ISBN 978-82-326-4118-5 (printed ver.)
ISBN 978-82-326-4119-2 (electronic ver.)
ISSN 1503-8181

Norwegian University of
Science and Technology

María Díez-Gutiérrez

Doctoral thesis

Doctoral theses at NTNU, 2019:261

NTNU
Norwegian University of Science and Technology
Thesis for the Degree of
Philosophiae Doctor
Faculty of Engineering
Department of Civil and Environmental
Engineering

NTNU

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Printed by NTNU Grafisk senter

ABSTRACT

Fixed link projects are important infrastructure projects, as they provide a reliable, flexible and permanent connection between two previously separated geographical areas. These projects both remove travellers' waiting time and improve their travel time between the connected areas. Further, these projects change accessibility significantly and remove inconveniences. This in turn may affect travellers, who might react by changing either their residence or travel patterns, including trip frequency, transportation mode, destination, or route. These impacts trigger variations in traffic volumes. Little research has been done related to travellers' reactions against the removal of inconveniences due to fixed links, which could explain why current traffic simulations over- or under-estimate the traffic in these projects. This might then lead to biased transport assessments, and thus ineffective fund allocation. This thesis aims to contribute knowledge regarding these types of infrastructures as a basis for improving traffic simulations.

Firstly, a survey was conducted in order to understand travellers' behaviour when using a ferry connection and explain the potential inconveniences associated with this type of transportation dependency. Results showed that trips which include a ferry connection resulted in longer travel times for commuter trips than the national average. The major inconveniences of the ferry connections were related to overall trip planning, accessibility to family and friends, leisure activities, and a broader labour market.

Secondly, an embedded multiple-case study was undertaken to observe any impact on population relocation. Results showed that connected areas presented greater population growth than expected, especially after toll removal. The effects were greater for fixed link projects close to urban areas.

Thirdly, a holistic single-case study was conducted to identify changes in travel patterns. Results showed indications of changes made in routes and modes of transport due to toll removal in a fixed link. In contrast, no indications of changes in trip frequency or destination were found.

The findings from this thesis demonstrate and quantify significant differences in inconvenience perception among the different categories of socioeconomic and trip features. This might complete further and more accurate studies of including inconveniences in transport models. In addition, improved knowledge based on eleven ex-post analyses might serve as a basis for improving the transport models' population input data. Further ex-post studies should be conducted to validate the findings of travel pattern changes.

ACKNOWLEDGEMENTS

Thanks to the E-39 group in Statens vegvesen (The Norwegian Public Roads Administration), in particular Kjersti Kvalheim Dunham, for providing us with the necessary data and resources for our research. Additional thanks go to the social impact study group, led by Cathrine Helle-Tautra, for arranging gatherings with fruitful discussions.

I would like to express my deepest gratitude to my mentor Trude Tørset for giving me the opportunity to explore this topic. I met her during my time as a graduate exchange student, and she inspired me with her enthusiasm for transport models; quite simply, I have become a researcher thanks to her. She has supported me both professionally and personally throughout my years of study.

I would also like to thank my co-supervisor James Odeck for his invaluable feedback and remarks about this thesis. Additionally, he was of great help in expanding my network whenever I was out presenting my research at conferences.

Working closely with my thesis colleagues Stig Nyland Andersen and Øyvind Lervik Nilsen has been a great pleasure. I want to thank them for the countless interesting discussions we have had, these include funny moments during our video meetings, especially when running around with the camera looking for available rooms or trying to explain difficult concepts through drawings.

Thanks to Eva Larsen at the Directorate of Public Roads, Central Region for providing me with the opportunity to join their team - Ali Taheri, Tore Moan, and May Berit Eidsaune - and gain more practical knowledge about Norwegian transport models. Thanks as well to Eirik Skjetne and Sahar Babri for involving me in very interesting and challenging projects on the side.

To my colleagues at NTNU, especially Petr, Albert, and Miroslav, it was enjoyable to share experiences with you about our PhD studies during this time, on top of all the pleasant skiing and hiking trips we went on. I also wish to thank Liliya for sharing her enthusiasm with me and Patricia for taking long walks with me through the halls.

Finally, and most importantly, my love and gratitude go to my family for their understanding and support during this time. Special thanks go to Juanma, who is always there helping me to disconnect and being actively involved in my research project.

PART 1

Contents

1. Motivation

During my studies I became very interested in transport analysis. My master's thesis allowed me to dig deeper into transport models in which I found several areas worthy of exploring further. This PhD study of transport modelling has given me a challenge that has been enhanced by the E-39 project because of its unique features and international impact.

The purpose of the E-39 project is to upgrade the current Coastal Highway by building a continuous route comprised of improved road features. This 1,100 km highway connects Kristiansand to Trondheim. Important cities located on the western coast of Norway, such as Stavanger, Bergen, Ålesund and Molde, lie along E-39 as well. The current total travel time for driving from Kristiansand to Trondheim is estimated at 21 hours, including waiting times and time spent onboard the seven ferries operating along the route.

The total cost of this project is estimated to be around NOK 340 billion distributed over a period of approximately 20 years. When finished, the travel time will be reduced almost by half down to a total of 11 hours. The National Transport Plan (NTP 2018-2029) has assigned most parts of this project a high priority classification, approving a significant budget for its realisation. Construction of the project's first fixed link, Rogfast, began in December 2017; at its completion in 2025/2026 and at a budget of NOK 16.8 billion, Rogfast will be the world's longest and deepest subsea road tunnel ever built (Statens vegvesen, 2018).

The E-39 project comprises technological challenges and high investment costs connected to fixed link projects, highlighting the need for increased knowledge about these kinds of projects. Ferries might also be replaced by fixed link projects in countries such as Canada, China, Denmark, Italy, the Netherlands, and Scotland. In addition, similarities with other large infrastructure projects in terms of accessibility changes make this knowledge interesting for a wide international audience.

This thesis is located within the E-39 project's social impact subgroup. The approach has involved analysing empirical data from surveys and ex-post cases in order to understand the inconveniences associated with fixed links and expand upon existing knowledge about travellers' reactions to the removal of these inconveniences due to fixed link projects. By anticipating the changes in travel behaviour through improved transport models, funds might be better allocated to projects pursuing a higher number of societal benefits.

The topic is introduced in section 2, which contains a subsection comprised of a more detailed literature review. Section 3 includes the relationship between the research questions and papers included in this thesis as well as a brief description of the collaboration with the co-authors. The research design is described and discussed in section 4. Section 5 highlights the results, while their implication and a call for further research are covered in section 6. Finally, section 7 offers a summarising conclusion.

2. Introduction

In this section the topic background is described, leading to the research questions. A subsection follows with a literature review of transport models in relation to fixed links, including concepts that might cause over-or underestimations of traffic forecasts: inconveniences, population relocation, and daily travel patterns.

Transport infrastructure projects generate changes in land use (Holl, 2006), economic growth (Meersman and Nazemzadeh, 2017), regional development (Vickerman, 1998), territorial cohesion (Stepniak and Rosik, 2013), urban growth (Ng et al., 2018), growth in and optimisation of the labour market (Louw et al., 2013), promotion of economic activities (Coppola et al., 2013a), or support for location changes of these activities (Boarnet, 1998). Most consequences caused by these infrastructure projects relate to people's mobility, i.e. the number of trips an individual makes in relation to their activities, origins, and destinations as well as the transport mode used, and route chosen. These trip changes directly reflect on traffic volumes. Likewise, traffic volumes impact people's health due to the noise (Recio et al., 2017), air pollution (Qin and Chan, 1993), or accidents (Martin, 2002); it also affects habitat fragmentation (Chen and Koprowski, 2016). Moreover, it is responsible for almost a quarter of the EU's greenhouse gas emissions (European Commission, 2016). Traffic volumes are thus an important factor to consider when evaluating infrastructure projects.

Different levels of traffic volumes are simulated by transport models (Ortúzar and Willumsen, 2011). These models simulate people's travel patterns based on several variables ranging from transportation features to users' socioeconomic backgrounds. Traditional four-step transport models, firstly, estimate the number of generated or attracted trips in each zone, secondly, distribute the trips based on origins and destinations, thirdly, estimate the transport mode used in each trip, and fourthly, assign traffic volumes to the available modelled network. This process requires making assumptions about people's travel behaviour. The lack of accuracy in these assumptions, as well as in the variables included in the transport model, might lead to biased forecast traffic volumes for both 'do-nothing' and 'do-something' scenarios.

This thesis focuses on fixed link projects, for example bridges or tunnels, that join areas previously separated by geographical barriers, e.g. fjords. The completion of these projects might cause significant travel time savings since they often replace ferry connections, which take a much longer time to use. In addition, they remove waiting time, provide a flexible link 24 hours a day, 7 days a week, and increase reliability, as problems related to ferries' capacity constraints are no longer relevant. Finally, weather conditions do not affect the availability of the connection to the same extent they do to ferries. Despite the inconvenience removal, fixed links may not present their full benefits before their eventual toll removal (Baldacchino, 2007). For instance, a reduction to half of the toll on the Øresund bridge would quadruple traffic volumes (Matthiessen, 2004). In Norway, the average toll costs per fixed links are two to eight times higher than other tolls (Odeck and Kjerkreit, 2010), indicating their greater potential effects after their removal.

National and international literature highlight the inaccuracies in the traffic volume forecasts for fixed link projects. For instance, traffic volumes after the opening of Eiksundsambandet were more than double than that projected by simulation (Samferdselsdepartementet, 2000). As regards Trekantsambandet, traffic in the first year was 14% above the forecast (Odeck and Welde, 2017). Welde et al. (2017) observed 23 fixed link projects in Norway, showing that forecasts were an average of 13% less traffic than actual volumes in the opening year. This underestimation doubled after three years and almost tripled after five years. However, traffic forecasts are usually revised after a project's opening, so it is only relevant to compare the first-year values. Other international transport models also present inconsistencies when simulating traffic in this type of project, as shown in some ex-post evaluations. For instance, passenger traffic over the international fixed link of The Channel Tunnel between England and France was lower than 20% of what was forecast for the opening year (Flyvbjerg et al., 2006). Another case involves traffic on the Oresund Bridge between Denmark and Sweden, which was only 80% of expected traffic during the opening year (Knowles and Matthiessen, 2009). Lastly, traffic on two Danish projects, the Great Belt Fixed Link and Sallingsund Bridge, exceeded the opening year forecast by 73% (Knowles and Matthiessen, 2009) and 27% (Skamris and Flyvbjerg, 1996) respectively.

Unlike other infrastructure projects, fixed links remove inconveniences caused by being dependent on a ferry connection (Bråthen and Hervik, 1997). The current practice of including these inconveniences in transport models might be key to explaining their inaccuracies. However, little research has been done to understand these inconveniences and the consequences triggered by their removal on travellers, including changes in their behaviour. Assuming that traveller behaviour remains static may also cause inaccuracies when transport models simulate traffic volumes. The aim of this thesis has therefore been to fill in these literature gaps by addressing the following research questions:

- RQ1: What are the inconveniences in ferry connections?
- RQ2: How is travellers' behaviour affected by fixed link projects?
    - RQ2a: What are the reactions to population relocation?
    - RQ2b: What are the reactions to daily travel patterns?

RQ1 presents a deeper understanding of the inconveniences associated with ferry connection dependency. It also explores how different travellers perceive these inconveniences. Research was conducted based on a cross-sectional survey of seven Norwegian ferry connections. The findings might provide a basis for critical study of current practices when including the inconveniences in the transport models.

RQ2 presents travellers' reactions to the removal of inconveniences. These reactions were divided into population relocation (RQ2a) as these affected the origin of the trips, and daily travel patterns (RQ2b) as these directly affected the route, destination, mode, and potential new trips. A case study design was selected to address these research questions based on ex-post analysis. RQ2a was based on the opening of eleven Norwegian fixed links and the toll removal of six of them, whilst for RQ2b the toll removal of one of these fixed links was further analysed.

The findings might serve as a basis for detecting potential limitations of the four-step transport models for fixed link projects. These limitations and improvement suggestions are further discussed in section 6.

2.1. Literature review

Few research projects have been completed in relation to ferry service inconvenience, and traveller reactions to its removal due to fixed link projects. Nevertheless, transport models are rarely fully documented (Furnish and Wignall, 2009); consequently, literature on how the models simulate these projects and inconveniences is scarce.

The Norwegian transport models that simulate personal trips could be divided according to their trip distance into the National Transport Model (NTM) for trips having distances greater than 70 km and the Regional Transport Model (RTM) for shorter trips. Generally, fixed link projects are simulated by the RTM as the projects' area of influence might be sufficiently covered. Nevertheless, some fixed links are part of a larger project, thereby influencing trips longer than 70 km. The RTM models dynamic demand for short trips and uses fixed matrices for long trips. When changes in long trips are expected, as in the case of fixed links that affect greater areas as part of a larger project, (including the E-39 project), the NTM is used to estimate the fixed matrices.

One potential bias might be that ferries do not include distance as a variable in the model; thus, when replaced by a fixed link, the driving distance suddenly becomes longer. This might discourage simulated travellers, thereby resulting in fewer trips. Another limitation caused by the distance variable might be that a few trips, estimated in the RTM at being less than 70 km in the 'do-nothing' scenario, are no longer estimated, as the distance becomes greater than this limit in the 'do-something' scenario.

Traffic forecasts at the regional level in Norwegian models have been tested in Odeck (2013) and resulted in minor discrepancies, mainly long-term ones. Nevertheless, when analysing these forecasts in a disaggregated way, they have been imprecise. In particular, the weaknesses of these models are highlighted in relation to fixed link projects (Tørset et al., 2013b).

In addition, bias in traffic volumes from the transport models might be generated as these include inaccurate inconveniences related to ferry connections or disregard dynamic changes in population relocation and travel patterns because of the fixed link projects. These three topics are presented in more detail in the following subsections.

2.1.1. Inconveniences

The over/underestimation of traffic volumes in the simulations may be partly explained by inaccuracy in simulating the inconveniences associated with ferry connections. These inconveniences are all variables representing a hindrance to travel using ferry services. Figure 1 illustrates the inconveniences and coverage by both RTM and NTM (green), by NTM (blue) or by none of them (red).

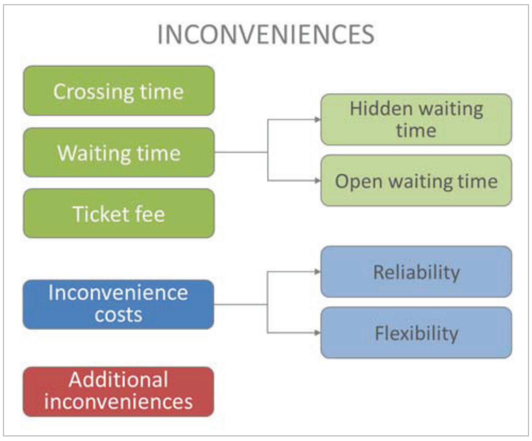

Figure 1: Inconveniences and the coverage by both RTM and NTM (green), by NTM (blue) or by none of them (red).

Crossing time denotes the actual time that the ferry lasts when going from the origin quay to the destination quay, and this value is directly included in the transport models. Waiting time includes both open and hidden waiting time. The former refers to the actual measurable waiting time on the ferry quay, whilst the latter refers to the schedule inconvenience and synchronisation costs for low-frequency services (Furth and Muller, 2006). The first element of hidden waiting time represents the time difference between the desired schedule and real one, whilst the second element is related to travellers' stress about being on time. Most of the transport models include hidden waiting times under their posted waiting time, although these would improve if the hidden waiting time had been properly simulated (Eltved et al., 2018). In Norwegian transport models, hidden waiting time has recently been included as an extra variable, although the value is not based on empirical evidence. The ticket fee is also included in the transport models. However, one potential bias here might be that the trip costs in the model are higher than in reality, as not all travellers pay the entire fee. Discount factors are common for all ferry and road users in the transport model; however, the share of travellers paying a reduced ticket fee might vary according to the ferry's particular features.

The concept of inconvenience costs (IC) includes the lack of reliability due to passenger capacity or weather conditions and the lack of flexibility travellers have to decide when to travel, as this depends on the ferry schedule (Bråthen et al., 2003). The inclusion of this non-monetary impact corresponds with recent studies that have demonstrated through economic models that trips and activity schedules affect users' welfare (Fosgerau, 2009; Laird, 2012). On the other hand, there might be an inaccurate estimation of their willingness to pay for a fixed link (Bråthen and Hervik, 1997).

In Norway, IC are included in the assessments in two different ways, whether at the national or regional level. At the national level, IC are added directly to the transport model as a multiplying factor for the travel time on-board the ferry connections (Statens Vegvesen, 2018). However, perceptions depend on individual characteristics (Krosnick et al., 2014); therefore, aggregating the IC into a common value for all types of users might produce biased outcomes. This concerns the value of time, which is around four times greater for work-related trips than for other trips (Samstad et al., 2010). In fact, individuals with different socioeconomic backgrounds might perceive the value of time differently (Mackie et al., 2003). Kouwenhoven et al. (2006) estimated the value of time on board ferry connections according to socioeconomic groups, finding that users with lower incomes display greater price sensitivity.

At the regional level, when the user benefits are not estimated by additional modules in the transport models, IC are included in the CBA as a monetary value for traffic volumes (Statens Vegvesen, 2018). Then, the potential effects that IC pose to travel patterns, i.e. traffic volumes, are disregarded. IC are a function of the number of individuals in each vehicle type (light, heavy, and public transport) and a unit price that depends on the type of traffic (local or transit) (Bråthen and Lyche, 2004). For ferries with frequencies lower than one departure per hour and no other modes available (or if they represent a long detour), IC have a multiplying factor. Nevertheless, the values used are not based on empirical studies; rather, they are an approximation based on ex-post analysis of fixed links in Norway by Bråthen and Hervik (1997). The authors found a significant shift in the demand curves that represented an extra benefit in four out of the five studied cases. The exceptional case might have experienced a lower willingness to pay for the fixed link since it connected islands to each other, with some of the islands losing their direct ferry connection to the mainland.

