volume and market share, since the line was opened. Furthermore, it explores the effects of light rail transit on travel behaviour using Bergen as a case city. These goals are accomplished by combining and analysing data from different sources, including five travel surveys, and other data concerning building stock, population, business activity, commuting and traffic counts. The study identifies four potential driving forces for changes in travel behaviour: (1) the introduction of the light rail; (2) a new high-frequency bus network; (3) increased rates in the toll cordon system; and (4) changes in the urban structure. The study concluded that the introduction of light rail was the main driving force behind the growth in public transit use. The study also highlighted that transit use was highest in areas served by the light rail. The effects of the light rail investments are reinforced by an optimal location of the line with respect to potential users.

Keywords: light rail, travel behaviour, travel survey, register data

1 Introduction

1.1 Modern light rail systems

Modern tram or light rail systems have become attractive options for improving urban public transport. By light rail or light rail transit (LRT), we mean an urban form of public transport often using rolling stock similar to a tramway, but operating primarily along exclusive rights-of-way (Transportation Research Board 2000). A number of cities and regions have planned, built or extended light rail systems over the past two decades (Hanssen et al. 2005, UITP 2009). Between 1985 and 2000, LRT systems were introduced in 42 cities around the world, and in another 78 since 2000. In 2015, 850 km of track infrastructure were under construction and another 2,350 km were in the planning stage (UITP 2015). Usage of existing light rail systems are increasing and the networks are extended (Department of Transport 2016).

It has been shown that LRT increases the use of public transport, influences urban land-use, promotes economic growth and increases the status of a region or city (Knowles 1992, Knowles and Ferbrache 2014).

1.2 *The Norwegian challenge*

The Government has adopted a so-called “zero-growth objective”, which seeks to meet expected increases in transportation demand in Norwegian cities without increasing passenger car traffic (Ministry of Transport and Communication 2013). A main strategy for achieving this is to steer the development of land-use and transport systems to reduce transport demands and to shifts in modal split towards less car-usage (Ministry of Local Government and Modernisation 2014). With emissions reduction and social and economic sustainability in cities as priorities, Norwegian municipalities and regional authorities have implemented a wide range of policies and measures, such as congestion pricing, restrictive parking policies, high-density land-use development, and investments in public transport infrastructure.

Several Norwegian cities have been reviewing the possibilities for light rail, but Bergen is the only one in which a completely new system has been introduced (there are older systems operating in Oslo and Trondheim¹). This paper focuses on the impacts of Bergen Light Rail on travel behaviour.

The paper supports previous studies showing growth in public transit use following the introduction of light rail. The most important contribution to existing literature is the documentation of greater effects of a new light rail line as compared with a modernized bus network and increased road tolls, on the use of public transport. The significance of light rail services affects mode of transport regardless of urban structure and the possibility of car use.

1.3 *Bergen Light Rail – reintroduction of the tram*

Bergen is located on the west coast of Norway and is the second most populous city in the country. In 2017, the number of inhabitants in the municipality of Bergen is almost 280,000 (Statistics Norway 2017). Over the last twenty years, the municipal population has grown by about 24 percent – it is expected to grow by another 16 percent over the next twenty years (Statistics Norway 2016).

The original tram system in Bergen was an integral part of the city’s public transport system from 1897 until 1965 when politicians decided to abandon the tram network and invest in large road infrastructure projects. Consequently, there was a significant increase in road capacity. In 1986 Europe’s first toll road system for accessing the city centre was introduced to finance further investments in road infrastructure.

By the 1990s, the region had experienced rapid growth in car ownership and use (Fosli and Lian 1999). Improved infrastructure shortened travel time and improved accessibility for cars. In both absolute and relative terms, car users were the main beneficiaries (ibid.). Investments and subsidies in public transport were

¹ Oslo (the largest city and capital) has both a relatively extensive metro network and an extensive tram network (partly with light rail standard). Both networks are being expanded. Trondheim (third largest city) has retained one tramline with primarily light rail standard. In more than five other cities in Norway, light rail is under discussion.

not a priority during this time – as public transport fares increased in order to maintain service, the numbers of passenger fell.

During the 1980s, land-use development in Bergen was characterized by urban sprawl. Both housing and workplaces were moving to the outskirts of the municipality, while the inner city experienced a rapid decline. However, in the 1990s, Bergen experienced a period of re-urbanisation with new housing being developed in the central parts of the city (ibid.). Furthermore, it was during the 1990s that it became evident that Bergen was facing major challenges related to accessibility, congestion and environmental pollution (Norwegian Environmental Agency 2014).

It was in this context that initial suggestions for building a light rail system emerged. In the year 2000, the City Council decided to build a new public transport system, with light rail constituting its backbone. Parliament approved the necessary funding support for construction in 2006. The first section, between the city centre and Nesttun, opened in spring 2010 (Figure 1). Section 2, between Nesttun and Lagunen, was finished in June 2013. Section 3 was opened in two stages – August 2016 and April 2017. The light rail now operates along a 20 km stretch between the city centre and the regional airport.

It has been decided to expand the light rail system with a new line from the city centre towards Fyllingsdalen in the south-west. Construction is scheduled to commence in 2018 and conclude in 2022 (Bergen Program for Transportation, Urban Development and the Environment 2017). The project will receive 50 percent funding from the national government (Ministry of Transport and Communications 2017). An extension of the existing line towards Åsane in the north is also planned.

1.4 Driving forces – research questions

Though we are primarily interested in studying the effects of light rail, other initiatives in the city need to be considered as well in order to successfully map out changes in travel behaviour. In 2010 and 2011, Bergen introduced a new high-frequency bus network serving parts of the city not covered by light rail. Various studies have shown the effect of reducing service intervals, measured with both elasticities (Balcombe et al. 2004, Norheim and Ruud 2007) and value of time savings (Samstad et al. 2010). Balcombe et al. (2004) found a short run elasticity of bus demand of 0.38, rising to 0.66 in the long run. For Norway, a short run elasticity of bus demand of 0.42 (Ruud et al. 2005, Norheim and Ruud 2007) has been estimated. It is thus likely that Bergen's new bus network, with more frequent departures, has made public transport more attractive.

Restrictive measures aimed at car traffic can also have a significant impact on travel behaviour (Fridstrøm and Alfsen 2014). In 1986, Bergen introduced a toll cordon system, which has since been expanded several times. An important factor influencing our line of enquiry is the increase in toll charge from NOK 15 to NOK 25 in 2012. The city centre was made inaccessible by car without paying this toll amount. Furthermore, the municipality has restricted parking in the city centre. Studies undertaken in Norwegian cities show that parking restrictions

significantly affect car use, particularly in dense city-centre areas (Christiansen et al. 2017). This may enhance the effect of a high standard public transport system.

