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The geography of public transport competitiveness in thirteen medium sized cities

Abstract

Securing sufficient accessibility with public transport is essential in order to reduce private car commuting. While most studies of transport accessibility are based on travel times, other quality factors such as the perceived disadvantage of congestion and service frequency are also of importance for transport mode choice. In this study, we use generalized journey times to calculate accessibility and public transport competitiveness, allowing us to account for other characteristics of commute trips than just travel time. We use detailed trip data to calculate generalized journey times to typical employment areas in thirteen urban regions in Norway. The results show that public transport services compete better with the car in the largest cities. Specifically, public transport is competitive for access to central employment areas but less so for less central employment areas. In the smaller cities, the private car is the most competitive mode on most commute trips. With detailed travel data, the method developed in this study can be replicated in other contexts to provide a more holistic measure of accessibility than traditional methods.

1 Introduction

In order to achieve a transition to more sustainable travel behaviours in metropolitan areas, the alternatives to the private car – not least on commute journeys – need to be the preferred option for as many as possible. Understanding the relative attractiveness of public transport (PT) versus the private car, and how this varies within urban agglomerations is therefore of vital importance for creating targeted policy for sustainability transitions in urban mobility. Car-restrictive measures are often widely protested, as recently seen in the yellow vest movement in France. A probable explanation is that the private car is a far more preferable and competitive travel mode than PT for many commuters. Compared to the car, PT is characterized by fixed schedules and routes, and often poorer efficiency, longer travel times and lower satisfaction among travellers (Liao et al., 2020; Lunke, 2020). The attractiveness of PT relative to the private car is well documented in the literature. Factors such as travel time, service frequency and price have all been found to affect transport mode choice (Balcombe et al., 2004; Engebretsen et al., 2018; Fearnley et al., 2018, 2017; Flügel et al., 2018; Lunke et al., 2021b; Mokhtarian and Chen, 2004). However, most existing studies of accessibility focus only on one or a few factors, such as travel time. For example, the most common measure of accessibility is the cumulative opportunities method, which is usually based on door-to-door travel times (Handy and Niemeier, 1997; Kwan, 1998; Levinson and Wu, 2020). While travel time has a clear impact on mode shift, other factors, such as the perception of trip characteristics (i.e. congestion, service frequency and accessibility to PT stops), should not be let out of the focus (Fearnley et al., 2017; Levinson and Wu, 2020).

One way to fill this knowledge gap is by integrating more factors into the accessibility calculations. In this study we propose a new method for measuring accessibility and the competitiveness of PT compared to the private car, which integrates dimensions from both transport geography and transport economy. We measure the *generalized journey time* (GJT) for both PT and car, by weighing travel times based on factors such as congestion, transfers and walking distance to PT stations. The weights are gathered from a national value of travel time (VOT) study (Flügel et al., 2020). Subsequently, we calculate the ratio between car and PT GJTs as an indicator of PT competitiveness. Using this method in thirteen urban regions in Norway, we seek to answer two research questions.

First, how PT competitiveness on work trips varies between and within each urban region. We answer this by measuring PT competitiveness to the central business district (CBD) in each region. Using our method, we can measure the general PT accessibility in each region, as well as the geographical variations within each region, in a comparable way.

Second, how PT competitiveness varies between the CBD and other workplace destinations in the four largest urban regions. Intuitively, one will assume that the accessibility is higher to the CBD than to less central areas. Our approach allows us to measure how large this difference is, as well as to measure how these differences vary among different urban regions. With GJT we seek to improve the traditional way of measuring accessibility, by taking other factors than just travel time into consideration.

The urban regions studied were chosen as they are subject to the Norwegian *zero growth goal*, which states that all growth in personal transport should be absorbed by public transport, cycling and walking (Ministry of Environment, 2012). For many, walking or cycling is not a realistic alternative to the private car, either because of long travel distances, weather/climate, or physical limitations among the travellers. Public transport (PT) is therefore, for many, the only realistic alternative to the car. At the same time, Norway experiences the strongest urban population growth in Europe (Eurostat, 2016). In this context the development of an attractive and competitive PT service is seen as an important element in providing *sustainable* mobility (European Commission, 2004) and reaching the zero growth goal. The current study gives insight into inter- and intra-urban variations in PT competitiveness in Norway. This information is useful when evaluating the realism and social implications of reaching the zero growth goal.

This paper is structured as following: In the next section, we provide a literature review on accessibility and transport mode choice on commute journeys. In section 3, we describe the generalized journey time approach and the data sources used. Results are presented in section 4, and we end with a concluding discussion in section 5.

2 Background: Accessibility and commute mode choice

Accessibility has been defined in several ways in the literature, such as “the potential of opportunities for interaction” (Hansen, 1959), and “the ease with which any land-use activity can be reached from a location using a particular transport system” (Dalvi and Martin, 1976). The concept is complex and can be analysed on different levels, such as perceived (subjective) accessibility among individuals (Lättman et al., 2016), and objective accessibility based on travel times and other quality factors on a neighbourhood or city wide level (Levinson et al., 2017; Levinson and Wu, 2020). Increasing the accessibility to employment opportunities is seen as an important strategy in reducing inequality (Cui et al., 2019). This is often based on the assumption that there exists a spatial mismatch between certain population groups and relevant work opportunities (Kain, 1968). Increased use of restrictive measures towards car use, such as toll roads and congestion pricing, can create such a mismatch. In

Norway, the implementation of car restrictions have resulted in protest and increased political attention in recent years, including strong election results for the anti-toll political party in the 2019 local elections (Wanvik and Haarstad, 2021).