Moreover, none of the models (RTM or NTM) include potential capacity limitations, i.e. all vehicles could use the first arriving ferry independently of its capacity, which might simulate more demand than in reality.

In Canada and Scotland, traffic volumes are obtained from elasticities, including IC in the CBA for the changes in frequency and reliability (Litman, 2008; Fisher Associates, 2007). Nevertheless, estimations of the elasticities involved with demand changes when frequencies and services are improved have only been qualitatively explored, and additional analyses are required (Transport Scotland et al., 2015). In England, IC are directly included in the estimation of travel demand elasticity, covering the value of the quality attributes of a ferry connection, including factors such as frequency, reliability, and capacity problems (Kouwenhoven et al., 2006; Laird, 2012).

There might be additional inconveniences not covered by the IC concept, and thus these are disregarded in the transport models, for example those related to the poor accessibility to services and activities offered on the mainland. This might even reduce the labour market, as island residents would perhaps not want to consider commuting to the mainland.

Inconveniences are therefore considered to include all the above-mentioned variables. Crossing times and ticket fees are values provided by the ferry service operator. Open waiting times can be physically measured on the ferry quays. On the other hand, hidden waiting times, and those related to flexibility, reliability, as well as any potential additional inconvenience, cannot be directly measured, given that these might depend on individuals and trip characteristics.

In this thesis, inconveniences not directly measured are further studied, hereafter being referred to as personal inconveniences (PI). Moreover, the inconvenience perceptions for different trip and user features are analysed because, despite being important, they have not yet been addressed in the literature.

2.1.2. Population relocation

The over/underestimation of traffic volumes in the simulations may be partly explained by disregarding the effects on land use caused by transport infrastructure. Effects on land use could be considered as changes in population development, the housing market, and/or the labour market among others. Alam et al. (2005) classified the changes into three categories depending on the time period when these occur: short (3-4 years), medium (6-8 years), or long-term (more than 10 years). For instance, changes in the number of people living and working in the areas could be considered short-term (Wegener, 2004).

The interaction between infrastructure improvements and land use changes has already been mentioned in the literature (Banister and Berechman, 2001; Geurs and van Wee, 2004; Knowles, 2006; Coppola et al., 2013b). These changes are more likely to happen when changes in accessibility are great (Holl, 2006).

Therefore, the consequences of fixed link projects might be very significant. Hay et al. (2004) observed population growth in the areas close to the Channel Tunnel, which experienced an increase in housing demand. Royle (2007) likewise detected population growth in certain areas because of fixed links in Ireland. Gjerdåker and Engebretsen (2010) observed an important impact on commuting after the Trekantsambandet link in Norway, although the effects on population development and employment were low. In the Netherlands Meijers et al. (2012) observed that construction of the Westerschelde tunnel impacted the region's population and employment ; however, these were considered to be distributive effects, i.e. a growth in the connected area due to a population reduction in other areas. Knudsen and Rich (2013) found that the Oresund Bridge increased the number of commuters between Denmark and Sweden, where local policies also promoted these movements. Tveter et al. (2017) found that fixed links located close to urban areas in Norway affected population settlements.

Despite indications of impacts on land use due to fixed links, the ability to predict these effects caused by road projects remains limited (Handy, 2005). Matthiessen and Worm (2011) have developed a model to simulate spatial impacts on land use due to fixed links, but it has not been verified by quantitative analysis. While ex-post analysis of fixed link projects might improve appraisal methodologies (Welde, 2018), there is a lack of empirical studies supporting this idea (Bråthen and Hervik, 1997; Wegener and Fürst, 1999; Louw et al., 2013).

In this thesis, population relocation (understood as changes in residential location) caused by the opening and toll removal of fixed link projects has contributed to the literature through empirical analysis. This research could serve as a basis for identifying potential shortcomings in transport models about simulating whether people will relocate or not because of fixed link projects.

2.1.3. Daily travel patterns

The over/underestimation of traffic volumes in the simulations can be partly explained by disregarding travel pattern changes caused by infrastructure projects. Flyvbjerg et al. (2006) found that the main reasons behind forecast inaccuracies involve trip distribution. Gim (2011) observed that socioeconomic features, attitudes, and urban forms might affect the degree of travel pattern changes.

Route changes are likely to occur when a new or updated road minimises total travel expenses (Knorr et al., 2014). Destination changes due to a transportation project may occur for activities that can be transferred to other areas. Davidson et al. (2014) found that users' destinations are less likely to change because of a transportation project. This is consistent with the study from Fox et al. (2011) that also found destination choice less likely to be changed than users' choice of transportation mode. A larger amount of research has been done on changes in transportation mode than on destination; for instance, after being told of a hypothetical introduction of a toll in the Netherlands, more than 15% of respondents indicated that they would move from private car usage to public transportation (Ubbels and Verhoef, 2006). In New Zealand, this percentage was as high as 21% and include both walking and public transportation as alternatives to driving (O'Fallon et al., 2004).

Given that travel behaviour is directly reflected in traffic volumes, some research projects rely on observing traffic changes, for example, in the total kilometres driven by vehicles (Rentziou et al., 2012). Nevertheless, studies merely based on traffic counts cannot totally capture the changes in travel behaviour due to infrastructure projects (Hills, 1996). Studying travel patterns' different components might produce a better simulation of these projects' consequences. Most of the transport assessments focus on changes in route choice, disregarding other responses (Hills, 1996). On this topic, Davidson et al. (2014) highlighted the need for further research on changes in users' destination choice. There are few empirical studies on travel pattern changes due to infrastructure projects, especially for fixed link projects.

In this thesis, travel pattern changes caused by fixed link projects were observed to contribute empirical evidence to the literature, including trip frequency, as well as mode, destination, and route choice. This research could serve as a basis for identifying potential shortcomings in the transport model in relation to predicting changes in travel behaviour due to fixed link projects.

3. Research objectives

In this section, the research questions are presented and related to the papers included in this thesis. There is also a brief description of each paper.

3.1. Research questions

The aim of this thesis is to understand and provide a better explanation for people's perception of ferry connections and behaviour in relation to fixed link projects. The research questions below relate to the papers (numbered in chronological order) shown in Figure 2.

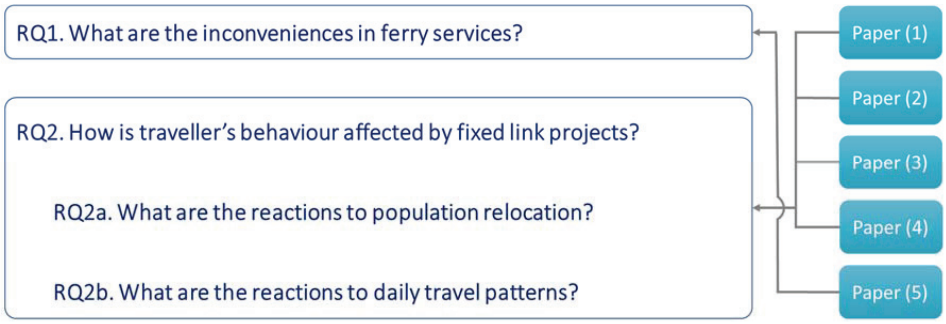

Figure 2: Research questions in relation to the published papers

3.2. Papers

Paper 1: Impacts on land use characteristics from fixed link projects. Two case studies from Norway

Díez Gutiérrez, M., Andersen, S. N., Nilsen, Ø. L., & Tørset, T. (2015). Impacts on land use characteristics from fixed link projects. Two case studies from Norway. Transportation Research Procedia, 10(2352), 286–295. https://doi.org/10.1016/j.trpro.2015.09.078

This paper analyses the effects of opening two fixed link projects close to urban areas on the local population as well as housing and labour market. A time series analysis of empirical data was used to record these effects. Results showed that the projects' opening, and toll removal led to an increase in population and housing prices in the affected areas. Despite this, the growth in the number of companies in the area did not experience any disruption due to this opening or toll removal.

In relation to RQ2a, this paper shows that population relocation due to the analysed fixed link projects does exist.

Paper 2: Modelling the Impacts on Population Caused by Fixed Link Projects

Díez Gutiérrez, M., Andersen, S. N., Nilsen, O. L., & Tørset, T. (2016). Modelling the Impacts on Population Caused by Fixed Link Projects. In Transportation Research Procedia (Vol. 14). https://doi.org/10.1016/j.trpro.2016.05.369

This paper observes the discrepancies between population forecasts and actual population growth in areas affected by fixed link projects. These differences grew larger after tolls were removed. By using regression models, significant variables that influenced these discrepancies were identified. Results showed that increased travel time and cost reductions as well as greater differences in housing prices between the mainland and connected island induced greater discrepancies.

In relation to RQ2a, this paper shows that population forecasts differ from reality, which may be an indication of the bias triggered by disregarding population relocation.

Paper 3: The impact of fixed links on population development, housing and labour market: The case of Norway

Andersen, S. N., Díez Gutiérrez, M., Nilsen, O. L., & Tørset, T. (2018). The impact of fixed links on population development, housing and labour market: The case of Norway. Journal of Transport Geography, 68, 215–223. https://doi.org/10.1016/j.jtrangeo.2018.03.004

This paper analyses the population development, housing and labour market in eleven fixed link projects. Difference in difference method was used to compare the case studies. Results showed that these projects, when occurring close to urban areas, increase the attractiveness of the adjoining areas, which in turn led to growth in the population, housing prices and labour market.

In relation to RQ2a, this paper both corroborates the findings from paper 1 and indicates that people relocation is mainly generated by projects located close to urban areas.

Paper 4: Generated and induced traffic demand: Empirical evidence from a fixed link toll removal in Norway

Díez-Gutiérrez, M., Andersen, S. N., Nilsen, Ø. L., & Tørset, T. (2019). Generated and induced traffic demand: Empirical evidence from a fixed link toll removal in Norway. Case Studies on Transport Policy, 7(1), 57–63. https://doi.org/10.1016/j.cstp.2018.11.007

This paper observed the travel patterns before and after a fixed link's toll removal. Traffic counts taken in the two connections to the island allowed accounting for route choice changes, and a panel data survey allowed estimating changes in the destination and mode as well as potential new trips. Results showed changes in route and mode, while the toll removal did not significantly affect destination choice, based on a mixed logit model. No indications of induced travel demand were found, either (although further research is needed in this area).

In relation to RQ2b, this paper shows that changes in daily travel patterns due to the analysed fixed link project do exist, in particular for mode and route.

Paper 5: Perception of inconvenience costs: evidence from seven ferry connections in Norway

Díez-Gutiérrez, M. & Tørset, T. (2019). Perception of inconvenience costs: evidence from seven ferry connections in Norway. Transport Policy, 77, 58-67. https://doi.org/10.1016/j.tranpol.2019.03.002

This paper analyses inconvenience factors for ferry users in seven ferry connections. By estimating four partial proportional odds models using data from on-board surveys, it was possible to observe how the trip features and users' socioeconomic backgrounds alter the perception of these factors. Results showed that waiting time, frequency of trips via the connection, trip purpose, gender, age and income played important roles in the perception of different factors. In addition, a quantification of the differences in the perceptions among the variables' categories was described based on the average marginal effects.

In relation to RQ1, this paper identifies nine inconvenience factors associated with ferry connections and shows that travellers perceive them differently.

3.3. Co-authorship

This thesis is part of a PhD group comprised of three candidates: Stig Nyland Andersen, Øyvind Lervik Nilsen, and María Díez Gutiérrez.

The motivation behind forming a PhD group was that we would all benefit from establishing a collaboration while at the same time setting clear boundaries between our individual research topics. The collaborative strategy was to initially work more closely together. Later on, the plan was to become more independent and self-motivated, developing our final paper alone with only our supervisor as co-author.

Being a group provided us with several strengths compared with just using an individual approach: we could thoroughly discuss relevant topics, achieving a better and broader understanding of the phenomena analysed in this thesis; we complemented one another through our different backgrounds and visions; and we could use a wider variety of analytical tools given we possessed diverse areas of expertise. Another important benefit of the group was being able to keep up each other's motivation for completing the research project, overcoming our occasional discouragement, and celebrating our achievements. On the other hand, one consequence of our working as a group could be that the line of research each of us pursued might be slightly conditioned by the group, resulting in a lower degree of freedom when addressing the research topics.

4. Research design

In this section, the research design is described and justified. The data sources and data analysis are briefly presented with a discussion on the limitations and potential implications of the results. Moreover, a discussion on the validity of the research methods used to address the research questions is presented.

Figure 3 illustrates the data sources (blue) used as input in the different methods (orange) as part of the research design (green) for each of the research questions (red).

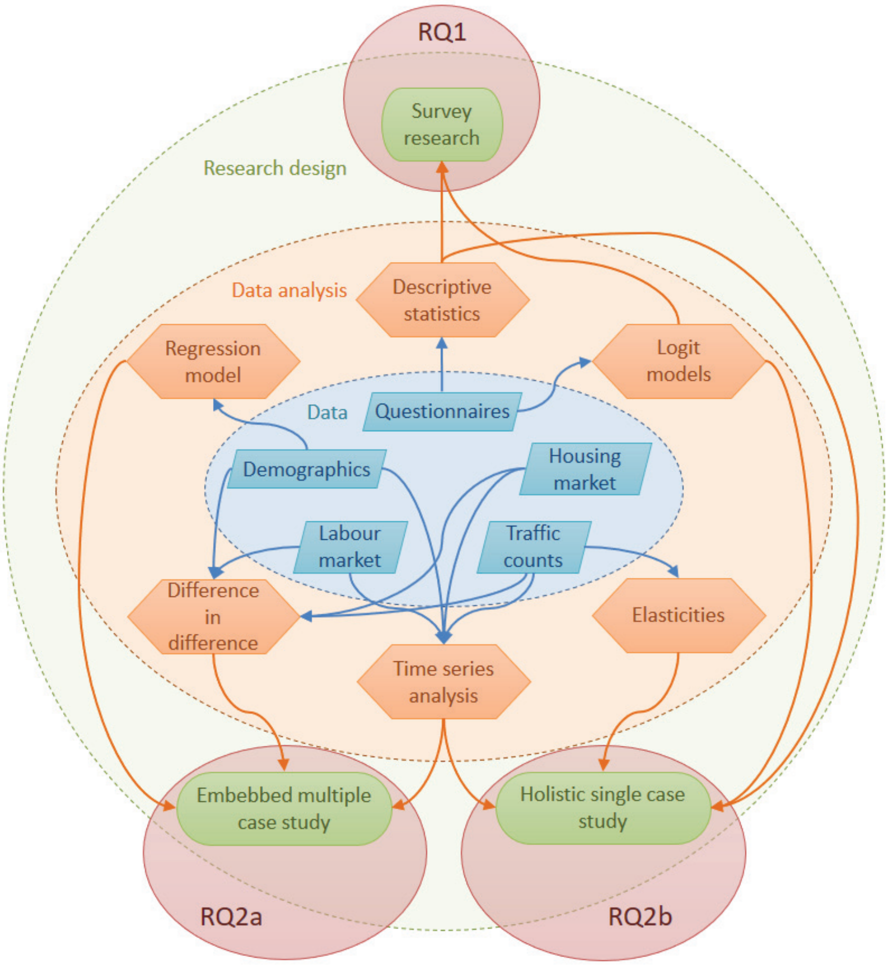

Figure 3: Research questions, research methodology, data analysis, and data sources

4.1. Survey research

RQ1 attempted to better understand the inconveniences (mainly PI) related to ferry connections and how individuals perceive them. Perceptions in general have to be stated by the individuals involved (Nelson, 2008), which is why the survey research method was selected to address this research question. Survey research is characterised by three aspects: first, the aim is to describe the studied population in a quantitative manner; second, the analysed data are based on responses to predefined questions; and third, the respondents are a representative sample of the studied population (Pinsonneault and Kraemer, 1993).

Interviews or survey questionnaires comprise just one part of survey research. The main difference is that interviews are led by interviewers; further, these are a method seeking to establish an in-depth understanding of respondents' experiences and the meaning of their reactions to a particular action, process or event (Broom, 2005). Most of the interviews gather qualitative data, although standardised interviews that follow close-ended questions may also include quantitative data. On the other hand, although survey questionnaires might be used to gather qualitative data through open-ended questions, they are instead commonly used to collect quantitative data from questions followed by a choice of set answers (McLeod, 2018). A survey questionnaire was selected to quantify the differences in perception based on close-ended questions, its aim being to facilitate researchers' understanding and reduce the need for an interviewer.

The questionnaire gathered socioeconomic information from respondents as well as their trip's characteristics at the time of the survey. The main questions were associated with their perception of the ferry connections pertaining to the dependency on a non-permanent connection. This dependency was translated into nine inconvenience factors in order for them to be more easily evaluated. These factors were then presented to users, who indicated their perception regarding the potential benefits of a fixed link project in accordance with the Likert scale (Likert, 1932).

The inconvenience factors were selected in 2011; these were inspired by travel purposes, newspaper articles with statements from local residents about how ferry dependency affected their lives, and a discussion with representatives from the Norwegian Public Roads Administration. These factors were reviewed in 2016. In so doing, locals as well as local companies and certain municipalities affected by fixed links were interviewed regarding the benefits of having this connection. Based on these interviews, the originally selected inconvenience factors were also used in the second survey. A different approach to select these inconvenience factors could have been to conduct focus groups with several stakeholders to ensure that all aspects were covered.