Consequently, in our analyses we considered these three potential driving forces, and framed the research question as following: *Have there been any changes in travel behaviour in Bergen linked to the introduction of light rail, and is it possible to separate this effect from the impacts of the new bus system, increased toll rates and more restrictive parking regulations?*

The tolls can be assumed to have a uniform effect throughout the city for travelling to and from the central areas. The same most likely applies to impacts of parking regulations since restricted parking zones extend from the city-centre with approximately the same distance in all directions. Similarly, if the effect of the new bus network is in line with the effects of the light rail service, any changes in travel behaviour should be comparable in similar areas. If light rail provides greater impact, changes in areas served by the light rail should be larger.

However, urban developments may also have affected travel behaviour. The planning of the light rail was coordinated with plans for land-use densification and transformation along the line (Svanes 2012). If this has been a success, a denser urban structure along the line may have affected demand for public transport and, therefore, should be included as a control factor in the analysis. Several studies have shown correlations between urban structure and travel behaviour. Erving and Cervero (2010) have made a summary of studies in American cities, and a summary for the Nordic countries is given by Næss (2012). Detailed analyses of urban structure and transport in Norwegian cities are presented in Engebretsen (2005), Engebretsen and Christiansen (2011) and Christiansen et al (2017).

2 International experiences

Most research articles studying the effects of light rail initiatives have primarily dealt with impacts on land-use and property values, often in the context of transit-oriented development (TOD). Studies of light rail's impacts on travel behaviour are more limited (Kim et al 2007, Gadzinski and Radzimski 2016).

In the early years of modern light rail, it was argued that the introduction of such systems had increased the use of public transport in some European and North American cities (Knowles 1992). Later, Mackett and Edwards (1998) expressed a need for more comprehensive before-and-after studies to identify any impacts on travel behaviour of light rail investments. Based on a worldwide survey among experts in 100 cities on new urban public transport systems, they concluded that the effects, in general, were very limited. However, at around the same time as Mackett and Edwards' study, other studies demonstrated positive effects of specific light rail projects.

Before-and-after surveys showed that Metrolink² in Manchester attracted more passengers than forecasted, and led to car users switching to public transport

² Metrolink was the first modern light rail system in the United Kingdom (Department of Transport 2011).

(Knowles 1996). A follow-up study some years later confirmed the findings based on changes in transit use from 1991 to 2001 (Senior 2009).³ In Portland it was found that households along MAX Light Rail were less car-oriented and more likely to use public transit as compared with a control group in a parallel bus corridor (Dueker and Bianco 1999). A cross-sectional study of 268 light rail stations in nine US cities, representing a variety of urban settings, showed that land use within one-half mile around stations, combined with the station's accessibility, is means to increase transit use (Kuby et al. 2002). Within 800 metres (half-mile) of stations along regional commuter train lines in California, residents generally ride public transit (Cervero 2007). The effect was partly due to residential self-selection⁴ as well as factors like employer-based policies that reduced free parking and automobile subsidies.

Hanssen et al. (2005) summarized the market effects of eleven different light rail systems in Europe. Increased or maintained public transport market share was reported for Helsinki, Stockholm, Gothenburg, Haag, Strasbourg, Croydon, Cologne and Vienna (mostly the Vienna metro).

The effects of Croydon Tramlink were studied in detail (Transport of London 2002). After the opening in 2000, the public transport share within 800 metres of Tramlink stops increased from 30 to 47 percent on weekdays and from 18 to 38 percent on weekends. Driving reduced from 42 to 35 percent on weekdays, with even higher reductions in some other areas. Tramlink's opening led to 69 percent of bus passengers and 16 percent of car drivers shifting to the tram. The survey showed that for passengers who shifted to Tramlink, 55 percent had a car and 86 percent had an alternative mode of transport available (ibid.).

Studies from recent years confirm that light rail initiatives appear to increase the public transport share. In Denver, the light rail system has reduced traffic on adjacent highways (Bhattacharjee and Goetz 2012). In Minneapolis-St. Paul the residents along the Hiawatha light rail use transit significantly more than residents in a comparable control corridor (Cao and Schoner 2014). In Poznan 42 percent of residents living within 1 km of light rail stops⁵ use public transport at least once a day, as compared with 33 percent in other parts of the city (Gadzinski and Radzinski 2016). The figure for car use is 30 and 34 percent respectively.

However, the recent studies are not unambiguous. Lee and Senior (2013) claim that the growing rail shares between 1991 and 2001 in four light rail corridors have mainly come from buses⁶. The evidence for light rail reducing car use is less clear. The conclusion seems to be partially in conflict with the results from previous studies of the same light rail systems (Knowles 1996, Senior 2009, Transport of London 2002). One explanation can be that Lee and Senior's study includes only commuting trips. According to the British National Travel Survey

³ However, despite Metrolink's success, the study concluded that the first line made only a minimal impact on road congestion, partly because of the lack of coordinated car-restraining policies.

⁴ Attraction of residents who are more disposed to use transit in the first place.

⁵ Poznan LRT is Poland's first light rail line, opened in 1997 (Gadzinski and Radzinski 2016).

⁶ The study includes Greater Manchester Metrolink, Croydon Tramlink, Midland Metro and South Yorkshire Supertram.

(Department for Transport 2016), commuting constitute no more than 15 to 17 percent of daily trips in urban areas (20 percent in London).

Effects of light rail on travel behaviour is also a matter of how well it fits the market. Knowles and Ferbrache (2014) conclude that similar light rail investments in different locations will not necessarily have same impacts, which is another way of saying that “geography matters”.

Our contribution to the pool of research studies focussing on light rail’s effects provides a relatively detailed before-and-after study, and thus corresponds to the challenge of Mackett and Edwards from 1998. Additionally, we have focused on a comparative analysis of trends and correlations between comparable areas. In this way, we have followed up on research designs and methods from several of the earlier studies. Bergen, with its special topography (situated on the coast and between mountains), provides an interesting case for making comparisons between residential areas that are relatively isolated from each other, but remain connected by bridges and tunnels. Access to a relatively large amount of data further provided the opportunity to supplement the existing knowledge of light rail’s effects on travel behaviour, especially relevant for medium-sized cities (100,000-500,000 inhabitants⁷). By using several general representative travel surveys combined with various types of geographical data, we have been able to test various possible causes, in addition to the introduction of light rail, of changes in travel behaviour.

3 Data and methods

We have used several approaches in studying the effects of light rail on travel behaviour. First, we looked at changes at the city level based on traffic and passenger counts, and statistical testing of travel surveys⁸. The idea of this temporal study has been to identify changes in travel behaviour that coincide in time with the restructuring of the city’s transport system from 2010. We focus on the development of public transport by including both the number of trips and the market share. An increase in public transit use, beyond the impact of population growth, could be an indication of the effects of the introduction of light rail, the modernized bus network, or the increased road tolls.

To identify the effects of light rail, we have used a temporal cross-sectional analysis at the level of urban districts, inside and outside the light rail catchment areas. The purpose of this approach has been to reveal whether the changes in travel behaviour along the light rail line differ from changes elsewhere in the city. The comparison is based on statistical testing of travel surveys before and after 2010. To control for other changes that may have led to an increase in public transit use, this growth is compared with changes in housing, population and jobs along the line. As a further test of the significance of the light rail when controlled for variations in the urban structure, we have used logistic regression models in spatial cross-sectional analyses.