Public transport (PT) is central in improving urban accessibility and access to employment opportunities. As opposed to the private car, PT is less space consuming, more cost efficient, more environmentally friendly and more socially equitable (Banister, 2011). Worldwide, policymakers recognise the importance of a mode shift from car to PT, although the means to achieve this shift is not straightforward. The most important factors are considered to be travel time, cost and the built environment (Cervero, 2002; Ewing and Cervero, 2010; Wardman et al., 2018). In a review of PT improvement strategies, Redman et al. (2013) found that travel speed was considered a critical factor in most studies. This is in line with the findings in Fearnley et al. (2017) and Wardman et al. (2018) that travel time has a stronger impact on mode shift than various cost elements (fuel, parking, fares, tolls). Decreasing the travel time with PT (relatively to the car) has been found to significantly increase PT ridership (Lunke et al., 2021b; Mokhtarian and Chen, 2004). In a comparison of different travel characteristics in the Seattle region, travel time was identified as the strongest predictor of mode choice, and reduced travel time with car was especially important in reducing PT ridership (Frank et al., 2007). In a survey among car drivers in Amsterdam, van Exel and Rietveld (2010) found that the participants were willing to switch to PT if the travel time ratio was below 1.6. These findings suggest that there is a clear potential for increased PT use by reducing the travel time disparity, either by increasing the speed of PT services or by increasing car journey times. In most cities and urban settings, however, the travel time ratio between PT and private car is usually well in favour of private car (Liao et al., 2020).

However, efficiency and travel time disparities is not the sole explanation behind low PT shares. Several other quality factors also have an impact on PT use: The number of transfers, service frequency, waiting time and walking distance to and between stops (Lunke et al., 2021a, 2021b), as well as on board comfort, crowding and seat availability (Redman et al., 2013) and travel satisfaction (van Lierop and El-Geneidy, 2016). For both car and PT, travel time unreliability because of congestion or other delays are also important in explaining mode choice (Redman et al., 2013; Sweet and Chen, 2011). Levinson and Wu (2020) argue that focusing on just travel time is rarely sufficient when analysing transport accessibility and modal competitiveness, as “time is perceived and experienced differently for different modes, and for different stages of a trip” (p. 134). In order to overcome this problem, accessibility calculations should account for the fact that different parts of a trip, such as waiting time, walking time and on board time, are experienced differently. In the current study, this is taken care of by calculating the GJT of hypothetical trips. This approach is not much used in the literature. A noteworthy exception is a study from London, which concludes that a more comprehensive approach, using GJT, provides a more precise measure of accessibility which better reflects the effectiveness and quality of the transport system (Liu et al., 2020).

Numerous studies of car and transport accessibility have been published in recent years, providing significant contributions to the transportation literature. First of all, several studies have mapped the general access with one or several transport modes, usually finding that car access is better than PT access (Jang and Lee, 2020; Pereira, 2019; Smith et al., 2020). Second, travel time disparities (or differences in access between car and PT) have been used to map “accessibility gaps”, i.e. the relative competitiveness between two modes (Golub and Martens, 2014; Salonen and Toivonen, 2013). However, there are at least four knowledge gaps that this study seeks to fill. First, most studies of accessibility and PT competitiveness focus on one or a few urban regions. Our study compares the accessibility levels and PT competitiveness in thirteen urban regions, providing relevant knowledge on the inter-urban variations in accessibility in the same national context. Second, we compare accessibility and PT competitiveness to central and less central areas in the largest urban regions. This gives insight into the effect of workplace location on the ability to commute with PT rather than car. Third, we base our accessibility calculations on GJT rather than just door-to-door travel time. This approach combines economic and geographical perspectives and gives a more comprehensive and realistic measure of accessibility and PT competitiveness, compared to most other studies on this topic. Fourth, our geographic approach highlights ways in which land use impacts the competitiveness of PT.

3 Methods and data

This section presents our reasoning for choosing the generalized journey time (GJT) approach, how we calculated GJT in this paper and how we created the dataset used for our analysis.

3.1 Generalized time or generalized cost?

In principle there are two approaches to compare disutility between transport modes (Lunke et al., 2021b): The generalised journey cost method (GC) and the generalised journey time (GJT) method. A trip's GC is the sum of out-of-pocket costs and the monetary value of the varying travel time elements (and possibly other sources of inconvenience). GJT summarises the different travel time elements (and, again, possibly also the value of other inconveniences as measured in journey time equivalents) in minute values. While GC and GJT may appear similar, they will in fact produce substantially different outcomes. The unit of measurement in GJT is time (minutes) – an objective measurement which does not differ between modes, trip purpose or passenger type. GC, on the other hand relies on valuation of various travel time elements (and other inconveniences) and do in fact vary distinctly between modes, trip purposes and travellers. Our study relies on GJT, for a number of reasons. From a theoretical point of view, there may be little difference between calculating disutility in minutes or Euros. However, this can result in substantial differences when comparing travel with different modes, that have different mode specific values of time (Flügel et al., 2020; Samstad et al., 2010) and different direct costs. Another reason for omitting direct costs from these analyses, is the fact that there is much uncertainty related to the actual expense faced by commuters. It is known that not all commuters pay for car or PT themselves. Some have these expenses paid by their employer. Further, it is not straight forward to set the bar between indirect cost such as car wear-and-tear, value depreciation or insurance, and the more behaviour-relevant direct cost such as fuel, parking and tolls. There is substantial heterogeneity in the cost structure of the vehicles, in particular between battery electric cars and fossil fuelled cars. The former currently makes up more than half of all new car sales in Norway (Statistics Norway, 2021). Also, PT ticket prices must be considered with caution. It is not obvious, e.g., whether the behavioural-relevant cost of a PT trip is the single ticket price or, for season ticket holders, whether to apply an average price per trip or a zero marginal price per trip. If all these cost are not handled correctly, they will add to the error in the model. Moreover, both Paulley et al. (2006) and Fearnley et al. (2015) mention that there is an established practice of using time as a unit when studying the demand effects of quality factors in PT. As a final note, time is easier transferable between contexts, e.g. between countries and over time, than are money. An alternative method would be to apply utility-based measures of accessibility which take other factors – such as trip characteristic, trip chaining and individual attributes – into account (Dong et al., 2006; Macfarlane et al., 2021). The reason for using the GJT approach in this study is to measure commuters' *perception* and *experience* of work trips, which we believe are more behaviour relevant, rather than the actual performance of different transport modes.