There are different data collection techniques within survey research depending on respondents and time periods. Cross-sectional surveys refer to data collection at one single point in time, which allows observing differences among population's subgroups and its relationships with the studied variables (Krosnick et al., 2014). In this thesis, a cross-sectional survey for several individuals was conducted at two different points in time. Another type of survey that could have been used was a longitudinal, or panel, survey, which consists of collecting data from the same users at more than one point in time (Duncan, 2015). However, a longitudinal survey would not provide any additional benefits, as it aims to describe the perception of a hypothetical project, i.e. there is no 'do-nothing' or 'do-something' scenarios. A retrospective survey would not be useful, either, as this is used to study past events (Thigpen, 2019).

A sampling plan is an important part of survey design, as it defines a sample of the population and the type of survey used to approach potential respondents (Levy and Lemeshow, 1999). Given that the aim was to analyse people's perception of the inconvenience factors pertaining to ferry connections, the target group included people travelling on-board a ferry. Due to this travel, respondents were familiar with the service, and their answers were based on known experiences. Two interviewers were on-board the ferries distributing the paper-based questionnaires to passengers and answering any questions that arose. Another possibility for passengers to complete the questionnaire was to have them use tablets, i.e. a computer-assisted questionnaire. Nevertheless, using paper allowed us to run several questionnaires per ferry crossing, thereby increasing the sample size. Ebert et al. (2018) encounter a higher response rate from paper-based questionnaires compared to web-based ones, although representativeness might not increase when the response rate is greater (Krosnick, 1999).

Figure 4 shows the location of the ferry connections where the survey was conducted; all the ferries were connected with the E-39 European highway along the western coast of Norway. These cases were selected because some of them were already in the process of being replaced (Statens vegvesen, 2018). The characteristics are further described in Table 1.

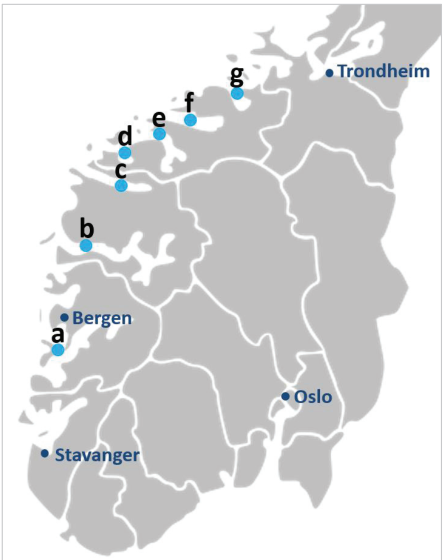

Figure 4: Locations of the ferry connections

Table 1: Ferry characteristics

	Ferry	Cross-time (min)	Headway * (min)	Approx. departures per day	Approx. price in EUR (car)	AADT (light vehicles)	AADT (heavy vehicles)	AADT left behind (light)
a	Bjørnafjorden (Sandvikvåg – Halhjem)	45	25	44	16	2,066	389	8
b	Sognefjorden (Oppedal – Lavik)	20	20	52	7.5	1,202	224	32
c	Nordfjorden (Anda – Lote)	10	20	53	7.5	1,101	191	2
d	Voldafjorden (Volda – Folkestad)	10	30	33	7.5	996	166	6
e	Storfjorden (Solevåg – Festøya)	35	30	42	7	1,290	241	0
f	Moldefjorden (Molde – Vestnes)	35	20	45	10.5	1,678	347	0
g	Halsafjorden (Halsa – Kanestraum)	20	20	50	7.5	784	135	0

*Headway defined as time between departures (at the rush period).

Prices in 2011 base year

The number of departures per day varied between 33 on Ferry d and 53 on Ferry c, the disparities mainly being due to night departures. The headway during rush periods was between 20 and 30 minutes, which was similar for all the ferries. The prices for a standard car in 2011 varied from approximately EUR 7 on Ferry e to EUR 16 on Ferry a. The share of heavy traffic was similar for all the ferries, representing approximately 18% of the total traffic. In 2011 Ferries a and f had an annual average daily traffic rate (AADT) approaching 1,800 light vehicles, while the others had approximately 1,000 vehicles.

According to the annual average daily traffic, few or no cars were left behind due to the ferries' capacity limitations, as only 30 light vehicles were left behind on Ferry b on an average day. However, observing the traffic for the whole year; more than 500 vehicles had to wait at the quay for Ferry b on certain days in the summer, and more than 200 vehicles were left behind by Ferry a in October. Therefore, there were capacity problems during peak periods.

4.1.1. Survey research data source

As mentioned above, the survey was a paper-based questionnaire distributed to ferry passengers during two working days in 2011 and 2016. The total number of valid answers, and the ferries on which these surveys were conducted, are described in Table 2.

Table 2: Questionnaire, years conducted, studied cases, and sample

	Years	Cases	Valid sample (N)
On-board ferry questionnaire	2011	a – g	9295
	2016	a	583

The sample in 2016 had a slightly higher share of commuters. This increase was assumed to be related to the actual days the survey was conducted rather than any changes in trends; therefore, the data for both years were jointly analysed.

Individuals belonging to various socioeconomic groups and having different backgrounds might perceive or show different attitudes toward the same situation (Krosnick et al., 2014); thus, taking a wide sample among the individual types could prevent biased results. In addition, obtaining a representative sample and avoiding non-response bias is essential (Bartlett et al., 2001). The sample accounted for approximately 30% of the total number of passengers during the survey days at all locations. Moreover, respondents' characteristics were evenly distributed among different users and trip features. Consequently, it was assumed that the results were not affected by the sampling.

There were few respondents who approached the interviewers on-board the ferries to clarify the questionnaire; thus, the survey was assumed to be without bias due to misunderstanding. Nevertheless, responses might differ due to respondents' interpretations. Their perception might lead to inaccuracies which may be systematic or random (Nelson, 2008). This potential inaccuracy was assumed to be random; therefore, there was no need for making any special adjustments before the data analysis.

4.1.2. Survey research data analysis

Descriptive statistics

Descriptive statistics was used in *Paper 5* to provide a summary of the sample characteristics from the ferry surveys. Mean, maximum, and standard deviation were the measurements used for describing the answers.

Logit model

A logit model was used in *Paper 5* to identify the user and trip characteristics affecting the inconvenience factors' perception. Among the logit models, ordered discrete choice models were selected, as these do not disregard the ordinal nature of the perception level (O'donnell and Connor, 1996). In particular, the model used was a partial proportional odds model because some of the variables remain constant for different categories of the dependent variable, while others vary (Peterson and Harrell, 1990). There was no need to resort to more complex models where all category variables differ, for instance, as happens in the generalised ordered logit (Terza, 1985).

An additional technique called marginal analysis was used to facilitate the interpretation of the model results. It provides an approximation of the amount of change in the latent variable for a unit change in the independent variable (Williams, 2012), thereby capturing the differences in perception of the inconvenience factors among the variable categories.

4.1.3. Survey research discussion

Survey research was selected to observe the inconveniences (mainly PI) related to ferry connections (RQ1). A questionnaire that had been handed out during seven ferry crossings along the western coast of Norway was analysed based on a descriptive statistical analysis and logit model in *Paper 5*.

Overall, survey research was adequate to cover the RQ1 because it provided both perception of nine inconvenience factors according to a scale and these factors' ranking in importance. However, the questions did not allow quantifying the willingness to pay for a permanent connection according to each of the nine inconvenience factors. This was considered a shortcoming, given that without the different perceptions' translation to monetary value, these variables could not be directly included in the transport models. On the other hand, using a logit model with the data contributed to quantifying the perceptual differences among the different types of users and trip features.

Fixed link projects remove the inconveniences of ferry connection dependency; subsequently, people adverse to using these services could also benefit from them. Although these people were not included in the sample, as it listed only ferry users, it was assumed that there were a few people who never used these ferry connections. The sample could be considered representative, as in addition to covering different socioeconomic factors, it was comprised of people using the ferry with different frequency rates. Therefore, the obtained results could be generalised. Despite this situation, respondents were on-board ferries belonging to the E-39 European highway, so further studies should focus on observing other types of ferries to verify the results. Users of different ferry connections might behave differently. For example, Jørgensen and Solvoll (2018), divided the Norwegian ferries into major state highways and other roads, and subdividing these further according to the traffic level. Another classification was suggested by Bråthen and Lyche (2004) depending on whether the ferry was located in an urban or rural area.

4.2. Case study research

Case study research design is suitable for addressing descriptive or explanatory research questions (Shavelson and Towne, 2002). It may be described as an intensive analysis of a single individual, group, community or some other unit in order to make generalisations about a larger sample (Gustafsson, 2017). This method is used to understand in-depth a real-life phenomenon within its context (Yin and Davis, 2007). Given that the phenomenon and context might be difficult to differentiate, a case study examines the potential minor data points (compared to the interest variables) by combining multiple sources of evidence (Yin, 2009). These sources might be a combination of quantitative and qualitative data, which may facilitate a holistic understanding of the questions at hand (Heale and Twycross, 2018).

Justification for the use of case study research design for the RQ2 related the aim to understand the consequences of two events by addressing 'how' and 'why' people's behaviour was affected. The events were the opening and toll removal of a fixed link project which were within the real-life context. This entails several variables being involved, some of them out of the researcher's control. Thus, an experimental research approach could not have been followed, as the event could not have been isolated from its real-life context (Yin, 2009). Survey research could have been another potential research design; however, this method may not have covered all of the events' consequences. In spite of this situation, questionnaires were one of the data sources in the case study research.

Case study research design is also useful for observing the accuracy of scientific theories and models in the real world (Shuttleworth, 2018). Consequently, the accuracy of the transport models to simulate the traffic on fixed link projects could be assessed.

There are four different types of case study research design, whether considering a single or multiple case, and whether observing embedded subcases within the general holistic case (Yin, 2009). Several case studies provide better insight into this phenomenon, which makes generalisation easier (Yin, 2009). A multiple case study was selected for the RQ2a (population relocation), where eleven ferry link projects were analysed. In addition, the project's opening and toll removal were observed; therefore, embedded approach was used. In contrast, RQ2b (travel patterns) were studied in detail for one single case and only in relation to the toll removal; a holistic single case study research approach was used.

Nevertheless, case study research might fail when addressing too broad a topic (Baxter and Jack, 2008). Narrowing the case might be a solution that could be done in terms of place and time (Creswell, 2003). Following the literature recommendations, this research was tied to the consequences of these projects within the islands, as these can be isolated and the scale of the analysis manageable (Baldacchino, 2007). In addition, the analysed time period covered only a few years before identifying the prior trends and the following years to identify immediate, short, medium and long-term changes wherever data were available.

Figure 5 shows the eleven analysed fixed link projects. There were more projects of this type in northern Norway that could have been used; however, as the E-39 project was a motivation for this thesis, the cases were selected along the western coast of Norway. Selecting these cases helped us to understand these infrastructure projects' potentially different consequences, as some of these appeared similar to one another. For example, some of the cases were located in urban areas and others in a more rural environment. Therefore, within each classification, the cases provided similar results (literal replications), whilst, when compared, produced contrasting results (theoretical replications) (Yin, 2009). The characteristics of these projects are further described in Table 3.

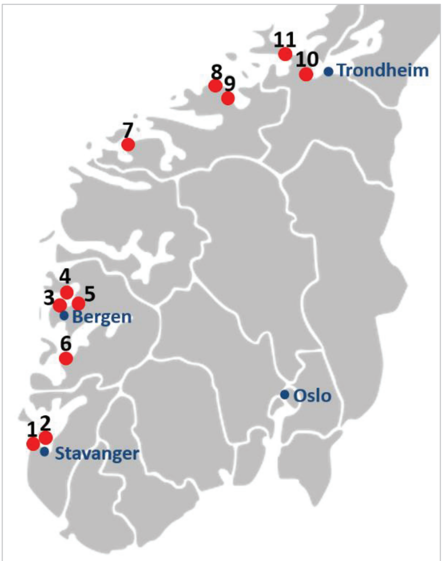

Figure 5: Locations of the fixed links

Table 3: Fixed link characteristics

	Name	Year of opening/ toll removal	Population in opening year		Travel time between island and town on the mainland (by car)		Ferry ticket (€)	Toll fee on fixed link (€)
			island	closest town on mainland	before opening	after opening		
1	Rennfast	1992/ 2006	2,600	135,500 (Stavanger)	150	25	16.40	15.50
2	Finnfast	2009/ –	2,800	190,000 (Stavanger)	90	50	8.54	23.30/ 17.80
3	Askøybrua	1992/ 2006	18,500	191,000 (Bergen)	30	15	9.20	6.40
4	Nordhord-landsbrua	1994/ 2005	21,400	195,000 (Bergen)	40	30	7.80	7.20
5	Osterøy-brua	1997/ 2015	7,000	200,000 (Bergen)	96	42	7.00	7.00
6	Trekant-sambandet	2001/ 2013	10,800	11,000 (Stord)	60	30	8.54	11.20
7	Eiksund-sambandet	2008/ 2014	22,500	5,500 (Volda)	50	30	7.00	8.54
8	Krifast	1992/ 2012	22,500	20,600 (Molde)	145	78	4.40	8.70
9	Atlanterhavs-tunnelen	2009/ –	5,400	17,000 (Kristiansund)	45	20	10.90	10.30
10	Hitra-tunnelen	1994/ 2010	4,200	6,000 (Orkanger)	152	88	8.50	5.30
11	Frøya-tunnelen	2000/ 2010	4,100	6,000 (Orkanger)	212	116	18.40	5.30

Prices in 2015 base year

The eleven cases were located along the western coast of Norway. They each opened sometime between 1992 and 2009, and their toll removal took place between 2005 to 2015. The fact that the cases were so spread out over time might have prevented bias from potential external factors such as the global crisis in 2008, which negatively affected the country's economic development (Bernhardsen et al., 2009).

Similarities among the eleven cases included significant reduction in travel time between the connected island and closest town on the mainland. Further, the size of these towns made a difference. The first five cases were close to cities having more than 100,000 inhabitants, and thus were connected by a relatively short commute to urban areas. Among them, the populations of the islands in cases 3 and 4 were almost ten times larger than in cases 1 and 2, which might have explained certain potential differences among these urban cases. On the other hand, the other six cases (6 to 11) were located in more rural settings. Moreover, commuting times were longer than 60 minutes in cases 8, 10, and 11, even after travel time reduction because these were located in quite remote areas.

The change in fee from ferry to toll in the fixed link varied from case to case. Even if the travel times were reduced after the opening of the fixed links, the toll might have been perceived as a drawback to generating changes in travel patterns. Therefore, the relative change might have explained a certain number of different consequences in the cases. Cases 2, and 8 presented a significant fee increase, whilst cases 10 and 11 had a fee reduction. The remainder of the cases had fees that were more similar to the ferry ticket and toll.

4.2.1. Case study research data sources

Several data sources were observed and analysed in the case studies. Table 4 describes the data in relation to the observed years and cases, as not all cases were analysed using the same data.

Table 4: Data sources, analysed years, and studied cases

		Years	Cases
Demographics			
	Population data	1985-2015	1-11
	Population forecasts	1982-2002	1-7,9-11
Housing market data			
	Housing prices	1993-2014	1-11
	Housing typology	2000-2014	1-2
Labour market data			
	Number of employees	2000-2015	2, 7, 9
	Commuting patterns	2000-2015	2, 7, 9
	Number of companies	1996-2013	1-2
Traffic counts			
	Road counts	1989-2015	1-11
	Ferry counts	1989-2015	1-11
Questionnaires			
	Paper-based questionnaire	2015-2016	5

Demographics

Regarding demographics, the population data consisted of the number of people residing in each municipality by age and gender. The data were based on population information provided by Statistics Norway. Potential errors in these number were regarded as insignificant (Statistics Norway, 2019). The demographic forecasts at the municipal level in Norway are based on a stochastic cohort component approach, i.e. based on births, deaths, migrations on the national level and five years of regional migration patterns (Keilman et al., 2001). The data were based on the main alternative (MMMM) of the population projection from Statistics Norway, which assumes medium-level growth for each component (Statistics Norway, 2018). Errors were expected given the data was based on assumptions. These errors were greater both for small settlements and forecasts made several years in advance, i.e. there were larger errors for population projections in 2050 than in 2020 (Statistics Norway, 2018).

Housing market

Housing market data consisted of the registered sold dwellings classified according to sale price, size, type of dwelling, number of rooms and location. The square metre price was estimated based on residential buildings at the municipal level. To avoid fluctuations in prices due to external factors, a smoothing method was applied. The data were collected from The Norwegian Mapping Authority's Cadastre and Land Registry. One possible source of error was that the properties were registered after the sale, so sales made late in the year might have been registered the following year. Moreover, some of the properties lacked size or sale price, while others consisted of several building types. The data regarding housing typology included the number of new buildings per municipality classified according to type. These data were registered by Statistics Norway. One possible source of error stemmed from the classification of dwelling type (Statistics Norway, 2015a).

Labour market

Regarding labour market data, employee data consisted of the number of residents in one municipality working in other municipalities. The total number of employees per municipality and commuters between the municipality on the connected island and the mainland were estimated. The data were registered by Statistics Norway. One possible source of error was that approximately 10% of the employees did not register the time when they started working in a specific municipality. Moreover, companies owning several establishments may have led to the incorrect registration of their employees in terms of workplace location (Statistics Norway, 2015b). The company data consisted of the registered companies according to type, location, number of employees, profit, and year of opening, moving, or closing. The data were collected by the Brønnøysund Register Centre. Potential errors might have occurred due to the lack of data regarding company type, number of employees and profits, depending on the area and company size. Another possible source of error was that self-employed individuals might have registered their home address instead of the company location.