⁷ According to Giffinger et al. (2007), this is the size range of a medium-sized European city.

⁸ Binomial tests and t-tests.

In the last part, we have made more detailed analyses of the extent of the light rails catchment areas (based on logistic regression) and, from this, examined how well the light rail matches the market.

We have set the light rail catchment area (LRC) at 1 km (as the crow flies) around the stops (Figure 1). However, in the south, the market area for the light rail may be somewhat extended by local feeder buses terminating at Lagunen public transport terminal. The bus lines connect more distant parts of Fana and Ytrebygda urban districts to the light rail. In addition, the terminal functions as an interchange point between the light rail and regional buses. Since 2016, the Birkelandskrysset public transport terminal has functioned similarly to the Lagunen terminal. In the north, the light rail system is linked to several bus lines through the northern part of Bergenhús urban district. The Byparken terminus on the light rail probably functions as an interchange point together with nearby bus stops.

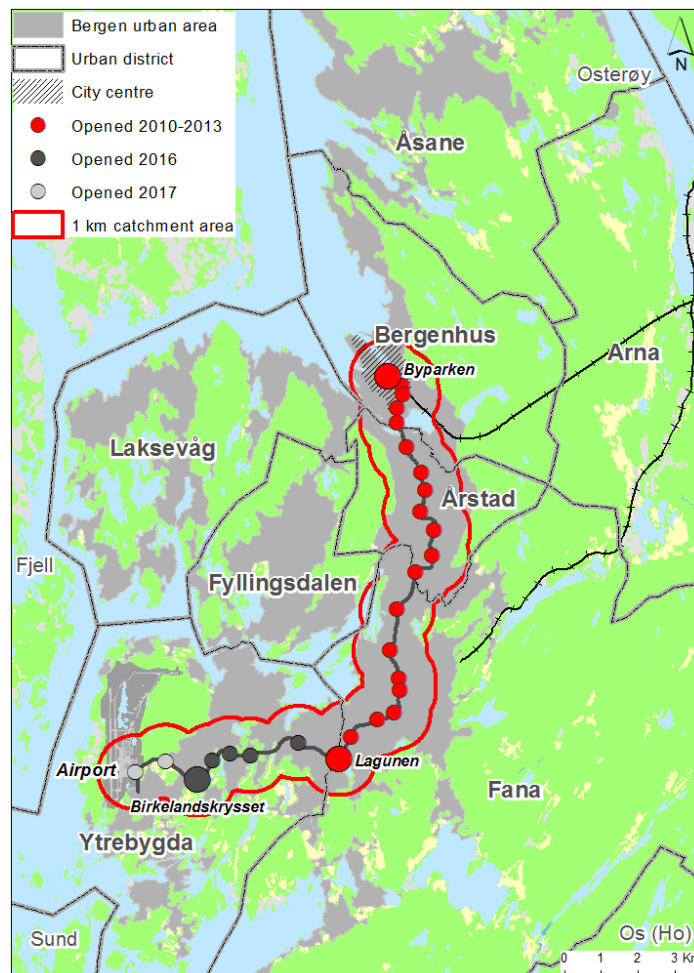


Figure 1. The urban districts of Bergen and the Bergen Light Rail.

The analyses are based on data relating to basic statistical units⁹ or address coordinates. Most of the analysis will concentrate on the two sections opened before 2016 (stops marked in red in Figure 1).

We have taken data from five travel surveys along with results from traffic (Hordaland County Council 2015a) and passenger counts (Hordaland County Council 2015b) in order to analyse how the light rail system has influenced travel behaviour. Three travel surveys, TS08, TS09 and TS10, were used in the analysis of travel behaviour before the light rail system opened.

TS08 is a regional travel survey from 2008 based on 9,653 interviews with residents in Bergen and surrounding municipalities (Meland 2009). TS09 is the 2009 National travel survey with 902 interviews covering the Bergen region (Vågane et al. 2011). TS10 is a travel and attitudinal survey containing 3,000 interviews with residents (from 18 years and above¹⁰) in the light rail corridor. The interviews were conducted in March and April 2010 (Christiansen et al. 2010). The findings from these surveys are compared with the results from two travel surveys conducted after the light rail system opened. TS13 is a regional travel survey from 2013 containing 10,570 interviews with residents in the Bergen region (Meland and Nordtømme 2014), while TS14 is the 2013–2014 National travel survey with 4,205 interviews in the region (Hjorthol et al. 2014). To obtain a sufficient number of interviews and comparable data, most analyses are based on TS08 and TS13. Because TS08 and TS13 do not include Saturdays and Sundays, we confined most of the analyses of travel behaviour to weekdays¹¹.

Data from various registers are used to control for any effects of changes in the urban structure along the light rail line. The Norwegian Cadastre property register (The Norwegian Mapping Authority) contains regularly updated information on all buildings in Norway, including type of building, year of construction, number of dwellings (in each building) and exact location. We used data from this register for a complete overview over changes in the housing stock in Bergen, especially within the LRC. Similarly, we quantify population changes along the line and in the rest of Bergen by using Statistics Norway's population register, which provides population figures within the basic statistical units on an annual basis. For an overview of changes in the industrial localization related to the basic statistical units, we used data from a complete national register of businesses and enterprises (Statistics Norway/Institute of Transport Economics). In addition, we used data from a complete national register of commuting between the basic statistical units (Statistics Norway/Institute of Transport Economics).

⁹ Basic statistical units are subdivisions of municipalities, used by Statistics Norway to provide stable and coherent geographical units for regional statistics. There are approximately 14,000 basic statistical units in Norway, most of which include only a few hundred inhabitants. In cities, units have only a small geographical extent. E.g., the light rail catchment area in Bergen consists of more than 130 basic statistical units.

¹⁰ The other four travel surveys include residents 13 years and above.

¹¹ We must take into account that TS08 and TS13 interviews were carried out in the autumn, TS10 interviews in the spring, while TS09 and TS14 covers the whole year.

4 Results

4.1 Increased public transport in Bergen

During the period 2009-2014, car traffic to and from Bergen city centre decreased despite population growth (Figure 2). The decline coincided with a sharp rise in public transport after the light rail line was opened and a new high frequency bus system was introduced. From 2012, we observe a reduction in overall traffic throughout the city, including the areas around the city centre¹² (Figure 2 – Hordaland County Council 2015b). Changes in the market share of transport modes over the last two years must be seen in the context of increased road tolls and extension of the light rail line in summer 2013.