3.2 Calculating generalized journey times

To calculate GJT for car and PT journeys (GJT_{car} and GJT_{PT}), we draw on findings from two national VOT studies in Norway. The first study was conducted between 2008 and 2009 (Samstad et al., 2010), and the second between 2018 and 2020 (Flügel et al., 2020). Both studies have developed specific weights for work trips. To calculate GJT, we split each trip into separate elements, and weight the elements according to the recommendations from the aforementioned VOT studies.

GJT_{PT} is calculated as follows:

$$GJT_{PT} = \beta_1 + \beta_2 w_2 + \beta_3 w_3 + \beta_4 + T + S \qquad (1)$$

Where β_1 is the unweighted time spent on board a PT mode. $\beta_2 w_2$ is the weighted time spent walking to and from PT (i.e. access and egress walk time). $\beta_3 w_3$ is the weighted time spent at the destination because of early arrival[1], before the set arrival time at 8:30 am. β_4 is the unweighted time spent transferring between transport modes, while T is a fixed minute penalty of 17 minutes added for each specific transfer, in line with the VOT study. S is a fixed minute penalty added for crowding on board. Just like the transfer penalty, the VOT study (Flügel et al., 2020) recommends fixed time penalties for crowding, rather than weighing the travel time. In order to find time penalties for our study, we have gathered observed levels of crowding on PT trips in the study region from the VOT study, where respondents answered whether their last PT trip included free seating on the whole trip, on parts of the trip or not at all[2]. The fixed time penalties used in this paper are then estimated by combining 1) the recommended penalties from travelling with different levels of crowdedness, and 2) the observed levels of crowdedness on PT trips in the study region. Crowdedness is typically higher on shorter trips, which is why the time penalty for trips under 20 km is higher than for longer trips.

GJT_{car} is calculated as follows:

$$GJT_{car} = \beta_1 + \beta_2 w_2 + \beta_3 w_3 + \beta_4 w_4 \qquad (2)$$

Where β_1 is travel time with free traffic flow (no congestion). $\beta_2 w_2$ and $\beta_3 w_3$ are weighted travel times with moderate and heavy congestion, respectively. The share of time spent in different degrees of congestion is gathered from the VOT study (Flügel et al., 2020), where respondents described how much time they spent in moderate and heavy congestion during their last car trip. Based on this information, we define the share of time spent in different degrees of congestion, and apply weights to parts of the travel time, accordingly[3]. According to the VOT study, short trips in Oslo experience more congestion than long trips, while even less congestion is experienced on trips in other regions. So, for a hypothetical trip longer than

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[1] We use early arrival as a proxy for the difference between preferred and necessary time of departure, due to timetable scheduling (for PT) or congestion (for cars).

[2] We define separate penalties for 1) trips over 20 km in Oslo, 2) trips under 20 km in Oslo, and 3) trips in other regions. This broad categorization is made in order to get representative figures on observed congestion levels.

[3] Separate shares are defined for 1) trips under 10 km in Oslo, 2) trips over 10 km in Oslo, and 3) trips in other regions. See table S2 for specific shares. This broad categorization is made because of data availability.

10 km in Oslo in which travel time is calculated to 100 minutes, GJT_{car} in terms of congestion would equal *59*1 + 34*1.5 + 7*2.9 = 130.3.* $\beta_4 w_4$ is the weighted time spent waiting at the destination because of arrival before the set arrival time. Because of data limitations, time spent looking for parking is not included in GJT_{car}. A full description of all weights and minute penalties are included in Supplementary material Table S1.

The competitiveness of PT relative to the car is the main focus of this study. This is measured by calculating the ratio between GJT_{PT} and GJT_{car} : $GJT_{ratio} = \frac{GJT_{PT}}{GJT_{car}}$. GJT_{ratio} is 1 when GJT is equal for PT and car. The ratio increases when GJT_{PT} is relatively higher than GJT_{car}. In other words, low ratio levels indicate that PT competitiveness is high (compared to the car).

3.3 Data and study area

This study utilizes a comprehensive dataset of travel time calculations in thirteen urban regions in Norway (Figure S1). The dataset includes information on travel times and other trip characteristics for car and PT, extracted from Google Maps' API. We use this information to calculate GJT for both car and PT. For car trips, the API provides three travel time alternatives based on historical traffic congestion levels: Best guess, pessimistic and optimistic[4]. These alternatives are used to measure expected variations in travel time. For PT, the API provides detailed information on all trip legs: Trip distance, travel time, PT mode, waiting time while transferring, as well as distance and time spent walking to, from, and between stops. This information was gathered for a large number of trip segments: The building-weighted centroid of each basic statistical unit (BSU) in the thirteen regions were used as start points, while we selected a point in the CBD of each city as the end point. In total 4 394 BSUs were the subject of analysis, with an average population of 762. In other words, we measure accessibility by the distance to the city centre. Theoretically, this approach is based on Alonso's (1964) model of spatial attractiveness. Moreover, studies have shown that distance to the city centre is a relevant measure of accessibility (Baraklianos et al., 2020) and that this factor influences both overall driving distances and commute distances (Engebretsen et al., 2018).