Traffic volumes

Traffic volume data consisted of the daily average number of light vehicles travelling on the ferries and across the fixed links. Light traffic was considered as passenger cars with and without a trailer, vans, and vehicles shorter than six metres. The data on the ferries were based on counts provided by the ferry companies. Despite the fact that most of the registrations were based on electronic ticketing, a few ferries still used manual registration, which may have led to inaccuracies (Statens vegvesen, 2014a). The data across the fixed links were registered from counts by The Norwegian Public Roads Administration. One possible source of error might have been the vehicle classification, as it changed from ‘vehicle type’ to ‘vehicle length’ in 2001 on ferries (Statens vegvesen, 2014a) yet as late as 2007 for road traffic counts (Statens vegvesen, 2014b).

Questionnaires

These data were based on the answers from a paper-based questionnaire completed before and after the toll removal of the fixed link in case study 5 (Osterøybrua), reported in *Paper 4*. Panel data allow estimating the consequences of the events on individuals, as the same person answers the questionnaire during different time periods (Duncan, 2015). However, some limitations are related to the nonresponse for further surveys. Although there were 352 initial responses, only 132 users completed both surveys, representing 1.7% of the total population of the island. Another limitation might be related to respondents being conditioned by their participation in previous surveys (Krosnick et al., 2014), though this was assumed to be insignificant because the time lapse between surveys was more than one year.

Respondents provided their socioeconomic information and travel patterns of the previous working day. In particular, they were asked about the number of times and main reason why they had visited each destination. Respondents also stated if the transport mode they had used was the ferry or fixed link, which were the only two ways of getting off the island. They also stated the number of times they had used the ferry or fixed link. Finally, they specified whether the toll removal affected them in terms of changing residence, job, or car ownership.

One potential source of bias in the answers was linked to both the questionnaire itself and the sample. On the one hand, questions related to travel pattern were asked in the form of inquiring about the number of trips to different locations, already established, and the different reasons for these trips, including a combination of several purposes. Given the amount of invalid answers in the first round, the definition of 'trip' and combination of purposes were considered as insufficiently clear. Moreover, the travel patterns were based on a random working day, but travel patterns might present variability on different days of the week (Raux et al., 2016). On the other hand, the sample only represented the island residents and not all the users of the fixed link; few residents from other municipalities used the connection. Outer commuters comprised less than 20% of the island's employed, and the leisure and shopping activities on the island were scarce compared to other neighbouring municipalities. Another limitation might have been that most of the respondents lived close to the fixed link, so aggregating the sample could have led to biased generalisations.

Suggestions to overcome these limitations might result in expanding the questionnaire to the travel patterns for an week; however, an individual might find it difficult to remember all their trips in a week, leading to a potential underestimation of the total number of trips, especially short ones. In addition, respondents might be more reluctant to participate, as this would require more time and effort. The definition of a trip and different purpose combinations should be better clarified, including illustrations. Nevertheless, both shortcomings could be solved by using tracking systems to automatically record travel patterns. In addition, increasing the number of respondents on the island and including other users of the fixed link could increase the sample's overall representativeness.

4.2.2. Case study research data analysis

Time series analysis

Time series analysis was used in *Paper 1* to describe the chronological development of the traffic volumes, outer and inner commuters, population, housing prices, and number of companies. It was also used to identify the relationship among these developments and the events of two of the case studies' opening and toll removal. One potential limitation was that external factors which could have affected the variable development could not be isolated. To overcome this, neighbouring areas to the islands newly connected by the projects were also observed to detect similarities and differences.

An additional technique called trend analysis was used to identify the potential changes before and after the events. The prior trends were based on the previous five years, which could have already been slightly influenced by the project. Therefore, expanding the data backwards in time could have provided more robust trend lines.

In *Paper 3*, this technique was also used to identify the trend breaks for the population, housing prices, number of employees, and outer and inner commuters. In this case, the potential trend breaks on the islands were compared to similar areas, instead of neighbouring ones, that had not gotten a fixed connection to the mainland. This might have better captured variable development, as the mainland may have been affected by other factors.

Regarding one of the case studies, time series analysis was also used in *Paper 4* to describe the chronological development of the traffic volumes on the two connections off the island. This allowed the detection of route changes taken by the connections' users. However, this method only accounted for light traffic, and thus heavy traffic, public transport, or soft mode users were not observed. Nevertheless, the observed event was the toll removal, so it was assumed that only users whose travel costs had changed had modified their route.

Difference in Difference

Difference in Difference (DiD) method was used in *Paper 3* to identify the effects of the events on traffic volumes, population, housing prices, number of employees, and number of outer and inner commuters. DiD method compares the variable development in the affected area to a control area by controlling for bias from unobserved variables that remain fixed over time (Zhou et al., 2016). Given the small sample, the non-parametric DiD method (Lechner, 2010) was selected and estimated to use an index of 100 for the year of the projects' opening. This enabled comparisons to be made between the different case studies; however, it did not provide the real difference in variable development.

The parametric DiD would have shed light onto this shortcoming as well as indicated whether the events' effects were significant. The parametric DiD is based on a regression model having three extra dummy variables to account for the time before or after the event, the area, affected or control, and the interaction between them (Angrist and Pischke, 2008). Thus, given that the number of parameters in the regression model cannot be larger than the sample, the parametric DiD could not be used.

Some limitations of the DiD method concern the selection of the control areas themselves, as variable development should be similar before the project compared to the affected areas. In the case of housing prices, number of employees, and number of commuters, the control areas were islands with as similar features as those connected by the case studies in terms of population density and industry composition. Moreover, the selected control areas were assumed to be out of the influential area of the fixed links. Nonetheless, even if developments before the events were similar between the affected area and control area, some posterior differences could have been attributed to local policies, although these were assumed to be minimal. The benefit of using DiD was that external factors, including interest rates or gross domestic product, influenced both the affected area and control area, resulting in the differences between them being likely to represent the event's consequences.

In contrast, the actual traffic volume developments of the fixed links were compared to the extended trend found in previous years. One possible error may have been that a few years before the event traffic might have already started to be affected. Another possible source of error was that the extended trend did not account for external factors. The control area for the population was also based on the extended trend, although to account for external factors, it included trend changes from the county. One source of bias was that the county also included the population in the affected area, although its share was minimal.

Given the difficulty of finding suitable control areas, synthetic control areas could have been used (Abadie et al., 2015). This technique consists of creating control areas based on weighting several areas to better match the development of the variables in the affected area before the event. This method was not selected because for some of the studied cases, the synthetic control group did not hold a similar trend to the affected areas before the event. Nevertheless, Tveter et al. (2017) used this approach for some of the cases in this thesis, finding similar results.

Regression model

A regression model was used in *Paper 2* to identify the significant variables that triggered discrepancies between the actual population and population forecasts. The justification for its use is based on statistical method characteristics, as it allows the estimation of the relationship between a dependent and one or more independent variables (Smith, 2015).

The dependent variable was the population discrepancies, whilst the independent variables were travel time, travel cost in addition to population and employment densities. One of the method's limitations was the number of observations, as these were the fixed link cases. Only five cases were available to test the discrepancies due to toll removal. In order to try to overcome this, different combinations were tested to observe the significance of the model's parameters, correlations, and overall performance. Nonetheless, a larger sample could have improved the model results.

Descriptive statistics

Descriptive statistics were used in *Paper 4* to facilitate the understanding of the panel data survey since it provides a summary of the sample characteristics. While there are several types of measures found in this technique, only mean and maximum were used.

Percentages were also used to identify the potential changes in mode choice and trip frequency. For instance, mode choice was based on the changes for the respondents using the fixed link before and after toll removal. Even though the sample was representative with respect to the total island population, respondents using the connection were a small part of the sample, which might have not been representative for this group. Moreover, if a respondent changed their transport mode in combination with a new route, it was not detected (although this could have been further explored in the dataset). However, in favour of the followed approach, it is not likely that respondents changed their transport mode to cross the fixed link depending on the weekday; the shortcoming of the data due to daily variability might then have not influenced these results. In contrast, trip frequency might have been significantly affected by this variability. Suggestions to overcome these limitations are based on both the questionnaire design and sample as discussed in the previous subsection.

Elasticities

Elasticities were used in *Paper 4* to identify the change in travel demand after a 1% cost reduction due to toll removal. There are several ways to estimate elasticities, yet the arc-elasticity was used, as it is the most accurate (Litman, 2019).

The demand change was based on the traffic volumes from traffic counts, which were also quite accurate. Thus, the results were considered to be unbiased.

Logit model

A logit model was used in *Paper 4* to estimate the destination choice, analysing the variables that significantly influenced the choice decision. The logit model selected was a mixed logit model, as it accounts for heterogeneity in taste and correlation among variables and between alternatives (Ortúzar and Willumsen, 2011).

The estimation of the model was based on land use data and the panel data survey, which, as mentioned above, presented some shortcomings. When it comes to land use data, some observed variables included population and employment density in the destinations as well as travel times. Regarding the survey data, the variability between the travel patterns along the days did not affect the model, as it only observed the influence on the destination. Nevertheless, the limitation of the model was assumed to be that all individuals and trip purposes had the same set of alternatives concerning the destination choices. However, some activities could have been very specific and thus only available in a few areas. In such cases, toll removal may have had no impact because of the decision's inelasticity. This might have affected the model results if it had been the case for many respondents: perhaps more significantly, it could have been overcome by asking about the real set of alternatives for each individual and trip purpose.

4.2.3. Case study research discussion

Embedded multiple case study research was selected to observe the effects on population relocation due to fixed links' opening and toll removal (RQ2a). In *Paper 1*, traffic volumes, population, housing, and labour market data were analysed through time series analysis for two fixed links located close to cities. The data were expanded for up to eleven fixed links with different characteristics, and these were analysed following the difference in difference method in *Paper 3*. Moreover, in *Paper 2* the population prognoses of ten of these fixed links were further compared to real data in order to observe potential discrepancies due to the fixed link projects as well as to identify the variables affecting these discrepancies based on a regression model.

Holistic single case study research was selected to observe the effects on travel patterns due to the toll removal of a fixed link project (RQ2b). Panel data from questionnaires before and after the toll removal for one fixed link (case study 5, Osterøybrua) were analysed through descriptive analyses, logit models, elasticities and time series analysis of traffic counts in *Paper 4*.

Overall, the validity of the case study research could be divided into internal and external validity (Løkke and Sørensen, 2014). The former provides analytical credibility and increases the interpretations' accuracy, being based on checking evidence showing the contrary (Yin, 2009). However, case study is criticised as there is a tendency to confirm the researcher's hypothesis (Flyvbjerg, 2006). Triangulation of data sources supports the case study research, as the phenomenon is observed from multiple perspectives (Knafl and Breitmayer, 1989). This technique facilitates validation through cross-verification from two or more sources (Bogdan and Biklen, 2006), achieving the best convergence when at least three independent sources indicate the same facts or interpretations (Yin, 2009). On the other hand, external validity evaluates theories and extends the results to the context (Løkke and Sørensen, 2014). In fact, theories might help to provide explanations rather than merely descriptions (Dobson, 1999).

Regarding RQ2a, different cases were selected, urban and rural ones, as the consequences of the fixed link projects might differ among them. Moreover, similar areas without these projects were observed to compare the development of certain data and shed light on potential differences and similarities to avoid attributing the consequences of these projects being influenced by external factors. However, finding similar areas was not straightforward, and there were no perfect matches. Triangulation of different data sources, including demographics, the housing market, labour market, and traffic counts, helped to compensate potential bias due to data uncertainty, although these were minor. However, not all the data were available for every case, and thus certain results were only observed in a few cases (at least three). Several data analyses were used to avoid biased results linked to the methods. In sum, the results of the embedded multiple case study research presented internal validity. When it comes to external validity, the results were compared to existing literature when available, as fixed link projects have not been widely explored by researchers.

In contrast, RQ2b was based on a unique case study. No other areas were analysed to verify that the changes observed were due to the fixed link's toll removal. Moreover, the analysis was in relation to toll removal but not to the opening of a fixed link; thus, inconveniences due to dependency on a ferry service had already been removed. Although two data sources, questionnaire and traffic counts, were used, these did not complement one another, as they were used to observed different changes within travel patterns. Therefore, with respect to this research question, internal validity could not be ensured. Nevertheless, a theory was used to improve the results' explanations, finding some similarities and thus external validity for certain results.

5. Discussion of results

In this section, the research questions are discussed based on the results from the five papers included in this thesis. In addition, the traffic volumes in the studied fixed links are presented and discussed.

5.1. RQ1. What are the inconveniences in ferry connections?

The goal of RQ1 was to understand the travel behaviour of travellers using a ferry connection as part of their trips and explain any potential inconveniences, mainly PI, associated with dependency on a ferry. Moreover, the purpose was to find the differences in perception of these inconveniences among the different types of users and its trips' features.

On a national level, trips that include taking a ferry have different features than other trips, as described by Denstadli et al. (2013). Commuting trips are longer than average for ferries connecting rural areas, and the opposite is true for ferries connected to a city. One possible reason for this may be that long waiting times might be a significant drawback for commuting trips since these are daily trips. In this case, the share of commuting trips using ferry connections was lower. This was in line with the shares for trip frequency via a ferry connection, as 1-3 times per month represented the major share. One consequence is that even if the distance covered by the ferry is short, the associated inconveniences reduce the attractiveness of the connection.

The perception of the PI by the users was valued based on a three-point scale of the nine inconvenience factors shown in Figure 6.

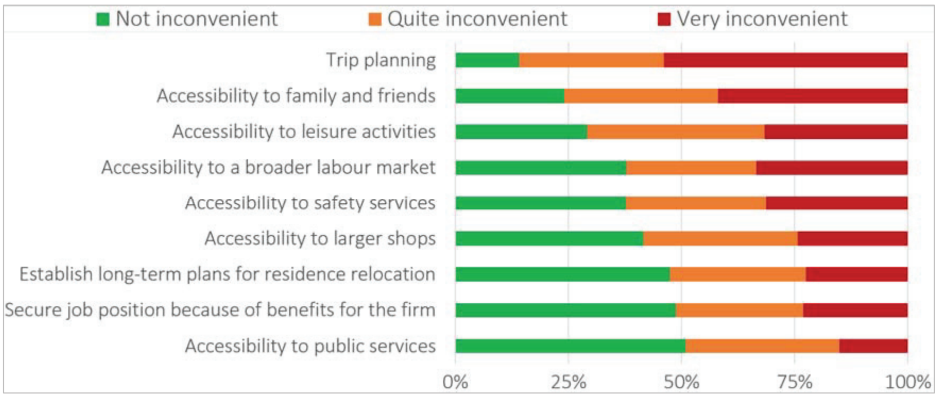

Figure 6: Inconvenience factors and their perception by users

More than 50% of the respondents perceived the factor of trip planning as very inconvenient. This was related to the dependency on the ferry connection. Morton et al. (2016) also revealed that improved frequency, availability and reliability reduce inconvenience among users.

The most important factors regarding the access to activities or services were accessibility to family/friends, leisure activities, and a broader labour market. The latter may involve new job opportunities and better salaries due to competition among employers.

The perception of these inconvenience factors varied across individuals. Similarly, Morton et al. (2016) described socioeconomic background as an influencer on the perception of public transport services' quality.

In relation to the trip features, waiting time was perceived as inefficient; therefore, users spending a lot of time waiting for their ferry were more likely to perceive the inconvenience factors as quite inconvenient. Waiting time was slightly less important for commuters, as they adapted to the ferry schedule, thus a minor part of their total travel time was waiting time.

The frequency of trips via ferry connection played an important role in the perception of the different factors. Frequent travellers considered the factors as very inconvenient with more emphasis on accessibility to a broader labour market and leisure activities. The opposite occurred for less frequent travellers, who considered the factors as less inconvenient but gave more weight to trip planning and accessibility to family and friends. One possible reason for these results may have been that, as trip frequency decreased, users were less affected by ferry connections; that is, because they were not used to the schedules, trip planning became an important part of their trip, as bad planning could result in more waiting time.

Concerning trip purpose, users travelling for private purposes were more likely to consider accessibility to family and friends very inconvenient than were commuters. Travellers on shopping and leisure trips were more likely to perceive accessibility to leisure activities as being very inconvenient when compared to working travellers. In contrast, commuters had a greater likelihood of considering the lack of accessibility to a broader labour market as very inconvenient. Therefore, these results showed that the trip's purpose directly influenced the perception of the related inconvenience factor. Consequently, asking users about the inconvenience factors not related to their trip's purpose might lead to biased results. Nevertheless, respondents might be frequent users of their ferry connection for several purposes. Thus, even if they were travelling during the survey for a certain purpose, they may have been fully aware of the inconveniences of the non-permanent connection for other trip purposes.

Regarding users' socioeconomic backgrounds, younger respondents had a greater probability of perceiving the inconvenience factors as being very inconvenient, while older travellers were more likely to perceive them as being convenient. This might be because older people are more used to existing infrastructures and might therefore be less open to changes than are younger people. Regarding gender, men were more likely to perceive the inconveniences associated with lack of accessibility to leisure activities and a broader labour market. The opposite occurred concerning trip planning, during which women showed a greater likelihood of perceiving this as being very inconvenient. Respondents with higher incomes were more likely to perceive accessibility to leisure activities and a broader labour market as being very inconvenient. These findings may be related to the generalisation that people with higher salaries place a greater value on time, meaning that they are more willing to pay to save time when travelling and reduce any inconvenience generated by ferry connections.