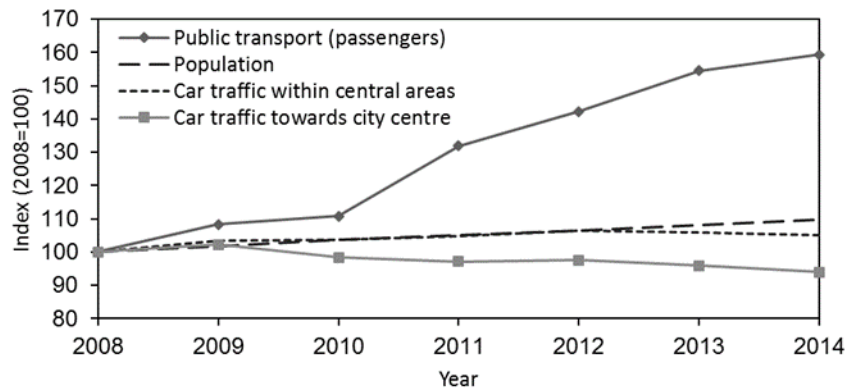
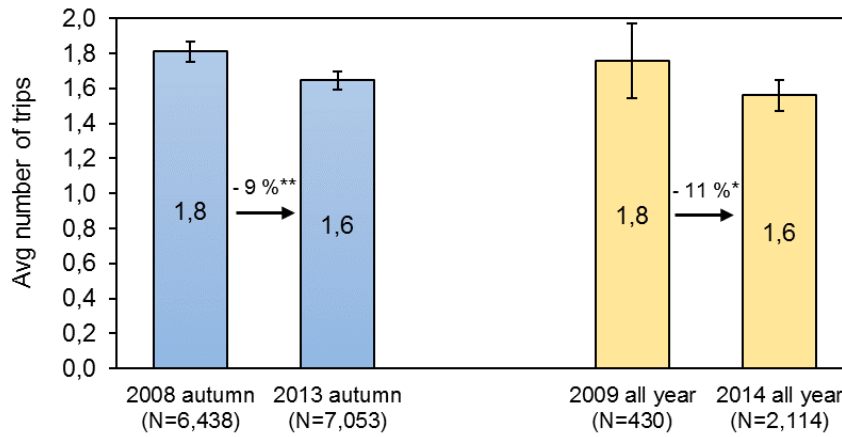


Figure 2. Development of car traffic, public transport (number of passengers) and population in Bergen, 2008–2014 (2008=100).

The growth in public transit use (shown in Figure 2) is overstated due to an increased number of transfers after the introduction of light rail (passengers were counted when boarding a bus or a tram – each line separately). In addition, some of the passenger increase reflects population growth. Changes of car traffic in relation to population growth is probably a better indicator of the overall trends. In central areas, per capita car traffic decreased by about 6 percent during the period 2009 to 2014. For traffic to and from the city centre, the relative decline was more than twice as much. The travel surveys confirm this trend, demonstrated by the average number of daily trips as a car driver (see Figure 3). Within a few years, daily car use in Bergen was reduced, measured for weekdays in the autumn (TS08 and TS13) and on a yearly basis (TS09 and TS14).

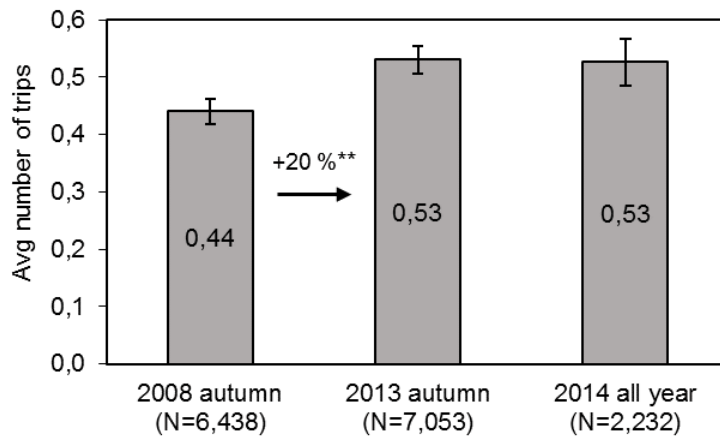
¹² Areas within 5-6 km from city centre.



**Significant decrease at the 0.01 level. *Significant decrease at the 0.05 level.

Figure 3. Average number of daily trips as a car driver for trips within or to/from Bergen, Monday–Friday, by residents of Bergen, 13 years and older. (Error bars: 95 percent confidence interval.)

The rise in the use of public transit can be measured similarly. Based on TS08, TS13 and TS14, within Bergen, the number of public transport trips per person increased by 20 percent from 2008 to 2013 (Figure 4), while the market share of public transport rose from 13 percent to 16–17 percent during this period (Table 1).



**Significant increase at the 0.01 level.

Figure 4. Average number of daily trips by public transport for trips within Bergen, Monday–Friday, by residents of Bergen, 13 years and older. (Error bars: 95 percent confidence interval.)

Table 1. Modal share (percent) of travel within the municipality of Bergen, Monday–Friday, by residents of Bergen, 13 years and older during the period 2008–2014. (Margin of error ± 0.1 – 1.2 percentage points.)

Year	Modes of travel				Total	N
	Walking and cycling	Car/MC	Public transport	Others		
2008	27.3	58.8	12.9	0.9	100	21,895
2013	29.8**	53.5**	15.6**	1.1*	100	23,960
2014	31.9**	50.7**	16.8*	0.6*	100	7,015

**Significant change 2008–2013 and 2013–2014 at the 0.01 level. * 0.05 level.

Our task is to reveal the importance of the light rail system. Overall, it can be concluded that travel behaviour has changed since the opening of the new line. However, we have identified three possible driving forces behind the observed development: the introduction of light rail, upgrading and modernization of the bus network and increased road tolls. We now turn our attention to the question of whether we can separate the effects of light rail from the effects of the other two possible driving forces. In addition, we will examine whether developments in the urban structure may have affected the demand for public transport.

4.2 *Light rail – a driving force?*

Analysis disaggregated by residential location shows that the increase in public transport is primarily a characteristic of areas served by light rail. This is clear from Table 2, which highlights respondents' mode of travel by urban district and by access to light rail transit from home. The table includes all travel within the Bergen municipality based on TS08 and TS13. Residents in light rail catchment areas have, by far, the highest relative increase in market share for public transport. This is particularly evident in Figure 5, which shows the increased proportion of people using public transport among motorized trips. However, the increase is relatively high even outside the LRC in Bergenhus and Fana/Ytrebygda. This growth is still linked to light rail, largely in combination with bus (lines to Byparken interchange and feeder buses to Lagunen interchange – see section 3). In addition, residents in Fyllingsdalen showed significant increase in market share for public transport, although less than half of what was observed for the catchment areas. The increased market share of public transport in this area can be attributed to improved bus services.