In addition to the CBDs, we selected one additional end point in typical employment areas outside of the city centre in three of the four largest urban regions, and two additional end points in the largest region, Oslo. The CBDs are characterised by a large number and high density of workplaces. The additional end points are located in commercial and industrial business areas (Oslo and Stavanger), by a large hospital (Bergen) and a large university campus (Trondheim).

All trips were calculated with arrival 08:30 AM on a Wednesday in February or March 2019, a typical arrival time for work trips according to the Norwegian national travel survey (Hjorthol et al., 2014). The API extractions were conducted in January 2019. To avoid trips where walking and bicycling was a relevant alternative to PT and car, we omitted all trips shorter than 2 km (by car). This has been found to be a significant threshold in shifting from

[4] These are explained as follows. **Best guess:** Best estimate of travel time given what is known about both historical traffic conditions and live traffic. Live traffic becomes more important the closer the departure_time is to now. **Pessimistic:** Longer than the actual travel time on most days, though occasional days with particularly bad traffic conditions may exceed this value. **Optimistic:** Shorter than the actual travel time on most days, though occasional days with particularly good traffic conditions may be faster than this value. Source: https://developers.google.com/maps/documentation/distance-matrix/overview#traffic_model (accessed 21. September 2021)

active transport modes to car and PT: In the Norwegian National Travel Survey, less than half of the trips under 2 km are conducted by car and PT. From 2 km and upwards, the mode split changes drastically, and car and PT are used on more than two thirds of all trips (Hjorthol et al., 2014). To avoid outliers, we also removed all trip segments where car driving takes more than eight hours (approximately 8 % of the sample).

Among the thirteen regions, Oslo is the largest with a population of almost 1.3 million, followed by Bergen (0.43 m), Trondheim (0.28 m) and Stavanger (0.27 m). The smaller regions are Arendal, Ålesund and Bodø, with less than 80 000 inhabitants each (Table S3). In the largest regions in our study, policy packages have been introduced as a means to reach the goal of zero growth in car use. Changes in land use is a central instrument in these packages, where the strategy is to densify in central areas and around PT hubs (Tønnesen, 2015).

4 Results

In this section, we present the study results with maps and diagrams. In the maps, all BSUs are treated equally, independent of their population size. In the diagrams, however, the BSUs are weighted by population. This allows us to investigate the distribution of GJT_{ratio} among the inhabitants in the urban regions. According to previous research (van Exel and Rietveld, 2010; Liao et al., 2020), the travel time ratio should be well below 2 in order for the PT service to be competitive with the car and to achieve high levels of PT use. Although the travel time is not directly comparable to GJT, we can assume that a GJT_{ratio} below 2 is necessary to make PT a realistic alternative to the car.

The analysis is split in two parts. First we explore the differences in PT competitiveness between all thirteen urban regions, comparing the accessibility to the CBD in each region. Second, we look more detailed at the four largest urban regions, comparing the accessibility to the CBD and the less central end points.

4.1 Inter-urban comparisons

Figure 1 shows the spatial variations in PT competitiveness in the urban regions. Each point represents a starting point (BSU). There are striking differences between the different regions, where some of the smaller ones – such as Fredrikstad, Sandefjord, Arendal and Ålesund – show large areas with high GJT_{ratio} values, i.e. PT services are a poor alternative to the car.

In the four largest cities, the darker colours indicate that PT competitiveness is clearly higher here than elsewhere. Secondly, in the largest cities (Oslo, Bergen, Stavanger and Trondheim) the GJT_{ratio} tends to be higher in the suburban and peri-urban areas, indicating poorer PT competitiveness further away from the destination. In the smaller cities, PT competitiveness is generally lower both close and far from the destinations.