To sum up, ferry connections were used by less frequent travellers than the national average for the same trip distance; therefore, perhaps the commuter share was lower because of the inconveniences associated with dependency on the service. The major PI were related to trip planning and accessibility to family/ friends, leisure activities, and a broad labour market. Users perceived these inconveniences differently. Regarding trip features, longer waiting times and less frequent trips were related to greater inconveniences. Young and high-income users perceived the dependency as being more inconvenient, while gender also depended on the purpose of the trip. The purpose directly influenced the perception of the relevant inconvenience factor.

5.2. RQ2. How is travellers' behaviour affected by fixed link projects?

The aim of this section was to understand the consequences of the fixed link projects on travellers' behaviour, as their accessibility to activities and services were affected. On the one hand, population relocation understood as a permanent change of residence may have occurred due to changes in the housing or labour markets, i.e. linked to land use changes. On the other hand, users might have changed their daily travel patterns, including their number of trips, destination and route as well as mode of transport.

5.2.1. RQ2a. What are the reactions to population relocation?

The fixed links that joined small settlements to cities with more than 50,000 inhabitants within 45 minutes of commuting time experienced a population trend change after the openings. This increase in population was significant when compared to other areas with similar features that did not have a fixed link project. The larger differences were found after toll removal. Analysis of the population relocation indicated that most of the new island inhabitants came from the mainland. This population movement, known as a centrifugal movement, may have been started by people who wanted to keep the benefits of living in an urban area while residing on the outskirts of it, thereby avoiding pollution and noise (Burdett, 2018). This movement has triggered changes in the origin of the trips. That is, more trips are starting in the newly connected areas because of a reduction in the trips having the mainland as origin. Therefore, the effects of the fixed links might have been redistributive effects rather than growth on a regional level (Engebretsen and Gjerdåker, 2010; Louw et al., 2013). Unlike these cases, fixed links in rural areas did not experience additional population growth during the tolling period, also shown in Andersen et al. (2016).

Population growth is usually related to the housing market (Mulder, 2006). In correspondence with urban economic theory, increasing housing demand follows an increase in housing prices. Moreover, improved accessibility might lead to an increased attraction for residential location (Wegener, 2004; Osland, 2010; Simmonds et al., 2011). The housing market experienced an increase in housing prices in all the studied fixed links and caused the difference in growth; the corresponding control groups were larger in the fixed links connected to larger settlements. Nonetheless, one of the five fixed links within urban areas presented a decrease in long-term prices, which could be related to other external factors. These general findings were also in line with previous studies (Laakso, 1997; Christophersen et al., 2000; Andersen et al., 2016). Moreover, improved accessibility to the urban area might have affected the typology of the new constructions, moving from single houses to apartment buildings. Even with the significant increase in population after the toll removal, housing prices did not experience the same increase for the studied fixed links. Prior to these projects, housing prices on the connected islands were lower than on the mainland, increasing the attractiveness of the area for relocating. Future differences in housing prices in both areas may be reduced, and a market equilibrium may be reached.

Relocation of the population to the newly connected areas might not have been related to a job change, as the number of commuters from the connected islands to the mainland grew more than the commuters on the island itself; subsequently, people relocating from the mainland kept their jobs. In addition, shorter travel times allowed people living on the island to obtain more suitable jobs on the mainland. Therefore, fixed links may have widened the labour market, allowing companies to find more specialised workers (Nilsen et al., 2017). Nevertheless, although the number of companies grew steadily, no trend break was found on the studied islands. This could be justified because improved accessibility not only promotes agglomeration but also generates competition (Chen and Vickerman, 2017). Yet, changes in the labour market are normally long-term effects (Wegener and Fürst, 1999), and these data were not available.

Based on these results, fixed link projects, both at their opening and toll removal events, affected population growth on the connected islands. Since forecasts do not include potential changes caused by infrastructure, there are discrepancies with the actual population growth. Figure 7 shows the difference between the real population data and forecast five years after both the opening and toll removal events. The forecasts were made approximately five years before each event.

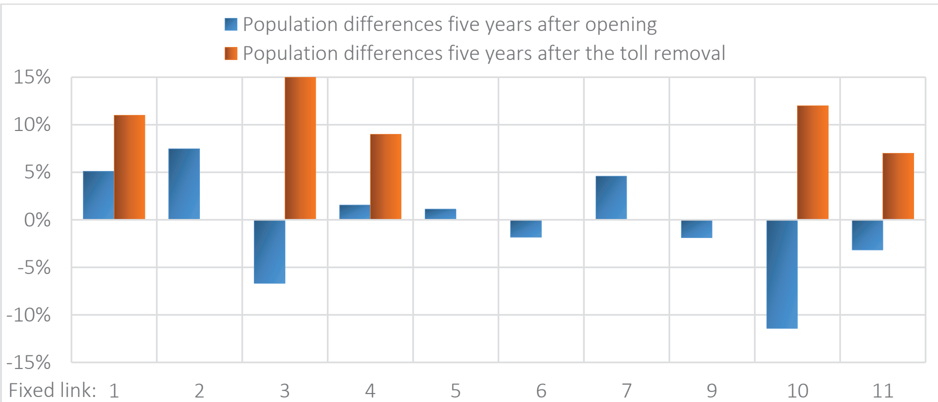

Figure 7: Differences in population forecast and real data (source: Paper 2)

The discrepancies were larger in the fixed links close to urban areas. Nevertheless, in all cases the additional population over the forecast was greater after the toll removal. This corroborated the population trends in the fixed links, which showed a greater trend break after the toll removal. Therefore, the accessibility improvements were not enough, as the toll could play an important part in the decision about population relocation. In fact, the population forecasts were less accurate in the areas affected by fixed links with higher toll fees. The number of jobs was also identified as a significant variable in the discrepancies. In this respect, the forecasts were less accurate when the differences in the number of jobs between the connected island and mainland were larger. This is in accordance with Vickerman (1998), who stated that infrastructure investments may lead to regional economic growth if there is development potential in the industries affected.

To sum up, fixed links projects in urban areas experienced larger population growth compared to similar areas without fixed links than did projects in rural areas. This growth, mostly from the mainland, increased the demand for housing; consequently, prices rose. The expansion of the labour market was also visible, as there were greater numbers of commuters between the islands and the mainland; however, the number of companies was not affected by the fixed link projects in the short term. Population forecasts in Norway do not include changes due to infrastructure projects; subsequently, there are discrepancies with the actual population in areas affected by projects that change accessibility considerably, even more after toll removals. The disparities were larger in urban areas, when job numbers differed between the island and mainland and for high toll fees.

5.2.2. RQ2b. What are the reactions to daily travel patterns?

The Osterøybrua fixed link (case study 5) connected an island to an urban area within an average commuting time. In addition to the fixed link, there was a ferry connection. Given the particular characteristics of the case, it was easy to observe the most widely used route off the island. Due to the fact that only two connections existed, the traffic reduction in one of them was directly related to the increase in the other. The traffic count revealed a 12% change in route for light vehicles because of the reduction in travel cost. Similar findings were found in Knorr et al. (2014).

In addition to the route change, some of the respondents experienced a mode change, switching from public transport to private car. The reduction in travel cost due to toll removal may have increased the attractiveness of using a private car, as even at the same cost, a car is the preferred mode because of the independence it provides (Steg, 2003). Several examples of changes in transportation mode may be found in the literature, especially the shift towards public transport from private car because of a toll (O'Fallon et al., 2004; Ubbels and Verhoef, 2006). In addition, few respondents stated that they had bought an extra vehicle due to toll removal. An increase in the number of available vehicles in the household might have led to a higher car share within the transport mode.

Other changes in travel behaviour due to fixed link projects are variations in the number of trips. The limited connectivity related to ferry connections might cause some people to travel less and optimise shopping trips, for example, buying larger amounts than desired to reduce these types of trips. Therefore, replacing the ferry may generate more trips, because it becomes easier to take them. Simultaneously, toll removal might also generate more trips due to a substantial reduction in travel costs. The panel data did not reveal any changes in trip frequency due to the toll removal. However, this may have been affected by comparing the number of trips between both surveys, as these may have corresponded to different days. Thus, other factors, such as scheduled activities, might have masked the results. Moreover, changes in trip frequency, if these do exist, are likely to occur gradually (TRB, 1995), whilst the second survey was conducted just one year after toll removal.

On the one hand, destination choice was not affected by toll removal. On the other hand, travel time significantly affected destination choice whenever individuals showed a variety of preferences. The potential combination of trips also affected this choice. In the case of commuters, workplace location increased the attractiveness of that area for other trip purposes. Conversely, shopping and leisure trips to an area each affected the destination of other leisure or shopping activities, respectively. Employee density in the leisure sector was also significant for destination choice, whilst it was not in the service sector. This could be explained by the idea that better accessibility to larger urban districts on the mainland might have increased the attractiveness of leisure activities given the greater number of these activities; despite this, only a few shopping options may have been available. This might reflect that certain trip purposes may influence destination choice sensitivity because, for example, the mechanisms behind the decision-making process for grocery shopping differ from those behind occasional shopping (Suel and Polak, 2017).

To sum up, reducing travel cost triggered changes in daily travel behaviour, as there were indications of changes in route and mode of transport. There were signs of changes in car ownership, which could give an indication of long-term effects. Although the data did not reveal trip frequency changes, this could have been due to bias in the questionnaire design. The destination choice was not affected by travel cost reduction in the study case. While other factors, including travel time, workplace location, potential combination of leisure and shopping trips, and employee density in the leisure sector, did affect destination choice. Nevertheless, the observed case was related to the removal of the fixed link's toll and not to its opening; thus, some consequences that were due to the removal of the inconveniences connected to ferry dependency might have already occurred.

5.3. Traffic volumes in the studied fixed links

Fixed link projects introduce variations in the network, for instance total travel time reduction. Therefore, when spending the same amount of time on a trip, the range of available services and activities increases. As previously discussed, accessibility changes trigger changes in people's behaviour, which is reflected in the traffic volumes. Table 5 presents the AADT (light vehicles) on the ferries the year before the opening of the fixed links and the percentage increase in traffic that same year.

Table 5: AADT (light vehicles) at the opening year and the percentage increase (observed after toll removal)*

Fixed link	AADT on the ferry, the year before opening	Percentage increase Years after opening of the fixed link					
		1	3	5	10	15	20
1	260	386 %	324 %	361 %	539 %	1218 %*	1637 %*
2	396	184 %	234 %	275 %	-	-	-
3	2,970	169 %	186 %	203 %	268 %	493 %*	638 %*
4	4,760	120 %	148 %	165 %	198 %	309 %*	348 %*
5	560	259 %	279 %	321 %	438 %	527 %	-
6	942	196 %	197 %	223 %	274 %	-	-
7	960	203 %	224 %	260 %	-	-	-
8	1,490	134 %	146 %	150 %	177 %	158 %	221 %*
9	890	226 %	261 %	283 %	-	-	-
10	940	195 %	207 %	217 %	274 %	397 %*	-
11	340	156 %	162 %	271 %*	362 %*	462 %*	-

Before the projects, the newly connected areas had little interaction with the mainland, as indicated by the ferries' low traffic volumes compared with the traffic on the fixed links. After the opening of the fixed links, there was immediate traffic growth because of greater interaction, which might have been in both directions, i.e. people travelling to the urban area for commuting, shopping or private trips, and people travelling to the islands for leisure trips. In addition to the instant increase, there was a trend break from low/no annual traffic growth to a large growth rate. This may have been an indication of changes in population relocation in the short and medium term.

Toll removal also affected traffic, introducing a new trend break in the growth rate. This change was larger than the one generated by the opening of the fixed link, suggesting that the full benefits of fixed link projects take place after toll removal, when both travel time and cost are reduced.

These traffic data might have served to corroborate the results despite urban and rural areas not presenting any clear disparity. Bråthen et al. (2006) stated that after a reduction in travel cost, connections with low traffic are expected to achieve a more modest traffic growth than those in urban areas having a large proportion of short trips. In urban areas, traffic increase after the fixed link projects' completion might have resulted from population relocation. In contrast, local policies might have played an important role in resulting traffic growth in rural areas. Such policies could be related to centralisation of public services to the mainland, given the added accessibility by the fixed link project, or to the industrial development which might have made certain rural areas a stronger labour market with increased job opportunities.

6. Implications and further research

In this section, a discussion about the inaccuracies in transport models' simulations and its implications for policy decision-making. Moreover, transport models are described in relation to population relocation, and travel patterns as well as potential simulation improvements are suggested.

6.1. Inaccuracies in the traffic volumes

The traffic data do not match the traffic forecast made by the Norwegian transport model, especially on fixed links. An ex-post analysis reflected that the forecast traffic volumes in Finnfast (2) one year after the opening was only 40% of registered traffic. In the case of Rennfast (1), the forecast traffic one year after toll removal accounted for 70% of actual traffic. On the other hand, traffic counts for the fixed link in a rural area, Eiksundsambandet (7), reflected only 70% of the traffic forecast. Other fixed link projects have also shown forecasting inaccuracies in both national and international contexts (Skamris and Flyvbjerg, 1996; Flyvbjerg et al., 2006; Knowles and Matthiessen, 2009; Lian and Ronnevik, 2010; Odeck and Welde, 2017; Welde et al., 2018).

The lack of accuracy in including traffic changes in the transport models generates biased transport assessments (Johnston et al., 2001; Ponnu et al., 2015; Seeherman and Skabardonis, 2016). CBA is a tool used in these assessments, exerting major influence in the planning phase (Jones et al., 2014). It consists of assigning a monetary value to the impacts generated by a new project. These impacts mainly consist of the project's differences in traffic volumes between the actual condition ('do-nothing' scenario) and hypothetical situation. Therefore, the correct simulation of traffic volumes by the transport models plays a crucial role in the CBA. Despite this fact, Manzo et al. (2018) stated that there remain uncertainties that should be quantified before using the results in transport assessments.

Eliasson et al. (2015) found that there is no correlation between the CBA and selection of alternatives in a Norwegian context, as they seem to be politically affected. Traffic volumes and the number of inhabitants affected by potential infrastructure projects were also found to be determinants for the selection of these projects (Sandberg Hanssen and Jørgensen, 2015). This could also be explained by the limitations of CBA, as even with the correct traffic volumes as input, the impacts observed occur only in the primary markets (Banister and

Thurstain-Goodwin, 2011). Traffic volumes might not reflect some effects, including those that are specifically environmental and social (Antonson and Levin, 2018) or wider economic impacts (Legaspi et al., 2015). Transport may affect the economic performance of an area, strengthening agglomerations and allowing regional, city and task specialisation (Venables, 2007), especially in infrastructure projects that change accessibility considerably (Fingleton and Szumilo, 2019), as do fixed link projects. This thesis provided indications that these projects widened the labour market, as there were more commuters in and out of the connected areas . Legaspi et al. (2015) demonstrated that wider economic benefits comprised up to 8% of the CBA. Disregarding the spatial distribution of a project's benefits could result in undesired policy outcomes (Metz, 2017). For example, gentrification might occur when an area or neighbourhood affordable for people with low to average incomes becomes very attractive to businesses and residence relocations because of accessibility improvements. Then, housing prices increase to the extent that some neighbours might not be able to afford living there any longer. Therefore, practitioners are researching the wider economic impacts in order to include them in the CBA (Wangsness and Hansen, 2014). Nevertheless, regional economic growth will be present wherever industry has the potential for growing and the existing transport network represents a bottleneck (Bråthen, 2001).Yet in spite of this situation, Tveter (2018) proved that agglomeration benefits in rural areas are minor.

6.2. Simulating changes in traffic volumes due to fixed link projects

Improving the forecasts yields an understanding of the source of traffic changes due to fixed link projects. There are several discussions on the nomenclature for these changes. The suggestion from Litman (2015) was followed to divide the extra traffic from a transportation network change into generated and induced traffic demand. Figure 8 describes the source of these traffic types.

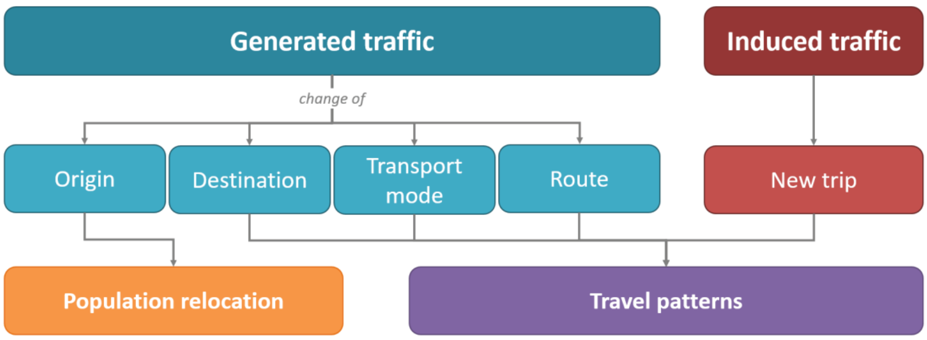

Figure 8: Generated and induced traffic

Generated traffic refers to existing traffic that modifies its route, transportation mode, destination, and/or origin. The latter is related to population relocation, whilst the other three variations occur from changes in travel patterns. Infrastructure projects may also trigger changes in vehicle occupation, as for example a new toll scheme might encourage colleagues to share a private car to commute. Nonetheless, this could be considered a change in transport mode. In addition, while there might also be changes made to the times when a trip is made, this would merely reschedule this trip, and no changes would follow with regard to road traffic volumes.