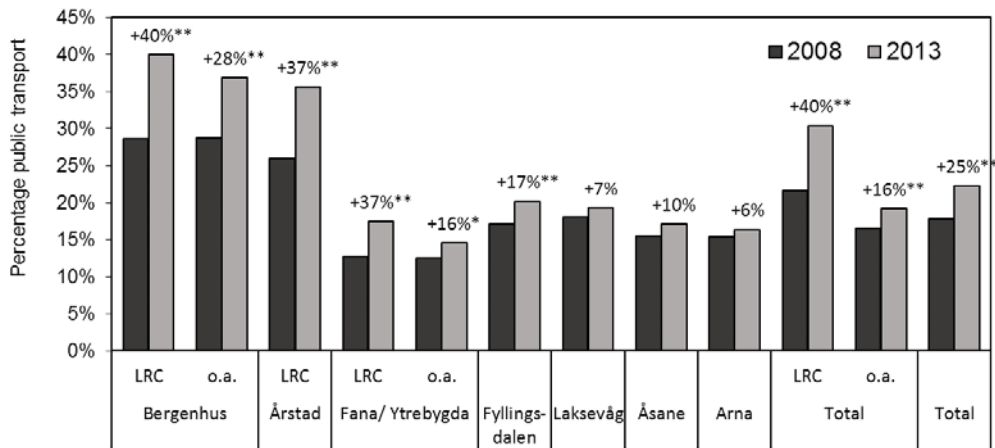
Table 2. Modal share (percent) of travel within the municipality of Bergen by the traveller's place of residence (urban district), 2008 and 2013, Monday–Friday.
(Margin of error ± 1.0 – 2.8 percent points.)

Place of residence (urban district)		Modes of transport 2008				Modes of transport 2013			
		Walking and cycling	Car/MC	Public transport	N	Walking and cycling	Car/MC	Public transport	N
Bergenshus (city centre)	LRC	70.5	20.3	8.5	2,181	65.4 **	18.8	13.8 **	2,710
	o.a.	42.4	40.1	16.6	1,558	45.4 *	33.7 **	20.1 **	2,145
Årstad	LRC	37.4	44.9	16.3	2,988	38.9	38.2 **	21.8 **	3,658
Fana/ Ytrebygda	LRC	20.4	68.4	10.2	1,789	23.9 **	61.6 **	13.3 **	1,972
	o.a.	14.7	73.9	10.7	3,580	17.8 **	69.2 **	12.0 *	3,690
Fyllingsdalen		19.1	66.0	13.9	2,426	22.5 **	60.9 **	15.6 *	2,613
Laksevåg		21.0	63.9	14.3	2,960	21.4	62.5	15.2	2,895
Åsane		15.4	70.6	13.2	3,387	18.0 **	67.1 **	14.1	3,214
Arna		15.8	70.9	13.0	995	15.6	69.5	13.8	1,034
Total	LRC	43.4	43.2	12.3	6,958	43.3	38.1 **	17.2 **	8,340
	o.a.	19.8	66.1	13.3	14,906	22.8 **	61.5 **	14.8 **	15,591
Total		27.3	58.8	12.9	21,895	29.8 **	53.5 **	15.6 **	23,960

LRC=Light rail catchment area. o.a.= other areas.

** Significant change 2008-2013 at the 0.01 level. * 0.05 level.

The changes within the LRC is quite similar to what happened after the opening of Croydon Tramlink in London (Transport of London 2002). Although the public transport share in Croydon is about twice as much, the relative changes are comparable. Within 800 meters of Metrolink stops, public transport share increased by 57 percent, while the motorist percentage decreased by 17 percent (based on the figures in section 2). The corresponding changes for the LRC in Bergen is a 41 percent increase in the public transport share and 12 percent decrease in the share of car use.



**Significant at the 0.01 level. *Significant at the 0.05 level.

Figure 5. Public transport as percentage of motorized trips within the municipality of Bergen, disaggregated by the traveller's place of residence (urban district), 2008 and 2013, Monday–Friday. Percentage figures show relative increase in the public transport's market share. (LRC=Light rail catchment area, o.a.=other areas.) (Margin of error ± 1.2 –3.5 percentage points.)

The more frequent use of public transport was mainly accompanied by reduced car use (Table 2). In the city centre (corresponding to the LRC in Bergenhus), however, there was an equal (relatively speaking) decrease in non-motorized travel, which may indicate that people more often "jump on" the tram or bus for short trips, perhaps because of frequent departures. A similar effect was found for Croydon Tramlink in London (Transport of London 2002).

For larger parts of the city, Table 2 shows significant decreases in the percentage of car and motorcycle use. However, much of this decrease can be attributed to a decline in the number of car passengers as opposed to vehicles. This emerges clearly from Table 3, which shows the changes in average number of daily trips for different modes of transport. Both in the total LRC areas and in areas outside the LRCs, there has been a significant decline in daily car usage by drivers. However, at the level of urban districts, this appears to be true exclusively for the residents of Årstad, Fana/Ytrebygda outside the LRC, and Åsane. In Årstad, the reduction in car drivers was attributed to increases in public transit use. To some extent, this also applies to Fana/Ytrebygda outside the LRC. More important for this area however, is an increased share of trips on foot and a reduction in daily trips. For Åsane, the reduction in daily trips was the dominant explanation. An important point is that car use was particularly high in Åsane and Fana/Ytrebygda outside the LRC in 2008 (Table 2). If we exclude these areas from the table, the reduction in car drivers outside the LRC total is only -0.05 and not significant.

Table 3. Changes in average daily trips by transport mode and the traveller's place of residence (urban district) for trips within the municipality of Bergen, Monday–Friday, 2008-2013.

Place of residence (urban district)		Changes 2008 - 2013					N	
		Walking and cycling	Car as driver	Car passenger	Public transport	All modes	2008	2013
Bergenshus	LRC	-0,17	0,03	-0,06 *	0,22 **	0,05	542	662
	o.a.	0,16	-0,04	-0,12 **	0,15 *	0,10	420	560
Årstad	LRC	0,09	-0,17 *	-0,04	0,22 **	0,08	828	990
Fana/ Ytrebygda	LRC	0,17 *	-0,21	0,05	0,14 **	0,17	482	508
	o.a.	0,10 *	-0,27 **	0,01	0,03	-0,16 *	884	948
Fyllingsdalen		0,15 *	-0,10	-0,06	0,08	0,08	645	680
Laksevåg		0,03	0,03	-0,01	0,05	0,10	823	782
Åsane		0,05	-0,30 **	-0,03	0,00	-0,27 **	879	896
Arna		0,03	0,12	0,04	0,06	0,24	276	269
Total	LRC	0,03	-0,13 *	-0,03	0,20 **	0,09	1852	2160
	o.a.	0,11 **	-0,16 **	-0,03 *	0,05 **	-0,03	3927	4135
Total		0,09 **	-0,16 **	-0,03 *	0,10 **	0,01	5779	6295

LRC=Light rail catchment area. o.a.= other areas.