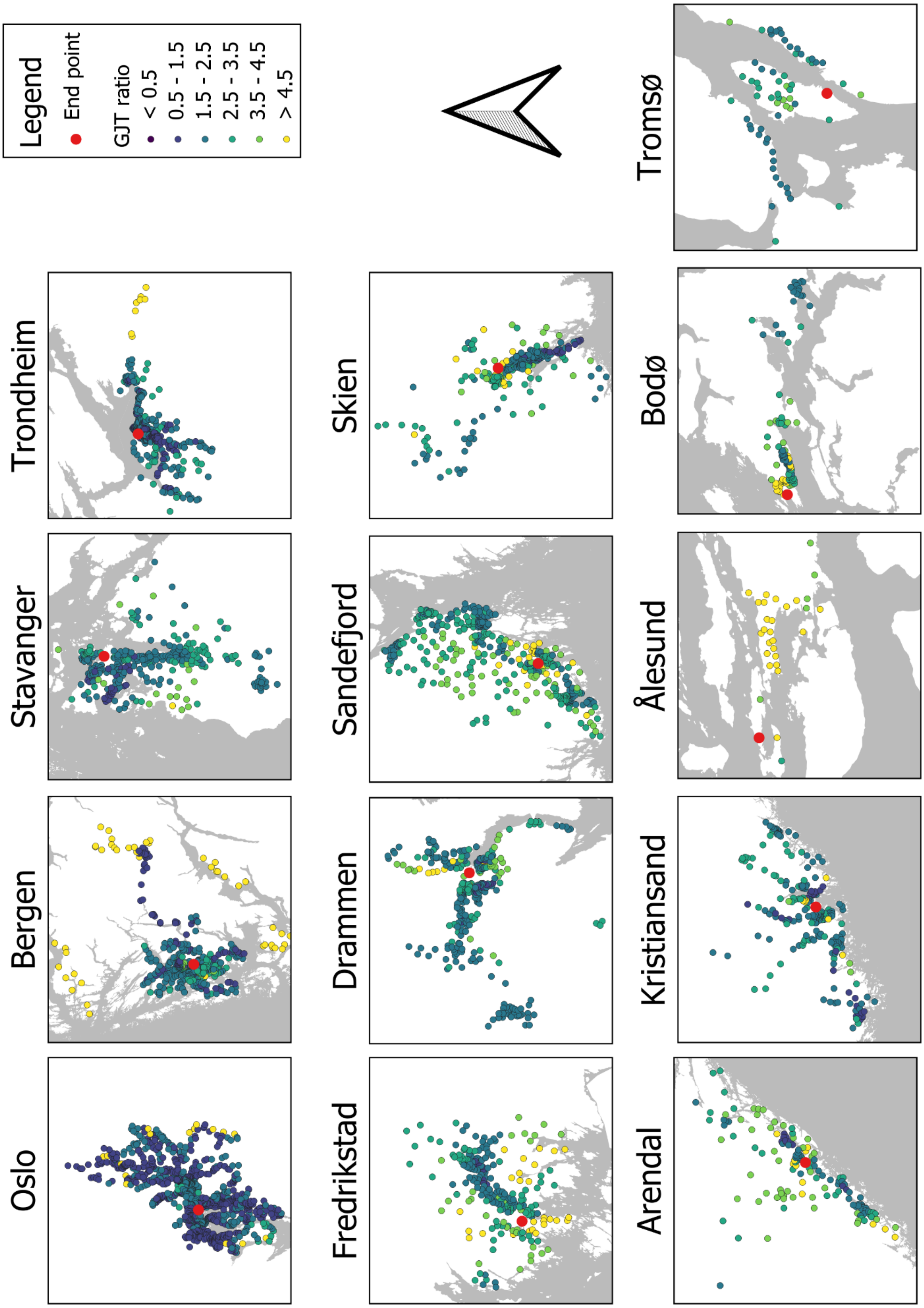

Figure 1: Spatial variation of GJT_{ratio} to CBD endpoints in the thirteen urban regions. Scales vary between maps.

A closer look at the accessibility to the CBDs shows that proximity to train stations is an important quality factor. Close to train stations and along the local train lines, GJT_{ratio} is normally below 1.5, while it increases rapidly when the distance to a station exceeds 1-2 kilometres. In Figure 2 (and Figure S2), GJT_{ratio} is calculated for the whole population in each urban region.

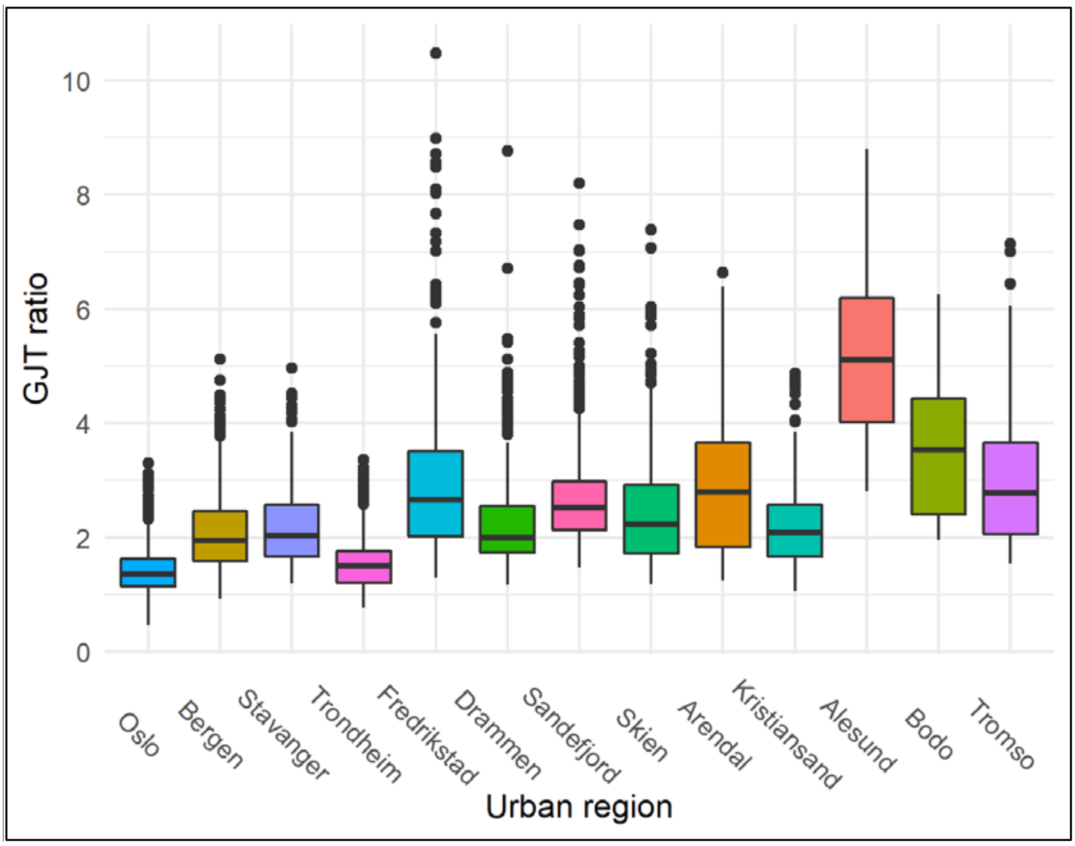

Figure 2: Boxplot of GJT_{ratio} to central end points in the thirteen urban regions. Weighted by population.

The highest average PT competitiveness (lowest GJT_{ratio}) is found in Oslo and Trondheim, while Ålesund is clearly at the other end of the scale. PT competes well, i.e. there is a low GJT_{ratio} in the four largest urban regions (Oslo, Bergen, Stavanger and Trondheim). In most of the smaller regions, the average GJT_{ratio} is visibly higher, suggesting that car is likely the preferred transport alternative. There is also a tendency that the average GJT_{ratio} varies more internally in some of the smaller cities, such as Fredrikstad, Arendal, Ålesund and Bodø.