Unlike generated traffic, induced traffic demands can be explained based on the principle of latent travel demand. This exists when the expected costs of a trip are greater than the expected benefits (Van Der Loop et al., 2016). If latent travel demand exists, more trips are expected after the reduction in the GC because of a transport project.

Generated and induced traffic are generally measured in the literature by the use of elasticities (Goodwin, 1996; Cervero and Hansen, 2002; Hymel, 2019). However, this method provides only marginal information. Other researchers use the changes in vehicle miles driven (VMD) as an indicator of generated and induced traffic (Cervero, 2003). Nonetheless, changes in VMD do not allow identification of the origin of the extra traffic because this origin could account for the extra distance driven by potential changes in destinations or routes. In contrast, the use of transport models might enhance the analysis of the consequences of infrastructure projects, as these models illustrate all generated and induced traffic changes in the entire network when correctly simulated.

6.2.1. Population relocation

Population data are an important input in transport models, as these are used in the first two steps of the model, trip generation and trip distribution, as shown in Figure 9. Therefore, population data influence the number of trips from each origin to each destination.

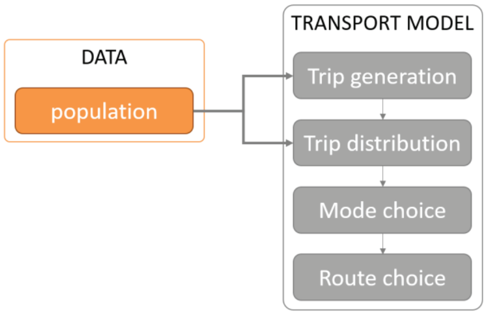

Figure 9: Population in the transport model

Norwegian transport models use fixed population data from forecasts provided by Statistics Norway (Tørset et al., 2013a). This thesis has shown that there are significant discrepancies between the forecasts and real data in areas where a fixed link has been opened; these become even greater after its toll has been removed. One reason for this increase might be that the forecasts do not include population relocation because of accessibility changes. Instead, the trend of the migration patterns over the past 10 years is used (Leknes, 2016). However, as observed in this thesis, population was affected by fixed link projects, i.e. residence relocation did occur. Disregarding this fact might have led to incorrectly simulating the number of trips originating in each area.

Likewise, the data related to workplaces are also fixed in the transport models. These data are used to estimate the number of trips that occur because of an area's attractiveness. Given that fixed links might encourage companies to expand and require more employees, more trips are attracted to certain areas. This is not considered in the current transport models, triggering a potential incorrect simulation of the number of trips attracted to each area.

The conclusion may be drawn that inaccuracies in land use development play an important role in traffic-biased estimations (Flyvbjerg et al., 2006). Understanding the dynamic of the causative processes in land use changes is essential in the previous description of policy and planning implications (Polasky et al., 2011). Although the complexity involved in spatial and temporal land use changes cannot be fully captured by any model (Verburg et al., 2008), research is being done on land use transport interaction models (Iacono et al., 2008; Cordera et al., 2017). However, few transport models include interactions with population forecasts (Ortúzar and Willumsen, 2011). Further research should therefore focus on transforming the fixed population data currently used as input to a dynamic population data subject to accessibility changes.

6.2.2. Travel patterns

Travel patterns are the outcome of people's choices regarding their daily trips. These influence the second, third and fourth steps in transport models, i.e. trip distribution, mode choice, and route choice, as shown in Figure 10. Therefore, travel patterns affect the number of trips generated and attracted to each destination, the share of transport modes between OD, and traffic assignment.

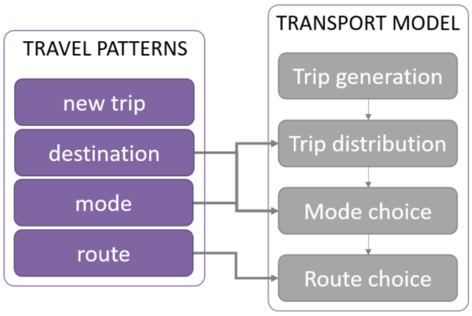

Figure 10: Travel patterns in the transport model

New trip

Traditional four-step transport models do not account for induced traffic, i.e. new trips (Schiffer et al., 2005). There were no indications of induced traffic due to changes in cost after a fixed link's toll removal in this thesis. Alternatively, the opening of these types of projects could induce extra traffic. According to supply and demand theory, latent demand could be considered to be suppressed demand; while there is desire for the trip, there are constraints enabling it (Clifton and Moura, 2017) which could be related to the transport system. For instance, a person with no access to a private car might be limited to participating in activities offered in the locations connected by public transportation. Therefore, simulating the latent demand depends on stated preferences, thereby incorporating all its challenges (Cherchi and Hensher, 2015). Even though including the latent demand in the transport models might improve traffic forecasts, more work is needed to correctly simulate this demand (Cervero, 2002; Clifton and Moura, 2017).

Destination and mode

Norwegian transport models treat destination and mode jointly, as they could influence each other (Tørset, 2012). The choice of the destination and transport mode corresponds to Random Utility Theory. This theory states that an individual associates an index of attractiveness to each alternative, and the choice results in the alternative that maximises this index (Domencich and McFadden, 1975).

Nevertheless, simulating people's behaviour is a complex task which may entail several potential biases. The theory assumes that individuals have perfect rationality, although they do have limitations in their capacity to process information and make calculations (Simon, 1957). Within the transport models' context, it is possible to identify the source of uncertainty whether it falls on the estimation of the attractiveness creating the travel patterns or on the variables associated with the alternatives.

The National Travel Survey (NRVU) is the data source for the estimation of travel patterns in Norway. This survey provides information about daily trips, including: purpose, from-to, departure time, transport mode, cost and travel time (Hjorthol et al., 2014). Moreover, the NRVU provides a certain number of socioeconomic details such as income, gender, age, number of family members and vehicle availability at home, amongst others. When it comes to trips involving ferry connections and/or fixed links, the NRVU's sample is somewhat limited (Statens Vegvesen, 2015). This thesis showed that trips involving ferries were generally longer than average in the NRVU, which might indicate that the behaviour for these trips is different. Given the under-represented nature of these trips, the parameters estimated for the modes' attractiveness might not be completely accurate, meaning the travel patterns associated with ferries might be imprecise. Parameters based on travel surveys including a larger representation of ferry trips could improve their estimation and thus travel patterns.

Moreover, the behavioural consequences of a fixed link project are based on the trends and patterns prior to these projects, which may lead to erroneous assumptions (Bradley and Gunn, 1993). In fact, travel behaviour is associated with and evolves according to travel experiences (Mokhtarian and Salomon, 2001; De Vos et al., 2016; Bláfoss Ingvardson et al., 2018). Companies and services might also relocate, triggering additional changes in travel patterns. These statements were corroborated by this thesis, as there were found non-immediate impacts generated by some fixed link projects. Therefore, not capturing travel patterns' dynamic changes by their interaction with the fixed links might lead to incorrect traffic forecasts. This could be overcome by adding a variable related to the time after the infrastructure's opening or using different parameters according the years after the event in the transport models. Therefore, more ex-post analysis of the behaviour associated with fixed link projects to observe the effects on travel patterns in the short and long term could provide further knowledge for simulating dynamic changes.

Variables that affect the decisions behind destination and mode choice are traditionally quantitative, i.e. time, distance, cost, or socioeconomic features. Waiting time is an important quantitative variable within the choice process. This variable includes open waiting time and hidden waiting time. The former refers to the time that could be registered at the ferry quays, whilst the latter is related to scheduled service inconvenience. Norwegian transport models considered open and hidden waiting time as one unique coefficient equal to half of the headway, although this information has been recently updated. Open waiting time is a function of the headway proposed by Knudsen (1995). This value is lower than half of the headway, being in line with recent studies done by Andersen and Tørset (2017), as more passengers time their arrival at the station (Csikos and Currie, 2008). Hidden waiting time corresponds to the square root of the difference between half of the headway and the open waiting time. Nonetheless, improving the differentiation between hidden and open waiting time in relation to service type might improve the transport models (Eltved et al., 2018).

Yet, qualitative variables, for example comfort and reliability, are quite significant when travellers are to make a destination and mode choice (Litman, 2008). This thesis showed there were inconveniences which, although indirectly measured, related to the trips with ferry connections, such as trip planning to match the ferry schedules, and lack of accessibility due to dependency on a non-continuous connection. Therefore, when ferries are replaced, simulated users do not perceive the extra benefit or reduction of these PI, leading to biased traffic forecasts.

As previously mentioned, inconveniences in Norwegian transport models are partially covered by the concept of IC. On the national level, the IC are added as a multiplying factor to the travel time on-board ferry connections (Statens Vegvesen, 2018). The travel time is also multiplied by the value of time, which mainly differs according to trip purpose. One potential shortcoming here is that different types of users might perceive IC differently, independent of travel time, and the perception of the IC and value of time might not be the same relationship. For example, the value of time is greater for commuting than for leisure trips (Samstad et al., 2010); however, this thesis showed that commuters were likely to perceive the IC as less inconvenient. Trip and socioeconomic characteristics also affected the perception of the IC, thus aggregating them might entail inaccuracies. On the regional level, the IC are generally directly included in the CBA (Statens Vegvesen, 2018). This thesis showed that people travelling with ferry connections perceived their dependency and reduced accessibility as being inconvenient, which may affect their travel patterns and, as a result, traffic volumes. Therefore, disregarding the IC when simulating traffic may lead to inaccurate volumes used as input in the CBA.

Further research should focus on including all inconveniences directly in the transport models, which would prevent a potential double count concerning waiting time. Inconveniences should differ among the ferries' location as well as users' trip and socioeconomic backgrounds. This thesis does not provide a quantitative factor for the different inconveniences; consequently, a stated preference (SP) survey could quantify the willingness of ferry users to pay for a permanent connection based on relevant trip and socioeconomic information. Nonetheless, results from this thesis might complement the obtained values, as these quantified the difference in perception among the different variable categories.

Route

Once users have decided their destination and transport mode, the route choice or traffic assignment is used to quantify the traffic volumes on the network's different roads. The assignment consists of allocating these trips within the alternative route sets, generally following an iterative process where the simulated users select the route that minimises their travel time until an equilibrium is reached, i.e. users cannot reduce their travel time by choosing another route (Wardrop, 1952).

Therefore, travel time is the key element in route choice, waiting time being a part of this time. The transport models use half of the headway as waiting time with a maximum of two hours, thus not differentiating between open and hidden waiting time. As stated above, simulating the waiting time more precisely would reduce uncertainties in the forecast traffic volumes (Eltved et al., 2018).

At the same time, the models do not account for the ferries' capacity limitations. As a result, the simulation does not take into account the fact that a person might have to wait for the next ferry (Tørset, et al., 2013). The implication of this shortcoming is that the model will simulate more demand than there is. Nevertheless, this is only relevant for a few infrequent ferry connections, or at peak periods, as was the case for Ferries a and b in this thesis, which had capacity problems during certain months of the year. To compensate for this limitation, the model could include an extra component as part of the waiting time when the traffic on the link before the ferry quay exceeds the ferry's capacity.

This thesis showed that there were inconvenience factors associated with the ferry connections, and thus when replaced, behavioural elements might take place in the route choice that are not included in current traffic assignments. This may lead to a certain amount of bias, especially when some of the alternative routes entail features that may influence users' psychological perception. Therefore, improving knowledge of the PI and using behavioural theories for route assignment, for instance logit models, could be a further step to take in the research process.

7. Conclusion

Ferries were associated with inconveniences, and the PI depended on trip purpose and were more significant for trips with longer waiting times and low frequencies as well as for young and high-income users. The replacement of ferry connections was associated with inconvenience suppression and hence, consequences in people's behaviour were expected. In particular, there was population growth related to higher housing demand, leading to an increase in housing prices. There was also an expanded labour market reflected in the increased number of commuters travelling to and from the connected areas. Regarding travel patterns, when a toll was removed from a fixed link, this removal led to changes in mode and route choice, although destination and trip frequency were not affected.

Following survey research, this thesis contributed to the literature identifying inconvenience factors and quantifying the differences in the perception of these factors according to users' socioeconomic backgrounds as well as the trip features themselves. The findings could be considered as representative for ferries along the E-39 corridor, and other ferry types could thereafter be further studied.

This thesis also contributed empirical evidence to the literature by analysing eleven ex-post fixed link cases through an embedded multiple case study research design. The analysis allowed observing population relocation because of inconvenience removal and shedding light on the variables affecting the discrepancies between the actual and forecast population. Moreover, changes in the housing and labour markets were also observed. These findings were assumed to be valid given the multiple sources of data and triangulation of the data analyses.

In addition, this thesis used a holistic single case study research design to identify changes in travel patterns because of a toll removal in a fixed link. It was possible to detect changes in trip frequency, destination, mode, and route. Nevertheless, the findings could not be generalised due to the fact that they were based on a unique data source, and there was no triangulation within the data analyses. Further research should focus on observing more cases, including the event of the fixed links' opening.

These findings were used to discuss potential limitations of the current transport models, suggesting areas where the research should focus on improving traffic volume forecasts. The most relevant would be to develop a land use transport interaction model and more accurately include all inconveniences in the transport models, estimating the willingness to pay for a permanent connection regarding different travellers and trip features. Better simulation of traffic volumes would translate into better transport assessments.

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PART 2

Paper 1

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 10 (2015) 286 – 295

Transportation Research Procedia

www.elsevier.com/locate/procedia

18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015, Delft, The Netherlands

Impacts on land use characteristics from ferry replacement projects. Two case studies from Norway

María Díez Gutiérrez [a,*], Stig Nyland Andersen [a,b], Øyvind Lervik Nilsen [a,c], Trude Tørset [a]

[a]*Norwegian University of Science and Technology, Department of civil and transport engineering, 7491 Trondheim, Norway*
[b]*Norwegian Public Roads Administration, Askedalen 4, 6863 Leikanger, Norway*
[c]*Rambøll, Fjordgaten 15, 3103 Tønsberg, Norway*

Abstract

Fixed links projects are bridges or tunnels that connect two areas separated by geographic barriers. Fixed links reduce dramatically the travel time and provide reliability and flexibility, as often they replace ferry services. This might impact on land use characteristics and travel behaviour. We aim to explain these impacts by making time series analyses of empirical data on two fixed links that connect islands to the mainland on the west coast of Norway. We find that changes in travel time and cost might generate an increase in the attractiveness of the municipalities connected by the fixed links, leading to an increase in population. The greater demand for housing triggers a growth in square metre price for dwellings and construction rates. There is also a higher annual traffic growth than the experienced before the fixed link was opened. Despite that, we do not find either an additional increase in the number of companies or changes on number of employees in the existing companies.

Peer-review under responsibility of Delft University of Technology

Keywords: Fixed link, regional development, land use, housing market, labour market, population

1. Introduction

Fixed links are bridges or tunnels that join areas previously separated by geographic barriers, e.g. fjords. Fixed links might cause significant travel time savings since they often replace ferry services. They remove waiting time, increase speed of travel and provide a flexible link 24 hours 7 days a week. In addition, it is less likely that a fixed link would close due to bad weather conditions. The technology advances make it possible to build longer and more challenging fixed links and, hence, the number of planned fixed links projects have been increasing in recent years. The west coast of Norway is an example as seven ferry crossings are planned to be replaced by fixed links (Statens vegvesen, 2012). This paper aims to improve the knowledge on how these infrastructures affect land use characteristics and society.

* Corresponding author. Tel.: +47-47735050 ; mail: maria.diez@ntnu.no

Peer-review under responsibility of Delft University of Technology
doi:10.1016/j.trpro.2015.09.078

Fixed-link impacts have been scarcely studied; nonetheless the weakness of the traffic forecast models have been highlighted in Norway by Tørset et al. (2013) and in Denmark by Knowles and Matthiessen (2009). Some ex-post evaluations of fixed links have shown the inaccuracies of the forecasts. The traffic over the international fixed link of The Channel Tunnel between England and France was lower than 50% of what was forecast even five years after the opening (Flyvbjerg et al., 2006). The traffic on the Øresund bridge between Denmark and Sweden was only 81% of the expected traffic the opening year. In contrast, the traffic on the two Danish projects the Great Belt Fixed Link and the Sallingsund Bridge exceeded the forecast by 73% (Knowles and Matthiessen, 2009) and 27% (Skamris and Flyvbjerg, 1996) respectively. In Norway, Trekantsambandet presented an overestimation by 40% and the North Cape by 20% (Lian and Ronnevik, 2010).

The over/underestimation of traffic volumes in the forecasts can be partly explained by the inaccurate prediction of the willingness of the users to pay for a fixed link (Bråthen and Hervik, 1997). This is also mentioned in Knowles and Matthiessen (2009) whose study stresses the lack of data on the physiological effect of substituting a ferry with a fixed link. In the study by Flyvbjerg et al. (2006) 208 road projects, fixed links among them, were evaluated by ex-post analysis. They found that the main reasons for the forecast inaccuracies are within trip distribution and land use development. There is little empirical data explaining changes in destination choice from infrastructure projects. In Norway, population forecasts from Statistics Norway are the key input factors for calculating traffic generation in the transport model. In the current methodology, the model uses the same population forecasts regardless of the possible impact on land use characteristics and society.

Interaction between infrastructure improvements and land use changes has been previously highlighted in Banister and Berechman (2001) and Geurs and van Wee (2004). According to Vickerman (1998) fixed links can promote regional development and cohesion. Integrating communities might widen and optimise the labour market (Louw et al., 2013). This may lead to redistribution rather than growth in the labour market (Gjerdåker and Engebretsen, 2010) (Louw et al., 2013) which is often evident in the commuting data. Our research question for this paper is: What are the possible impacts on land use characteristics and travel behaviour by fixed links, in a Norwegian context? We expect that a fixed link increases the interaction between the affected areas, triggering growth in population and housing market. Moreover, we presume an increase in the number of companies; a wider labour market might result in a growth in commuting between the affected areas.