** Significant change 2008-2013 at the 0.01 level. * 0.05 level.

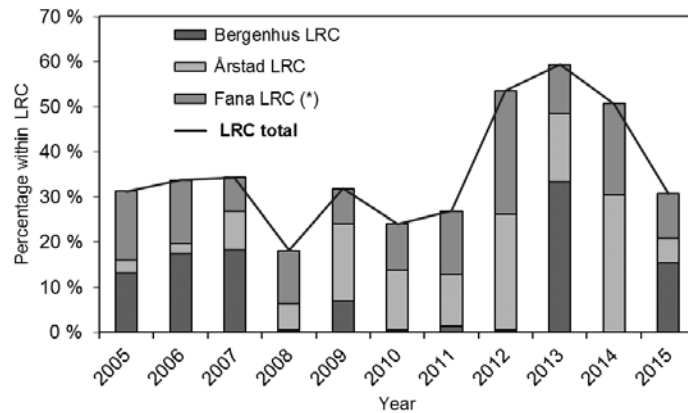
Given that there is a slight increase in the share of public transport in all districts (albeit not statistically significant for all) (Figure 5), the overall findings suggest that both restrictive measures (road toll) and improvements in public transport services (improved bus network and introduction of light rail) contributed to an increase in public transit use. However, the LRCs have, by far, the highest relative increase, indicating that light rail is the main driving force behind the growth in public transit use.

As for car traffic, we hypothesized (section 1.4) that the increased tolls must be assumed to have a uniform effect throughout the city. This would imply an equal decrease in daily trips for car drivers in all areas outside the city centre. However, this does not seem to be the case as no effects were found in many areas.

On the other hand, other changes within the LRC may have contributed to the growth in public transport. People moving into the area, perhaps motivated by the possibility to use the light rail, could be such a factor. Many previous studies have addressed such residential self-selection (e.g. Dueker and Bianco 1999, Cervero 2007, Cao and Schoner 2014).

Based on analysis of various register data, we can confirm that there has been an increased concentration of residential development along the light rail line (may be a result of the land-use plans targeting densification, Svanes 2012). Before 2010, about 30 percent of new homes in Bergen were built in areas now serviced by the light rail. Since the opening of the new transit system, the spatial

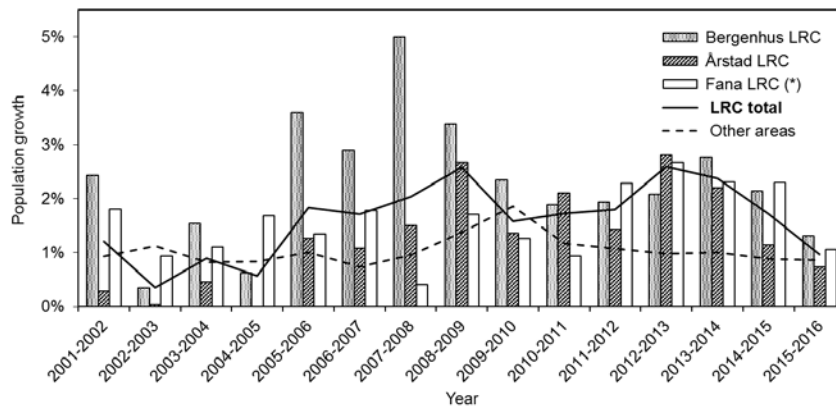
distribution has changed. Figure 6 shows that from 2012 to 2014, more than 50 percent of the new dwellings in Bergen were built in the LRCs.



(*) Fana LRC includes some areas in the urban district of Ytrebygda – see Figure 1.

Figure 6. Percentage of new homes in Bergen built within the LRC, 2005–2015.

Higher housing prices (Fredriksen 2013) and population growth rates along the line, indicates increased attractiveness. Since the opening of the light rail line, the population growth rate within the LRC has increased significantly, while the rate in other areas has diminished (Figure 7). From 2011 to 2015, the ratio between the growth rates within the LRC and other areas was approximately two to one.



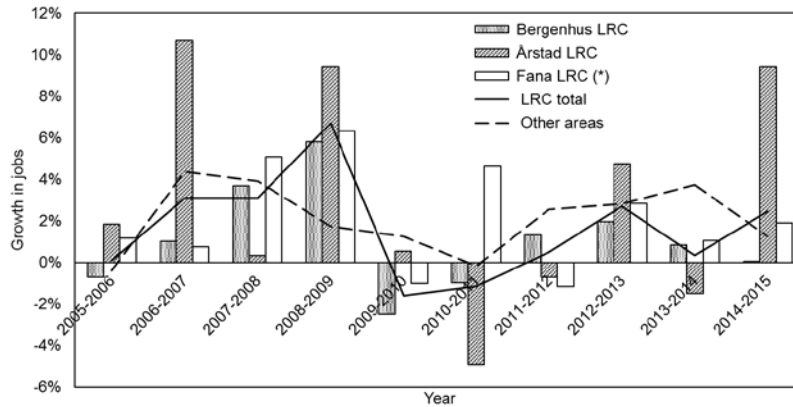
(*) Fana LRC includes some areas in the urban district of Ytrebygda – see Figure 1.

Figure 7. Population percentage growth per year in selected zones within Bergen municipality, 2001–2016.

Although Figure 6 and Figure 7 show clear changes, this cannot explain much of the increase in public transit use from 2008 to 2013 (Table 2 and Figure 5), even if we assume that all new residents are using the light rail. This is because the population growth within the LRC from 2008 to 2013 was just under 11 percent, whereas the market share of public transport increased by 40 percent.

Industrial developments along the light rail line cannot explain the increase in public transit use either. Admittedly, after a period of decline, there have

gradually been more jobs within the LRC since 2011 (Figure 8), but for the most part, growth has been lower than in other areas of the city.



(*) Fana LRC includes some areas in the urban district of Ytrebygda – see Figure 1.

Figure 8. Percent growth in jobs per year in selected zones in Bergen municipality, 2005–2015.

After controlling for developments in the urban structure, the introduction of the light rail stands out as the main driving force for the growth in public transit use among the residents. This conclusion corresponds largely with people's ratings ahead of the opening of the line. In the travel and attitude survey in spring 2010 (TS10), a third of the residents within the LRCs expressed that they expected to travel more by public transport after the opening (Christiansen et al. 2010).

To confirm that light rail proximity is an independent factor affecting travel behaviour, we have carried out a double cross-sectional multivariate analysis based on TS13 and TS14 respectively. We have tested the effect of proximity to light rail when controlling for the overall effects of variations in city structure and possibility of car use. To ensure that we have similar areas in the analysis, we have limited the study to the Bergen urban area within 11 km from the city centre. This provides three urban corridors, one to the north, one to the south-west and one to the south (where the light rail runs) in addition to intermediate areas primarily near the city centre. The study area is divided into 320 residential zones equal to the basic statistical units.

The results are shown in Table 4. Both regression-models are based on trips to or from the resident's home, starting and ending within the urban area. The dependent variable is use of public transport on motorized trips (non-motorized trips are excluded). The independent variable for light rail proximity is the distance to the nearest light rail stop (km). In the TS13-model, the distances are measured from the midpoint of each residential zone. In the TS14-model the variable represents the distance from each individual home address (address coordinates). Distances greater than 1.0 km are set to 1 as an indicator of being outside the LRC.