The *GJT_{ratio}* for trips to CBDs is relatively low for a larger part of the population in the largest urban regions. In many of the smaller regions, there is more variation in GJT_{ratio}, as well as more outliers. In Oslo and Trondheim about 90 percent of the population has a GJT_{ration} of less than 2. This is the case for less than 60 percent of the population in Bergen and Stavanger. In smaller regions, the share of the population with a GJT_{ration} of less than 2 is even lower.

4.2 Intra-urban comparisons

In this second part of the analysis, we focus on the four largest regions. In these regions, we have calculated the GJT_{ratio} to different end points, with the intent of comparing PT competitiveness for different workplace locations. There is a visible difference between CBDs and the less central workplace locations, as shown in Figure 3. PT is clearly more competitive on trips to the CBDs.

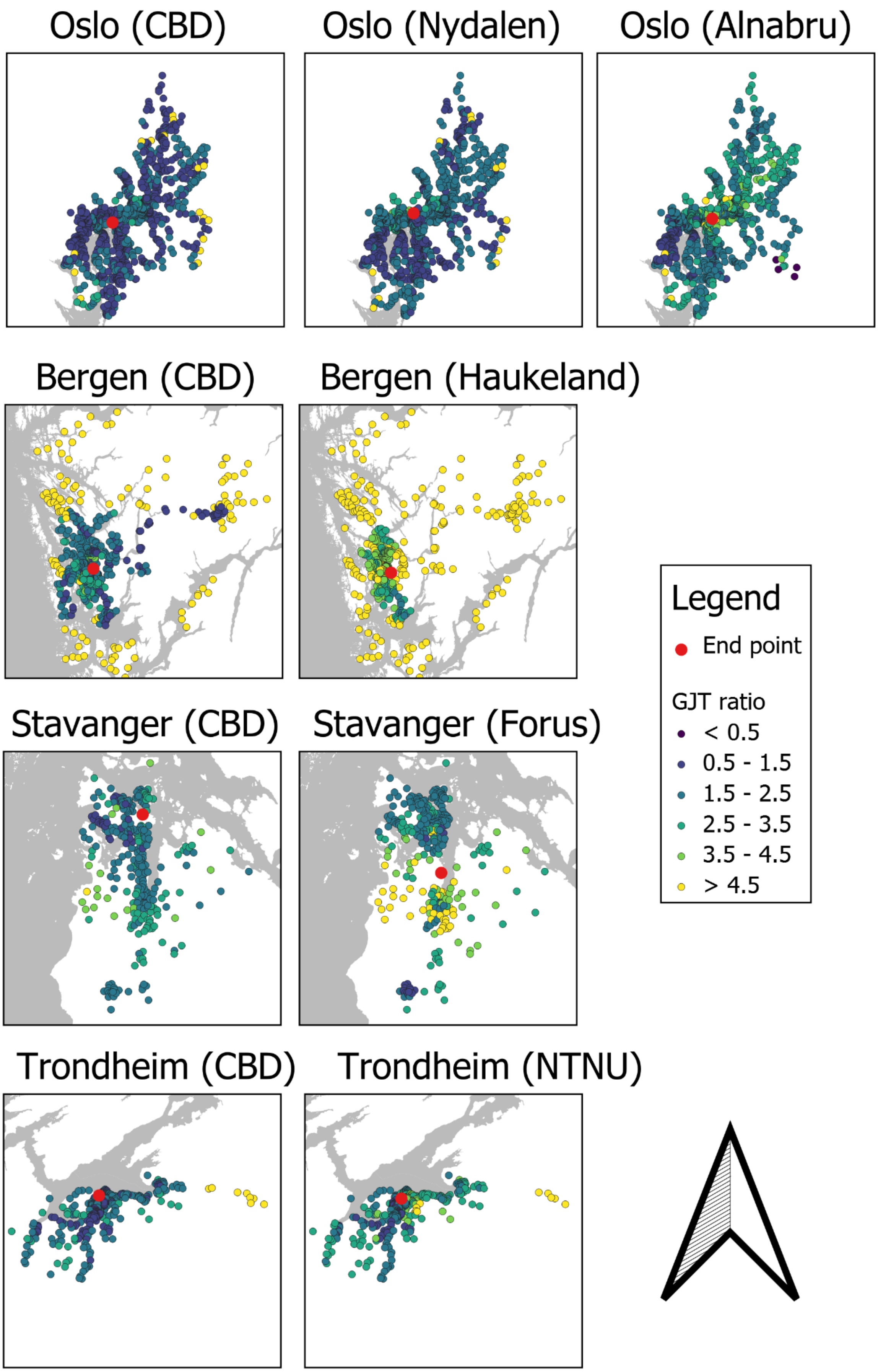
Oslo (CBD)
Oslo (Nydalen)
Oslo (Alnabru)
Bergen (CBD)
Bergen (Haukeland)
Stavanger (CBD)
Stavanger (Forus)
Trondheim (CBD)
Trondheim (NTNU)
Legend
End point
GJT ratio
< 0.5
0.5 - 1.5
1.5 - 2.5
2.5 - 3.5
3.5 - 4.5
> 4.5

Figure 3: Spatial variation of GJT_{ratio} to end points in Oslo, Bergen, Stavanger and Trondheim. Scales vary between cities.

Figure 4 shows how GJT_{ratio} is distributed among the population in each urban region (see also Figure S3).