This paper aims to contribute to the research on fixed link impacts by analysing and combining several types of empirical data over a long time period. The analysed data are traffic volumes, commuting patterns, population, construction and sales of dwellings, and company data. Unlike most of earlier studies, we focus on islands, which have a defined influential area. In addition, we also compare the cases to similar areas without the influence of a fixed link.

In this paper we investigate the ex-post impacts of two fixed links in Norway, presented in chapter 2. In chapter 3, we explain the methodology and the data. The results from the analysis are presented in chapter 4, where we observe possible trend changes before and after the opening of the fixed links. Furthermore, in chapter 5 we discuss the pattern variations, and how the impacts of the fixed links may affect the inaccuracy of the traffic estimations. Chapter 6 comprises the conclusions of this study.

2. Case studies

In this paper, we examine two fixed links, which connect the main islands of the municipalities of Rennesøy and Finnøy to the mainland in the Stavanger area. The study is conducted at municipality level as shown in Figure 1.

We look at a total of six municipalities or regions. Kvitsøy and Strand are municipalities still connected to the city of Stavanger by ferry services. The mainland is divided into two parts; the Stavanger, Sola and Sandnes region (SSS-region) and Randaberg. The SSS-region is well-integrated with a common labour and housing market, thus we look at it as a single entity. We look at Randaberg separately since both fixed links from Rennesøy and Finnøy are joined to the mainland on this municipality.

Figure 2 shows the different connections from the mainland to Rennesøy and Finnøy for three different periods.

Before 1992, Rennesøy and Finnøy were only connected to Stavanger by ferry services, presumably with a frequency of 4 trips per day. The travel time from Rennesøy (Vikevåg) to Stavanger was approximately 150 minutes, including 30 minutes waiting time, with a fee of 148 NOK. The travel time from Finnøy (Judaberg) to Stavanger was

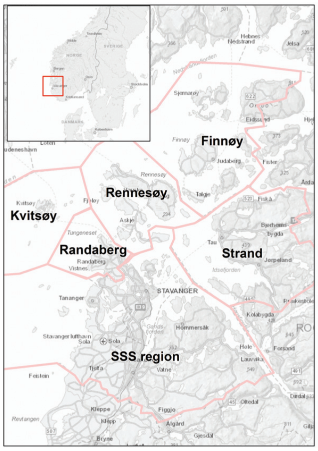

Fig. 1. Location of the case studies area and studied municipalities

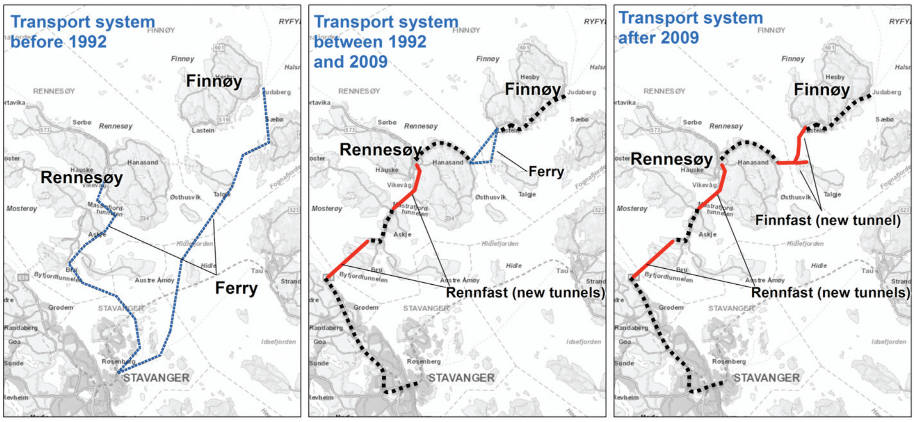

Fig. 2. Description of the transport system (a) before Rennfast (1992), (b) before Finnfast (1992-2009) and (c) after Finnfast (2009)

approximately 180 minutes, including 30 minutes waiting time, with a fee of 208 NOK. The only connection between Rennesy and Finny was through Stavanger, with a travel time of 330 minutes approximately.

In November 1992 the fixed link Rennfast replaced the Stavanger-Rennesøy ferry service. The toll fee was similar to the previous ferry fee, whereas, the travel time dropped to about 25 minutes. Finnøy became connected to Rennesøy by a new ferry with a higher frequency (14 departures per day). The travel time from Finnøy to Stavanger was reduced to 90 min, including 20 minutes of waiting time, with a 60% reduction of the ticket fee. The travel time between Rennesy and Finny was reduced dramatically to 65 minutes.

In 2006, the toll collection at Rennfast was removed.

In October 2009 the fixed link Finnfast replaced the Rennesøy-Finnøy ferry service. The toll fee was almost 300% of the previous ferry fee, while the travel time decreased to 25 minutes. Moreover, the travel time between Stavanger and Finnøy decreased to 40 minutes.

In 2011 the toll fee at Finnfast was reduced by 25%.

3. Research approach

3.1. Research methodology

The variables selected in the analysis aim to cover a wide range of potential changes in traffic and land use characteristics. We divide them into five main groups: traffic volumes, commuting patterns, population, housing, and labour market.

Fixed link projects might affect the variables at different time periods. Alam et al. (2005) suggested that the interaction between infrastructures and land use characteristics may be perceived in terms of short, medium (6-8 years) and long term effects (15-20 years). This is also mentioned in Wegener and Fürst (1999), where the impacts are divided into very slow, slow, fast and immediate changes. The Organisation for Economic Cooperation and Development (OECD) stresses that ex-post evaluations should be carried out over a long period of time (OECD, 2002). Therefore, we look at the variables from the furthest possible back in time point until 2013/4 in order to detect all possible changes.

Our methodology consists of a time series analysis of the empirical data. We focus on observing the trends and identifying potential pattern changes caused by the fixed link projects. In these case studies, fixed links connect islands which facilitate the identification of the influence area. We validate our findings by testing the hypothesis that the slopes before and after the infrastructure changes are equal. Moreover, we test whether the slopes of the affected municipalities and reference areas are equal. In case of similarities, the changes might be explained by external factors, such as policies or GDP growth for example. Additionally, we combine different variables and hence unclear patterns might be better explained. Doing so, we should get some indication of the impacts of the fixed links in a prior, immediate, short and medium term perspective. The description of each data type, assumptions and specific methods are described below.

3.2. Traffic volumes data

Traffic volumes on the ferries are based on counts provided by the ferry companies from 1986. These counts are mainly from electronic ticketing. However, there are still a few ferries using manual registration, which may lead to potential inaccuracies (Statens vegvesen, 2014a). Traffic volumes on the fixed links are registered from counts by Statens vegvesen. A possible source of error might be the vehicle classification. Before 2001, vehicles on the ferries were classified according to its type (i.e. car, bus). Afterwards, the classification was based on the vehicle length (Statens vegvesen, 2014a). However, the new classification of the road traffic counts started in 2007 (Statens vegvesen, 2014b). We assume that light traffic consists of passenger cars with and without trailer, vans, and vehicles shorter than six metres.

We analyse the average annual daily traffic for light (passenger) and heavy (goods) vehicles, independently. We assume that the traffic volumes to Rennesøy or Finnøy are the volumes on the fixed link minus the traffic on the ferries starting on the islands towards the north. Nevertheless, some traffic volumes on the ferries might have started the trip on the island and hence were not registered in the fixed links. As a consequence, the estimated traffic volumes may be less than the real. Despite that, we assumed that the difference is small so it might be ignored. Traffic volumes are presented in a time series graph in four periods divided by the opening of Rennfast, its toll removal, and the opening of Finnfast. Potential trend changes are verified by linear regressions and the observed volumes are compared to the estimated following these regressions.

3.3. Commuting patterns data

Employee data consist of the number of residents in one municipality working in the others. They are based on several databases from 2000. A possible source of error is that administrative formalities might take some time, so a person may not be registered as an employee even if he/she was employed the year before. Employees registered in the End of the Year Certificates Register (approx. 10%) have not registration on dates, so it is not possible to know when the person started working. For larger enterprises with several establishments this may cause employees to be incorrectly registered as employed by the wrong establishment (Statistics Norway, 2015b). Finnøy municipality includes other islands not connected by the fixed link, and thus few commuters are not affected by the fixed links.

We analyse the development in commuting to/from/within the municipalities. We use index 100 in 2000 to visualize the relative changes of the commuters among the municipalities. We test the significance of the differences between the slopes of the number of commuters along the period and if there is a trend break.

3.4. Population data

Population data consist of the number of people residing in each municipality by age ranges from 1986. The statistics are based on population register data from Statistics Norway. Some errors in the registration of the data might occur but these are minimal (Statistics Norway, 2015c).

We analyse the population rates, total and working age, to detect possible changes due to the opening of the fixed links. Population numbers have a large variation among the municipalities, therefore, we represent them using index 100 in 1986. We also test the significance of the difference between the population trends of the municipalities.

3.5. Housing market data

Housing market data consist of the registered sold dwellings from 1990, collected from the Land Registry and Cadastre. A possible source of error is that the properties are registered after the sale has taken place, so for sales late in the year they might be registered the following year. Moreover, some of the properties do not have information about the size and/or the sale price. Moreover, a sale can consist of several buildings both residential and other, e.g. agricultural buildings. The data regarding new buildings are registered in Statistics Norway from 2000. A possible source of error stems from the data registration itself and from the classification of type of dwellings (Statistics Norway, 2015a). The housing data in Finnøy refer only to the two islands (Finny and Talgje) connected by the fixed link. We also observe the Norwegian interest rate (Norges Bank, 2015) to relate possible variations to national trends.

We analyse the average square metre price per year of residential houses in each municipality. The data present fluctuations that makes it difficult to observe the trends. Therefore, we use a smoothing method based on the average medium (three values) to reduce the sensitivity of the data. We test the significance of the difference between the trends of the municipalities and look at the relation with the interest rate. We represent the square meter price by the index 100 in 1993. We also observe possible changes in the typology of new dwellings at municipality level.

3.6. Labour market data

Company data consist of all the companies registered in the Brønnøysund Register Centre on the last day of each year since 1996. A possible source of error is the lack of data regarding the company classification, number of employees and profits, depending on the area and the company size. Hence, it is not possible to generalise about these variables, although they are observed as they might indicate the general trend. Another possible source of error is that self-employed individuals might register their home address instead of the firm location. Only the two islands of Finnøy connected by the fixed link are observed.

We examine openings, relocations and closures of firms in the period. We test the significance of the difference between the number of companies in the municipalities. We also look at the types of companies in terms of sector activity (agriculture, forestry and fishing; manufacture; construction; transportation; accommodation, food and leisure activities; shops; other). In addition, we observe the changes in the number of employees for the studied areas.

4. Results

Table 1 summarises some of the impacts that fixed links have on the affected areas (Rennesy, and Finny). They are represented as differences in cumulative percentage increase using as base years the opening of Finnfast (2009), opening of Rennfast (1992) and the toll removal of the latter (2006). Observed traffic volumes are compared to those expected without the infrastructure change. Commuters outside the islands are compared to the commuters within the municipality. Population, square meter price and number of companies in Finnøy and Rennesøy respectively, are observed in relation to the average population for the reference areas (SSS-region, Strand, Randaberg, and Kvitsøy). Nonetheless, SSS-region is not included in the number of companies, neither Kvitsøy in the analysis of the square metre price due to lack of data.

Table 1. Summary of the fixed link variables over the observed periods

		2-1years before	0-1years after	2-3years after	4-8years after
Traffic volumes	*Open Finnfast*	+	+	+++	++++
	Open Rennfast	0	+	+++	++++
	Toll removal Rennfast	0	+	++	+++
Commuting patterns	*Open Finnfast*	0	+	++	++
	Open Rennfast	n/a	n/a	n/a	n/a
	Toll removal Rennfast	++	+	+++	+++++
Population	*Open Finnfast*	+	+	+	+
	Open Rennfast	0	0	+	++
	Toll removal Rennfast	0	+	++++	+++
Square metre price	*Open Finnfast*	+	+	+	+++
	Open Rennfast	n/a	n/a	++	++++
	Toll removal Rennfast	++	++	++++	+++
Number of companies	*Open Finnfast*	+	+	+	+
	Open Rennfast	n/a	n/a	n/a	n/a
	Toll removal Rennfast	+	+	+	+
n/a No data / 0 No change / + 1-5% / ++ 5-15% / +++ 15-30% / ++++ 30-50% / +++++ 50-75%					

4.1. *Traffic volumes*

Figure 3 shows the changes in average daily traffic volumes to Rennesøy (left) and to Finnøy (right). Five years after the opening of Rennfast, the observed volumes were around 50% more than following a linear regression prognosis without the fixed link. Traffic volumes to Finnøy also increased, as Rennfast became part of connection between Stavanger and Finnøy. After the toll removal of Rennfast in 2006, the traffic volumes to both islands rose with a higher rate than previous years. In Rennesøy, the additional growth in traffic volumes was 20% more than following a linear trend maintaining the toll. After the opening of Finnfast in 2009, the annual traffic growth remained at the same rate. After 2011, the traffic volumes to Finnøy experienced a similar increase than the growth in traffic to Rennesøy after its fixed link was opened.

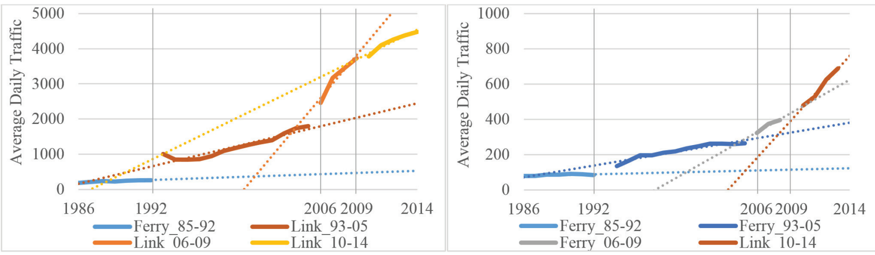

Fig. 3. Traffic volumes (a) to Rennesøy and (b) Finnøy. Data adapted from Statens vegvesen (2014a) and Statens vegvesen (2014b)

4.2. *Commuting patterns*

There was an annual growth of commuters to the mainland from all the studied municipalities since 2003. Rennesøy experienced the largest increase. Finnøy and Kvitsøy had a similar steady growth, although the few commuters in Kvitsøy leaded to some fluctuations. Strand had the lowest annual growth in the period. Commuting numbers between Rennesøy and Finnøy were low and showed very little change.

The number of commuters from/to Rennesøy to/from outside started growing more than the commuters within the municipality a couple of years before the toll removal of Rennfast. The hypothesis that both growth rates were equal can be rejected with a confidence level larger than 95%. The extra growth in cumulative percentage increase reached more than 50% five years after. In the case of Finnøy, there was an additional growth mainly in commuters from Finnøy to outside, 15% five years after the opening of Finnfast.

4.3. Population rates

Figure 4 shows the population changes. The population growth in Rennesøy and Finnøy presented a significant different than the growth in the reference municipalities with a confidence level larger than 95%. There was an increase in Rennesøy population after the fixed link Rennfast opened in 1992. The largest growth was experienced within the working age group (16-67 years). The toll removal of Rennfast in 2006 triggered an increase in the growth. The hypothesis that the growth rates before and after were equal can be rejected with a confidence level higher than 95%. The greatest increase in population was in Rennesøy five years after the toll removal, experiencing a growth of 12% more than the reference areas. Finnøy also presented a trend shift from a modest decrease until 2007 to an increase in population.

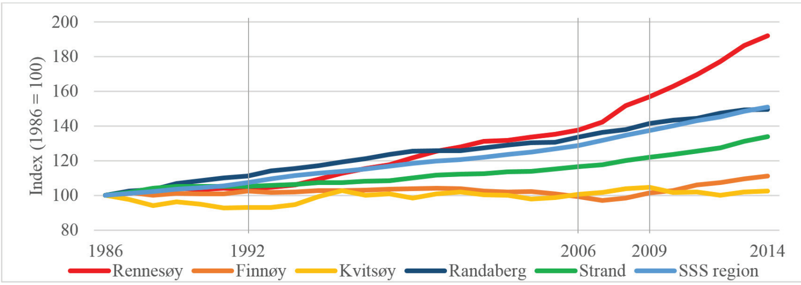

Fig. 4. Population index (1986=100). Data adapted from Statistics Norway (2015c)

4.4. Housing market

Finnøy and Rennesøy experienced an increase in the construction of residential buildings two years before the opening of the fixed links. The growth was higher compared to the neighbouring municipalities after the toll removal in Rennfast and the opening of Finnfast. There was also a change in the construction of new houses towards higher density dwellings, such as apartment buildings, in both islands.

Figure 5 shows the development of the square metre price in the six studied areas and the Norwegian interest rates. When the interest rates decrease there is an increase in the demand for loans to buy houses. The larger property demand triggers an increase in the square metre prices. Conversely, both the interest rate and the housing prices in Rennnesøy grew from two years before the toll removal in Rennfast. Between 2008 and 2011 there was no price change in Rennesøy, while the others areas experienced a slight growth. After 2011, the prices in Finnøy grew significantly more than in the rest of areas.