Based on experiences from studies in Norwegian cities (Engebretsen and Christiansen 2011, Christiansen et. al. 2017), we have chosen distance to city centre, local population density and local workplace density as independent

variables describing the city structure. Distance to city centre was measured, as the crow flies, from the midpoint in the residential zone (km). Population density was measured as the number of residents in the zone divided by the standard distance for all residential and commercial buildings. Workplace density was measured in the same way¹³. The standard distance was used here as a substitute for built-up land. The range for population density in the 320 zones is 0-13, and for workplace density 0-40.

Having a driving license was used as an indicator of people's ability to drive. The percentage who have this option was approximately the same in all zones. In the TS14-model we have also incorporated access to private parking at home (not asked for in TS13), which in many areas, influences vehicle ownership and usage patterns¹⁴.

The independent variables were tested for collinearity.

Table 4. Logistic regressions for use of public transport as part of motorized trips among residents living less than 11 km from the city centre within Bergen urban area for trips starting or ending at home.

TS13 - weekdays autumn. N = 10,219.	B	S.E.	Sig.	Exp(B)
Distance from residential zone to nearest light rail stop	-0.616	0.018	0.000	0.540
Distance from residential zone to city centre	-0.164	0.002	0.000	0.849
Population density in residential zone	0.023	0.002	0.000	1.024
Work place density in residential zone	0.006	0.001	0.000	1.006
Driving license (1 or 0)	-2.271	0.011	0.000	0.103
Constant	2.114	0.023	0.000	8.279
TS14 - all days, whole year. N = 3,323.	B	S.E.	Sig.	Exp(B)
Distance from home to nearest light rail stop	-0.733	0.170	0.000	0.480
Distance from residential zone to city centre	-0.070	0.016	0.000	0.932
Population density in residential zone	0.078	0.022	0.000	1.082
Work place density in residential zone	0.036	0.013	0.005	1.037
Private car parking at home (1 or 0)	-1.295	0.119	0.000	0.274
Driving license (1 or 0)	-2.056	0.105	0.000	0.128
Constant	2.238	0.221	0.000	9.376

TS13 Nagelkerke $R^2 = 0.244$ / TS14 Nagelkerke $R^2 = 0.253$

Both models in Table 4 show that the city structure affects travel behaviour. Use of public transport decreases as distance from the city centre increases. Densely built-up areas, i.e. areas with high concentration of residences or workplaces, have more public transit use. The possibility to drive, measured as access to parking and having driver's license, lowers the use of transit significantly.

¹³ Standard distance: $\sqrt{(sd_x^2 + sd_y^2)}$, where sd_x and sd_y are the standard deviations for the coordinates of the residential and commercial buildings in the residential zone.

¹⁴ Since limited availability of parking is typical for densely built-up central areas in the cities, this variable is also an indicator of city structure.

The most important finding in this context is that both models show that the light rail has a separate impact on travel behaviour. Close to the light rail, use of transit is definitely higher, even when controlling for other factors. An important aspect is that the two independent travel surveys with different designs, give the same result. This is an indication of a relatively robust conclusion.

In Table 5 we have implemented availability of car (including having driver's license) and an indicator of regular trips (trips made almost every day). Regular trips include work trips, traveling to school and accompany trips to kindergarten or school. The availability of a car provides considerable flexibility in mode choices, making it less attractive to use public transport. Regular trips can be an expression of constraints that may reduce the options.

Table 5. Logistic regression for use of public transport as part of motorized trips among residents living less than 11 km from the city centre within Bergen urban area for trips starting or ending at home (TS14, all days, whole year).

Independent variables	B	S.E.	Sig.	Exp(B)
Distance from home to nearest light rail stop	-0.827	0.191	0.000	0.437
Distance from residential zone to city centre	-0.043	0.018	0.016	0.958
Population density in residential zone	0.074	0.024	0.003	1.076
Work place density in residential zone	0.016	0.015	0.270	1.017
Private car parking at home (1 or 0)	-0.860	0.133	0.000	0.423
Access to car, have driving license (1 or 0)	-2.278	0.094	0.000	0.103
Regular trips (1 or 0)	1.318	0.094	0.000	3.735
Constant	0.931	0.224	0.000	2.536

Nagelkerke $R^2 = 0.410$

Access to car (including having driver's license) reduces the use of public transport (Table 5). Regular trips have the opposite effect - it increases transit use. By incorporating these two variables, the effect of dense urban structures decreases. Work place density was no longer a significant factor. However, the impact of the light rail is still significant and is even a bit improved.

Although Table 4 and Table 5 are not temporal analyses, we can conclude that the results underline that proximity to the light rail has a significant impact on the choice to use public transport. This contributes to the conclusion that the introduction of the light rail stands out as the main driving force for the observed growth in public transport among the residents in Bergen.

4.3 *Transit use is highest where light rail is available*

If our conclusion above is correct, one would expect public transit use to be highest on trips to/from sites within the light rail catchment areas. To answer this question, we focus on single trips to and from different sites in Bergen (while so far, we have focused on people's travel behaviour during a whole day depending on residential location, we now consider single journeys as the units).

Generally, it can be said that the city centre is the most accessible point to reach by public transport. For all sites, we would, therefore, expect more use of public transport when dealing with interaction with the city centre. Similarly, we would expect decreasing use of public transport as distances between the site and the city centre increases.

We tested these two hypotheses¹⁵ with a logistic regression analysis of individual mode choices. In addition, we test whether location within the LRC has any effect. The results of the analysis are given in Table 6.

Table 6. Logistic regression of choice of public transport in favour of travel by car on trips to and from sites in Bergen (Monday–Friday, 2013).

Independent variables	B	S.E.	Sig.	Exp(B)
Site within LRC (1 or 0)	0.502	0.005	0.000	1.651
Distance from site to city centre	-0.144	0.001	0.000	0.866
To/from city centre (1 or 0)	1.567	0.006	0.000	4.793
Constant	-0.920	0.006	0.000	0.399

Nagelkerke $R^2 = 0.181$

As we can see from the table, the further the site is from the city centre, the lower the propensity to use public transport. On the other hand, as expected, the propensity to use public transport is significantly higher if the trip involves the city centre at some point. Most important in our context is that if the journey starts or ends within a LRC, the propensity to use public transport is significantly higher – also illustrated in Figure 9 (based on the parameters in Table 6). Overall, this confirms that the share of public transport is significantly higher within the light rail catchment areas.