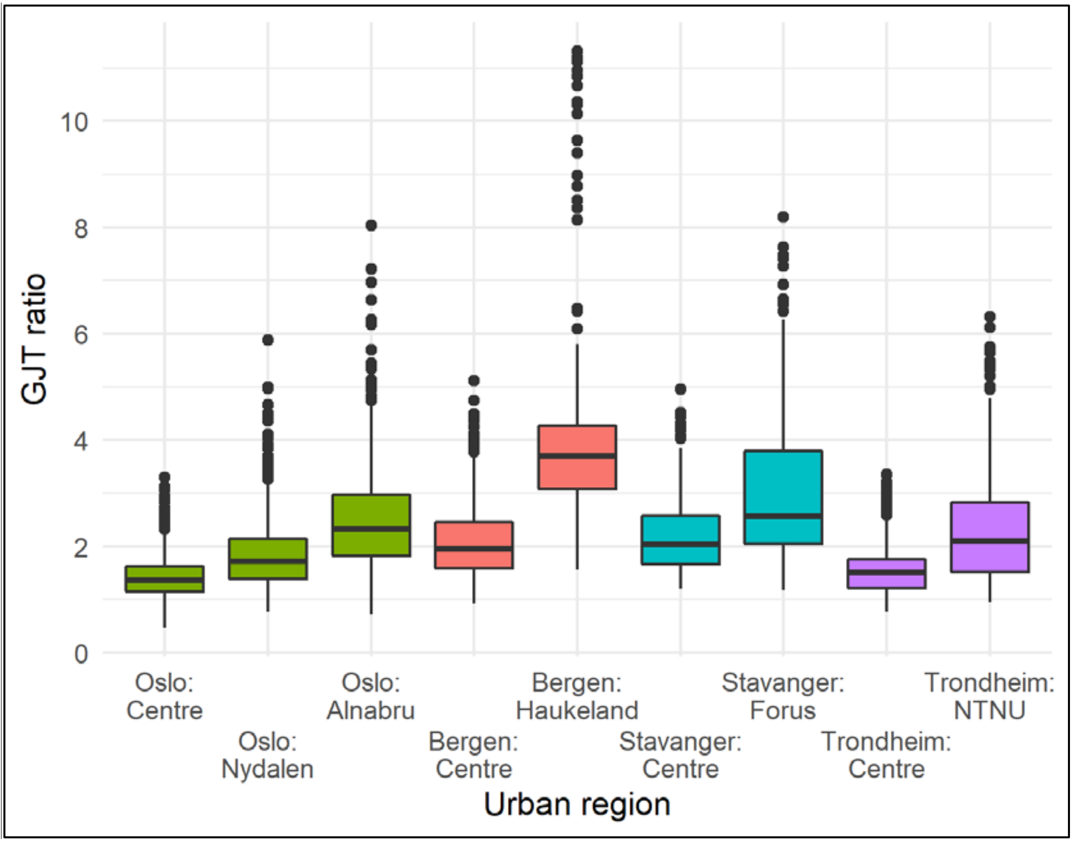

Figure 4: Boxplot of GJT_{ratio} to central and less central end points in Oslo, Bergen, Stavanger and Trondheim.Weighed by population.

In Oslo, the most striking difference is between the CBD and Alnabru. The latter is an industrial area, located 5-6 kilometres north of the CBD. In the CDB, over 90 percent of the population have a GJT_{ratio} under 2, while the share is just over 30 percent for trips to Alnabru. Alnabru contains a large amount of jobs, as well as a hotel and a high school. A subway line and several bus lines run through the area, and there is a train station close by. Still, the area is highly car based and the PT competitiveness is significantly lower than in the CBD. Nydalen however, shows a higher PT competitiveness than Alnabru, although not as high as the CBD. Nydalen, a former industrial area recently transformed to more high-skilled workplaces, is also served by a subway line, a train line and several bus lines, and is located with the same distance to the CBD as Alnabru. Still, 70 percent of the population has a GJT_{ratio} under 2 to Nydalen, which is twice as high as the share in Alnabru.

In the other three cities, we see similar differences between the CBD and the less central end points. In Trondheim, the second end point is located at the technical university (NTNU), just 2 kilometres from the CBD. In Stavanger, the second end point is in Forus, a large business area approximately 10 kilometres from the CBD. Here, many of the oil related businesses in the region are located. Both in Stavanger and Trondheim, we see that the CBD is characterised by a higher PT competitiveness than the less central end points. In Bergen, the difference between the CBD and the second end point (by Haukeland hospital) is higher than in the other three cities. In Bergen, a light rail service runs through the surrounding suburbs to the city centre. Since its introduction in 2010, the light rail has proven to be the main reason for increased PT use in the region (Engebretsen et al., 2017). However, the light rail does not serve the hospital at Haukeland, which is only accessible by bus. This is probably an important explanation for the large difference in GJT_{ratio} between the two end points in Bergen.

These intra-urban comparisons show that the geographical location of workplaces has a major impact on employees' ability to use PT, and that car dependency tends to be more widespread for workplaces located outside of the CBD.