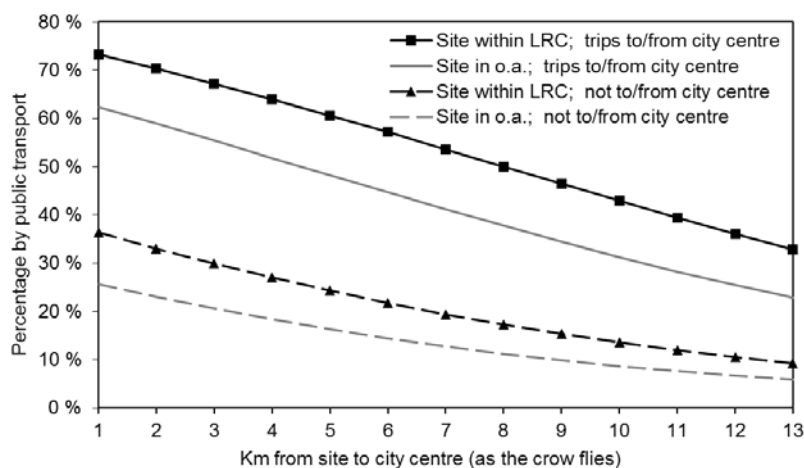


Figure 9. Percentage of motorized trips by public transport on trips to and from sites in Bergen (Monday–Friday, 2013).

¹⁵ City centre defined approximately as the shaded area in Figure 1 (dichotomous variable). Distance to city centre measured as the crow flies (continuous variable).

Proximity to the station is important for light rail being used. Figure 10 shows, for trips starting and ending within LRC, that the tram market decreases rapidly with increasing distance from light rail stops (as measured by distance from travellers' homes). The two graphs provide roughly the same distribution, although the TS13 graph relates to the basic statistical units (for the residences), while TS14 relates to accurate address points. The graphs show that the probability of travelling by light rail is quite small when distance to the stop exceeds 600 metres (as the crow flies). This corresponds with the travel and attitude survey in spring 2010 (TS10), where it was concluded that residents who were expected to increase their use of public transport lived primarily within the 600-metre radius (Christiansen et al. op. cit.).

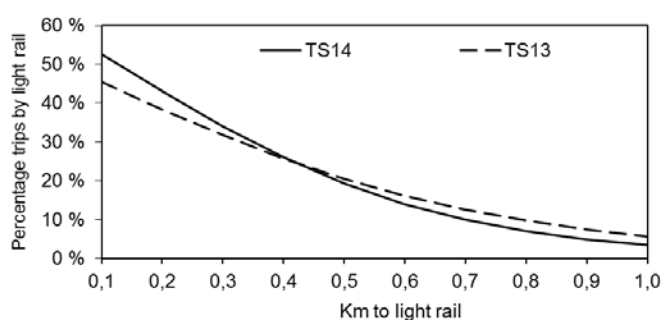


Figure 10. Percentage of motorized trips by light rail by km to nearest stop from the traveller's home for trips within LRC starting or ending at the traveller's home – estimated by logistic regression (Monday–Friday).

Since the transit use is highest where light rail is available, the next interesting question is how well the light rail matches the market. An examination based on register data shows a fairly good match. After the last section opened in April 2017, more than a third of Bergen's population and 40 percent of its residences are situated within the LRC (Figure 11). As for the jobs, more than 60 percent are located within the LRC.

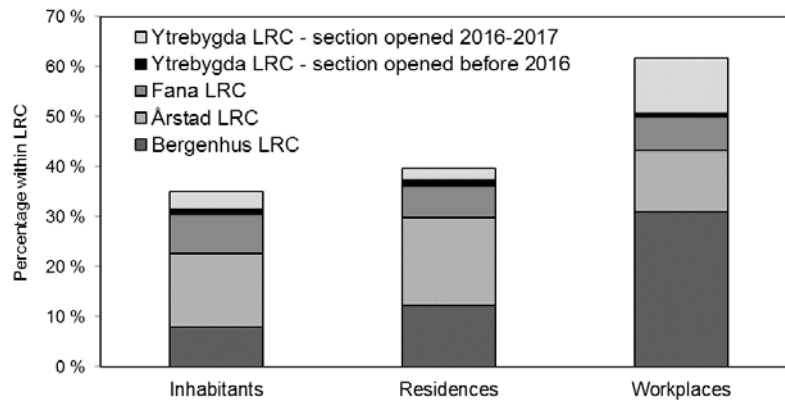


Figure 11. Percentage of Bergen’s inhabitants, residences and workplaces within the LRC (2016).

The commuting register shows that more than a third of the people who work within LRC also live within LRC. In addition, the light rail is attractive for work trips. In 2013 more than 40 percent of motorized work trips starting and ending within LRC were by public transport (according to TS13). About two-thirds of these public transport trips were by light rail. The public transport share was almost twice (180 percent) the market share as compared with work trips elsewhere within the Bergen municipality.

In summary, the registers show that the light rail line has a relatively optimal location in relation to the market, both in terms of settlement, jobs, and commuting. This has both supported and amplified the effects of light rail investments.

5 Conclusions

There are relatively few studies mapping out light rail’s impact on travel behaviour. Our study should, thus, make an important contribution to the literature. An overall impression from earlier studies is that the introduction of light rail in the transport system generates growth in public transport within the light rail’s catchment areas. In addition, previous studies have found that the use of public transport is higher in corridors served by light rail as compared with similar corridors served by bus. Our findings provide clear support to these conclusions.

The study consists of comparative temporal analyses and cross-sectional analyses based on data from five travel surveys, along with data on building stock, population, business activity, commuting and traffic counts. A key point has been to make comparisons between the urban districts as well as between areas within and outside the LRC. The analyses are based on data related to basic statistical units or address coordinates.

We have shown that public transport has increased both in volume and in market share since the opening of the light rail system in 2010 in Bergen. The study shows that the increase is mainly due to the introduction of the new transit

system. The daily travel behaviour of residents, who live along the line, has changed significantly. The findings correspond well with the expectations put forth preceding the opening of this line. We also observe that transit use is highest in the areas where light rail is available. In addition, the effects of light rail investments are reinforced through a relatively optimal location of the line relative to the market.

Our conclusion is that the effect of light rail in terms of growth in public transit use exceeds the effect of a modernized bus network and increased road tolls. This conclusion is the paper's most important contribution to existing literature. Another important contribution is that the significance of light rail services appears as an independent factor, which affects mode of transport, regardless of urban structure and the possibility of car use.

To distinguish the importance of light rail services from other factors that may influence travel behaviour, we have used different logistic regression models in spatial cross-sectional analyses.

In medium-sized cities, there is often a discussion of whether to develop a busway system (bus rapid transit) or a more expensive light rail system. While Bergen has chosen light rail, a busway system is under construction in the Stavanger region southwest in Norway. Our study can provide a knowledge-base to assess the possible effects of such strategies. The findings show that light rail initiative can provide significant effects when the physical plotting of the line matches the market needs. However, a similar study should be conducted to investigate the effects of busway systems as a basis for comparison.

This study does not document the light rail's impact on settlement, land-use, housing prices, wider economic benefits, and other relevant aspects. Some of our findings indicate possible inclination towards a more transit-oriented urban development along the line. This question needs to be further studied in greater detail to lay the grounds for planning the next phase of the Bergen Light Rail and for planning in other medium-sized cities. There is also a need for a new travel survey to document and investigate the effects of the two latest sections of the Bergen Light Rail, which has been operational since August 2016 and April 2017.

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