5 Concluding discussion

This study provides a comprehensive comparison of PT competitiveness, relative to the private car, within and between thirteen urban regions in Norway. The study contributes to the literature both empirically and methodologically. Empirically, this is the first study, to our knowledge, which measures variations in PT competitiveness in this magnitude in Norway. Moreover, comparisons between several urban regions – in the same national context – are rare. There are notable exceptions (ITF, 2019; Owen and Murphy, 2019; Pereira et al., 2019; Wu et al., 2021; Wu and Levinson, 2018), but few in a European context and none that uses GJT to measure accessibility. Methodologically, we introduce an approach to accessibility analysis which incorporates other quality factors than just travel time. This has rarely been done in the literature previously (Arbex and Cunha, 2020; Levinson and Wu, 2020; Liu et al., 2020). By using GJT as the main unit for analysis, we account for other travel related factors than sheer travel time, giving a more comprehensive basis for measuring accessibility and modal competitiveness. Our approach builds on results from national value of time (VOT) studies, and thus the concept of accessibility is adjusted to commuters' perceptions of various travel time elements. This is in line with the recommendations of Levinson and Wu (2020) to pay attention to perceived and experienced (or generalized) travel time. While most previous studies calculate accessibility by travel time, we use a more comprehensive approach, by measuring GJT. We show that when we account for the perception of factors such as crowdedness and congestion, transfers and waiting time, the private car is more competitive than PT in all studied regions except for the central areas of the largest cities. The utility-based measure is a relevant alternative to the approach used in this study (Dong et al., 2006; Macfarlane et al., 2021). However, the strength of the GJT approach lies in the stated preference VOT study data. These data describe how commuters value different trip alternatives, providing solid evidence of how different trip dis-utilities are perceived by commuters. In order to measure the perception of commute trips, we would argue that the GJT approach is a valid alternative to the utility-based measure. With the increased availability of travel time and value of time data, this approach can be replicated in other contexts, providing a more complex measure of accessibility and modal competitiveness. This study measures accessibility to typical employment areas in different cities. However, the same approach can be used on more complex accessibility calculations, such as cumulative opportunity and gravity models (Levinson and King, 2020).

Our analysis shows that the levels of GJT_{ratio} varies greatly within and between the different cities. In Oslo and Trondheim, around 90 percent of the population experience a GJT_{ratio}

below 2 for trips to CBD, while the share is less than 60 percent in Bergen and Stavanger. In the smaller cities, a minority of the population experience GJT_{ratio} levels below 2. These findings display the difficulty of achieving political goals of reduced car use. For most urban commuters, a shift from private car to PT will involve an increase in both absolute and perceived (generalized) commute times. Secondly, our findings resonate well with the protest against toll roads in Norwegian cities. In the local election in 2019, the anti-toll party gained higher support in the municipalities of Stavanger and Bergen (9.2 and 16.7 % respectively), where we find relatively low PT competitiveness, than in Oslo (5.8 %) and Trondheim (did not stand for election). Poor PT competitiveness is strongly related to political protest (Christiansen, 2018).

In the second part of the analysis, we compared different employment areas within the four largest city regions. The results showed a substantially better PT competitiveness on commute trips to the CBDs than to less central workplaces. This underlines the importance of workplace location in the discussion of reduced car use on commute trips. While commuters to the CBDs can travel by PT without much difficulty, commuters to less central workplaces are more dependent on the private car. Moreover, there is a distributional dimension to this variation, as high paying jobs tend to be located in the CBDs, while lower paying jobs are more often located less centrally in the urban regions (Gundersen et al., 2017). Restrictions on car use may therefore affect lower payed commuters more, as they tend to work in places that lack alternatives to private car commuting. Our results are well in line with the literature on accessibility gaps and travel time disparities from other cities. We find that in many Norwegian urban regions, similar to research in other countries, employment opportunities tend to be more accessible with the private car than PT (Golub and Martens, 2014; Liao et al., 2020; Salonen and Toivonen, 2013).

At the same time, our method is not without limitations. First, the data from Google, which form the basis for our analysis, has necessarily been weighted to some extent before we apply the weights to calculate GJT. For example, when providing travel time estimates for a given trip, Google's API will select one option, based on specific preferences for walking distances, transfers, and so on. Other trip alternatives, which could include shorter walking distances or fewer transfers, will thus be ignored. This selection could influence the validity of our method, if alternatives that are preferred by commuters are ignored. However, this weakness is present in other similar studies as well (Liao et al., 2020; Liu et al., 2020). We argue, however, that Google, which bases its choice of alternatives on observed travel behaviour (Wang and Xu, 2011), will more likely suggest trips with minimal GJT compared to travel planning software that are based on static, predetermined weights (such as OpenTripPlanner). Nevertheless, this uncertainty in travel time estimates is an appropriate topic for future research, for example by programming routing software to account for specific weighing between alternatives.

A second limitation is the uncertainty in the VOT studies' weights that are used to calculate GJT. For example, there clearly is some heterogeneity in preferences for different elements of a journey. Some commuters may be highly sensitive to crowding on PT journeys and long walking distanced to and between PT stops, while others may find this less problematic. Moreover, for employers with flexible working hours, travel time uncertainty will be a smaller problem than for employers with fixed working hours. However, the fact that we focus on work trips reduces this heterogeneity. Evidently, commuters are a more homogenous group than the overall population. Using alternative weights could affect the outcome of the analyses. However, moderate changes to the weights would not change the general results significantly, but could affect specific geographic areas differently. For example, changing the time penalty of PT transfers would entail larger changes on long trips and on trips to end points outside of the city centers, where transfers are more widespread. Moreover, alternative weights for congestion on car trips would lead to larger changes on short trips in Oslo (where there is more congestion) than elsewhere.

The third limitation to our method comes from the available data on congestion and crowdedness. In the GJT calculations, we have used average values on these variables from the national VOT study (Flügel et al., 2020) and applied the same congestion and crowding weights for both CBD and suburban endpoints. However, the level of congestion and crowdedness can vary greatly from day to day, between different transport corridors, and between different endpoints in the same urban region. These variations are not completely controlled for in our method. Moreover, in real life there is heterogeneity in congestion and crowding within the broad categorizations used in this study, which we have been unable to account for.

Increased restrictions on car use will have the largest impacts in areas with poor PT competitiveness, where people lack alternatives to the private car. Our results provide evidence on which areas suffer from poor PT competitiveness and can guide decision makers in Norway in designing policy that reduces such implications. Moreover, our results support the current land use planning paradigm of densification around PT hubs, as we see that PT is clearly more competitive close to local train stations, especially in the largest urban regions. Another policy implication of this study is in the method used. Policy makers can use accessibility metrics based on GJT, to get a more holistic understanding of transport accessibility and modal competitiveness in urban areas.

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