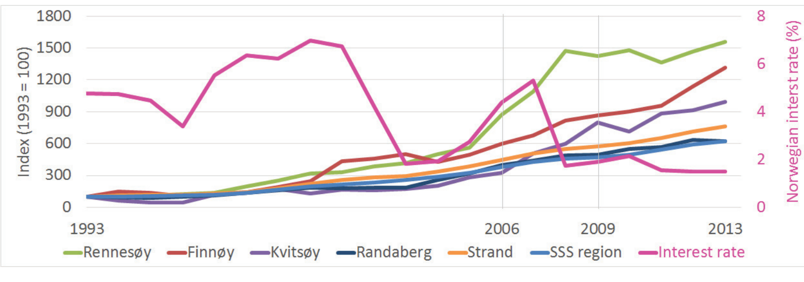

Fig. 5. Square metre price (smoothing) index (1993=100). Data adapted from the Land Registry and Cadastre. Norwegian interest rate adapted from Norges Bank (2015)

4.5. Labour market

Rennesøy experienced a growth in the number of companies of 183% from 1996 to 2012. This growth was larger than in the neighbouring municipalities. However, there was no trend change due to the opening of the fixed link or toll removal. The hypothesis that the growth rate before and after were equal can be rejected with a confidence level larger than 95%. The increase after 2008 was mainly due to relocation of companies moving to Rennesøy rather than the establishment of new companies. Finnøy did not experience significant changes in the number of companies during the analysed period. Agriculture, forestry and fishing companies dominate the labour market, representing more than the 35% of the total in Kvitsøy, Rennesøy, and Finnøy in 2000. After 2000, the three municipalities experienced a decrease in the share of this type of companies as the number of construction companies increased faster.

5. Discussion

In this paper, we analyse some variables in order to explain changes in land use characteristics and travel behaviour caused by the opening of fixed links. Despite the singularity of these case studies, the findings might be generalised to other infrastructure projects that join areas geographically separated in countries that have people with similar behaviour. Nevertheless, this paper only observe two cases. Another limitation is the lack of data prior to the opening of Rennfast (1992) for some of the variables. Moreover, both case studies are neighbouring islands and might influence each other. The toll removal at Rennfast was only three years before Finnfast opened, and hence it is difficult to separate the effects caused by either of them, particularly for the municipality of Finnøy. In addition, the toll of Finnfast was reduced by 25% two years after the opening of Finnfast.

This research might serve as reference in the way of analysing the empirical data and observing the relations between the potential variables that are affected by fixed links. The methodology selected is time series analysis, looking at the trends over a period of time, before and after the opening of the fixed links. This allows us to detect when the changes actually happen. The use of several variables make it easier to relate the changes and support the findings. In addition, we compare the development in the areas affected by fixed links to other unaffected areas. The case studies are islands, which make easier to identify the area of influence.

The results from the case studies reveal several interesting variations in the regional development. Some changes seem to happen instantly or even some years before the opening of the fixed link, whilst others happen after some years.

Prior effects(2-1 years before the opening of the fixed link and toll removal)

The population in Finnøy started growing slightly more than the average in the reference group two years before the opening of Finnfast. The reason might have been that people were aware of the upcoming opening of the fixed link to Finnøy. Nonetheless, that trend shift in population may have been a consequence from removing the toll of Rennfast rather than the new fixed link opening. On the other hand, Rennesøy did not experience population changes before the opening of Rennfast. Regarding the housing market, the expected travel time savings may have caused a growth in the attractiveness of the municipalities. Christophersen et al. (2000) and Laakso (1997) showed that the improvement in accessibility leads to an increase in housing prices. The increase in housing prices in Finnøy might have been triggered by the decrease in interest rates rather than the upcoming opening of the fixed link. Also supported by a similar increase in the reference municipalities. Conversely, Rennesøy experienced an increase in the housing prices a couple of years before the toll removal in 2006. This increase was extraordinary compared to other nearby municipalities. In this case, it might have been related to the reduction in travel costs since the interest rate also increased. Therefore, regional development might be promoted not only by improvements in travel time but also in travel costs.

The population growth generated an increase in traffic volumes from/to the island. The number of commuters from Rennesøy to the mainland started to increase at a higher rate a couple of years before the toll removal of Rennfast. The same was experienced in Finnøy and Kvitsøy while being connected to the mainland by a ferry service. Thus, it might have not corresponded to a fixed link impact, but rather to a more general growth in the demand for labour on the mainland.

Immediate effects (0-1 years after the opening of the fixed link and toll removal)

The population in Rennesøy experienced a trend shift towards a greater growth after the toll removal compared to the reference group. In contrast, the population in Finnøy grew following the same trend as two years before the opening of Finnfast. The reason might have been explained by the fact that the population in Finnøy started growing more than the average of the other municipalities some years before. Other studies also reveal different population reactions after the opening of a fixed link. Population changes are found in Meijers et al. (2012) but not in Gjerdåker and Engebretsen (2010). Regarding housing prices, the growth remained similar to previous years.

The growth in traffic volumes to Rennesøy immediately after the opening of the fixed link and the toll removal might have been explained by the increase in population or changes in travel destination for existing trips, since the number of commuters remained practically constant. An immediate increase in traffic volumes was also experienced in other fixed link projects close to major cities in Norway as described in Statens vegvesen (2012). There was an increase in the number of commuters from/to Finnøy. This was probably caused by the new residents who maintained their jobs in the mainland. This hypothesis might have been supported by the absence of changes in the growth rate for number of employees on both islands. Nevertheless, there was no trend shift in the traffic growth to Finnøy after the opening of Finnfast. The reason might have been due to the high toll fees, three times more than the fee of the prior ferry service. Hence, the number of leisure or private trips from/to the mainland might have been reduced.

Short term (2-3 years after the opening of the fixed link and toll removal)

While the population growth in Finnøy remained constant, Rennesøy experienced a larger increase in a short term perspective after the opening of the lixed link. The greatest increase in population occurred three years after the toll removal of Rennfast. Increased demand for housing might have contributed to the increase in square metre price. Moreover, there was a change in the construction type from single unit houses to apartment buildings. This might have been influenced by either the closer connection to the urban area, or a widening of the housing market.

The traffic volumes to Finnøy increased in 2011, rather than a short term effect it may have been due to the reduction of the toll fee by 25%. This might have caused a change in the destination pattern, as the number of possible destinations increased within acceptable travel cost. Moreover, previously combined trips might have been also separated. As a result, the interaction from Finnøy to Rennesøy and the mainland and vice versa may have increased. Hence, it is again supported the idea that reducing travel costs may promote regional development and cohesion. There was a slight growth in commuters to/from Finnøy a few years after the fixed link opened. It might have been interpreted as an indication of a more integrated labour market where the skills of the workers correspond better with the requirements of the employers. Growth in commuting due to accessibility improvements are also found in Gjerdåker and Engebretsen (2010) and in Louw et al. (2013).

Medium term (4-8 years after the opening of the fixed link and toll removal)

Medium and long term effects are often associated to labour market. However, Rennesøy had no indications of impacts caused by fixed links on the number of companies or in a change in the sector type. This findings are supported by the studies of Gjerdåker and Engebretsen (2010) and Meijers et al. (2012) which did not find either impacts on labour market. Nonetheless, the studies of Mackie and Simon (1996) and Bråthen and Hervik (1997) found impacts on the labour market caused by fixed links.

Can these impacts explain the inaccuracy of traffic volumes forecasts?

In the case of Finnøy, a population increase might have impacted on the traffic to/from the island and therefore, also on the traffic analysis of the fixed link. In the traffic analysis of Finnfast carried out by the Norwegian Public Roads Administration, they estimated an increase in traffic volumes by 150% from 2009 to 2033 after the tolls were removed (Statens vegvesen, 2009). Nonetheless, if the trend from our time series analysis is prolonged, the traffic volumes would probably reach this level in a few years even with the high tolls on the link.

The estimated traffic volumes in Rennfast were not available.

6. Conclusion

The time series analyses indicate that fixed links do impact on population, housing market and peoples behaviour. Better accessibility generates local development for the areas newly connected, as there might be a change in the destination for private and/or leisure trips. The housing market is affected a few years before the opening of the fixed link, increasing the square meter price and the construction rate of new dwellings. The population increases considerably after the reduction in travel time caused by the fixed links and after the reduction in travel costs caused by the toll removal.

The official Norwegian transport model does not account for new infrastructures as a potential factor for changes in population or land-use characteristics. As a result, there is an over/underestimation of the traffic volumes, also affecting the cost-benefit analysis. This leads to problems in the calculations of the toll fee and road capacity as both are based on traffic volumes. Our analysis shows that in the case of fixed links, changes are significant. These impacts should be included in transport analyses for more accurate assessment of fixed links.

This paper recommends observing the changes on the studied variables for more fixed link projects, using a time series analysis. In addition, we recommend eventually establishing a method to include land-use changes in the transport model.

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Transportation Research Procedia 14 (2016) 4468 – 4477

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Modelling the impacts on population caused by fixed link projects

María Díez Gutiérrez [a,]*, Stig Nyland Andersen [a,b], Øyvind Lervik Nilsen [a,c], Trude Tørset [a]

[a]Norwegian University of Science and Technology, Høgskoleringen 7A, Trondheim 7491, Norway
[b]Norwegian Public Roads Administration, Askedalen 4, Leikanger 6863, Norway
[c]Rambøll Norway, Fjordgaten 13, Tønsberg 3103, Norway

Abstract

Fixed links are bridges or tunnels that join areas previously separated by geographic barriers without a permanent connection. Fixed links can cause important travel time savings, which might be an incentive for population growth in the affected areas. Traditional population forecasts do not include potential changes caused by infrastructure investments, and this might cause misrepresentation of input to travel forecasts. The purpose of this paper is to address the question of whether the mismatches between the forecasts and real population numbers can be explained by the impacts of a new infrastructure.
For this purpose, we observe ten fixed links on the western coast of Norway. Different linear regression models with several independent variables in different time periods are estimated for two situations; after the opening of the fixed links, and after the toll removal on the fixed link. The results show that the differences between forecast and real population after the opening of the fixed link are not related to any of the observed explanatory variables. On the other hand, the mismatches after the toll removal are associated with the travel time and cost reductions between the main activity centre in the affected municipality and the closest urban district. In addition, the differences in housing prices is also a significant variable, correlated to the number of total jobs per individual. This reflects the differences among the affected and the newly reachable areas in size and labour opportunities.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: Fixed link; population forecast; demographic projection; transport model; accessibility change

* Corresponding author. Tel.: +47- 4773-5050.
E-mail address: maria.diez@ntnu.no

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.369

1. Introduction

Population forecast models can be 1) trend, based on population forecasts from previous years 2) ratio, forecast in smaller areas are estimated as a proportion of larger areas 3) cohort-component, births, deaths and migration are separately forecasted for different age-sex groups 4) structural, there is a relation between population variations and exogenous variables, such as economic development (Smith & Sincich, 1992). The models can be deterministic or stochastic. Deterministic models are based on combinations of assumptions about mortality, fertility and migration (Booth, 2006). Stochastic simulation, however, can be used to include the uncertainty in the population prognosis and to reduce the input parameters (Alho, 2014).

The demographic forecasts in Norway are based on a stochastic cohort component approach (Statistics Norway, 2001). Other countries, such as the Netherlands or the US, have also implemented this method in their forecasts (Hyndman & Booth, 2008). This approach requires the specification of the correlations between components, and across age, sex and time. Additionally, it entails the statistical distribution of the parameters over time, which can be obtained through time series methods (ARIMA), expert judgements, or extrapolation of empirical errors. Despite the sophisticated methods, mismatches between forecasts and real developments occur especially at less aggregated levels. The population forecasts at municipality level in Norway use regional projections. These regions are disaggregated into counties and municipalities in two ways. Population forecasts in the age group over 50 years old are disaggregated by the share of people in the same age group in the municipality. Forecasts in the age group up to 49 years old are also disaggregated according to the growth rates based on recorded patterns for the previous five years (Aase et al., 2014).

The population forecasts mismatches imply that policies or plans relying on the population forecasts might present potential bias. That is the case of the assessments based on the estimation of future traffic volumes. The estimation is obtained by transport models, which use forecast population as one of the inputs. This might be the reason for the inconsistencies in prognoses made by transport models when compared to actual traffic development. Traffic counts, for instance, often show the forecast traffic volumes are overly under/overestimated (Tørset et al., 2013; Lian and Ronnevik, 2010).

Some authors relate under/overestimation of population forecasts to the impacts of external factors not considered in the prognoses. Structural models can take into account some of these factors, however, the specifications might entail high uncertainty since the relation to the population is mostly based on hypothesis (Ahlburg and Land, 1992). The forecasting problem is, then, transferred from the demographic variables to the external factors (Booth, 2006). Regardless of these shortcomings, structural models might be the solution for improving the population forecasts (Ahlburg and Lutz, 1998). Some models of this type have been used in the last decades. The World3-72 model accounted for demographic, economic, and environmental interactions (Meadows et al., 1972). The Bachue models (Rodgers et al., 1978; Anker and Knowles, 1983) represented the interaction of economic, demographic, and human resource changes. Wheeler (1984) built an econometric model of the interactions between population, economic, and human resource growth. The independent variables considered were economic output, nutricion, literacy, life expectancy, investment, fertility rate, family planning effort, and death rate. An and Jeon (2006) related demographic changes to economic growth. Nikulina and Khomenko (2015) related the migration to quality of life, structure of organisations, and to economic development in one small rural community in Russia.

When it comes to the relation between population and transport, several researchers have focused on predicting residential and job relocations as output of land-use, socio-demographic, and transportation characteristics. LUTI models are widely known; a recent literature review of them can be found in Acheampong and Silva (2015). Another relationship is found in Meijers et al. (2012), where they explained by regression analyses the population and employment changes due to the replacement of two ferry services by a tunnel in the Netherlands.

The purpose of this paper is to fill the gap in improving the population forecasts in areas affected by fixed link projects. These infrastructures are bridges or tunnels that permanently join areas previously separated by geographic barriers, e.g. fjords. Fixed links can cause huge travel time savings since they often replace infrequent and slow ferry services. These remove waiting time, reduce travel time and provide a flexible connection 24 hours 7 days a week. The improvements in transport infrastructure might be an incentive for regional development as the reachable area widens. In addition, the attractiveness of the newly connected areas might change. Especially in those cases where regions get better access to urban areas, an increase in population might be expected. Díez Gutiérrez et al. (2015) found that the population at municipality level started to grow more from two years before the opening of the fixed link, when compared to the reference areas. On the other hand, when fixed links do not connect areas to larger cities, the tendency of the population to move to centralised areas might not stop, and, hence, the population is expected to decrease (NRK, 2013).

Under these premises, this paper aims to answer the following research questions: 1) Do fixed links affect population in the connected areas? 2) What are the variables causing changes in population density in areas affected by fixed links? 3) Can changes in population development explain the under/overestimation of traffic on the fixed links?

We observed ten cases along the western coast of Norway and analysed the differences between forecasts and real populations in the affected areas. We focused on explaining the mismatches after the opening of the infrastructures and after the toll removals. We considered different explanation variables, such as travel time and cost to the main activity centres, population and densities of the connected areas, differences in housing prices, and in number of jobs. We tested several regression models. We could have considered stochastic or more sophisticated models, however, there is no evidence that complex forecast models improve the population projections versus simple models (Smith and Sincich, 1992).

2. Case studies

The fjords and many islands along the western coast characterise Norway. For many years, these islands were connected to the mainland only by the use of ferry services. In this paper, we looked at ten cases of fixed links that opened in the period from 1992 to 2009, shown in Error! Reference source not found.. Seven of the ten cases observed are now free of charge.

Fig. 1. Location of case studies (opening year / toll removal year).

Observing the cases in more detail, these can be classified into three different types. The first type is fixed links that join municipalities with, mainly, rural activities to considerably larger urban districts with more than 100,000 inhabitants within commuting time up to 45 minutes. The examples are Rennfast and Finnfast, which provides connection to Stavanger, the fourth largest city in Norway. Askøybrua, Nordhordlandsbrua and Osterøybrua do so to the second largest city, Bergen. The second type is fixed links that join smaller settlements to larger urban districts of up to 20,000 inhabitants, as in the cases of Eiksundsambandet, Trekantsambandet and Atlanterhavstunnelen. The third type is fixed links that do not connect settlements, but rather serve as improved connection at the national level. Hitratunnelen and Frøyatunnelen are the examples. They connect two islands to the mainland, with the closest urban district more than one hour's drive away. The reason behind its construction was the important international fishing industry on the islands. Fish is a perishable good, which makes the reliability and good connections to relevant hubs important.

Fixed links in Norway are normally co-funded by the state and the users. The toll collection is set for a period of approximately 15 years. The authorities use transport analysis as part of the financial analysis to calculate the toll fee, mainly based on the expected traffic volumes, and hence on population forecasts. Inaccuracies in the traffic forecasts generate higher or lower income to the tolling company than expected. In the case of Finnøy, the toll fee was reduced by 25 % two years after the opening due to the underestimation in the traffic forecast. Other examples are Hitratunnelen and Frøyatunnelen, financed through the same tolling project, where the tolling stopped few years earlier than planned.

The changes in accessibility triggered impacts on the land-use characteristics for the affected municipalities. The influential area of these fixed links is very easy to delimit, as these are, mainly, islands. Díez Gutiérrez et al. (2015) and Andersen et al. (2015) observed the land-use impacts in two and four of these cases, respectively, finding that the population in the areas affected by the fixed links close to large urban districts grew more than in similar areas without the new infrastructure connection. Those differences increased noticeably and were present in all the cases after the toll removal.

The population forecasts were compared to the real population five years after the opening. In order to avoid the influence of the construction of the infrastructure in the forecasts, these forecasts corresponded to approximately five years before the opening of the fixed links. The comparison showed mismatches in the population, however, these did not seem to have a clear pattern as in some random cases the forecasts overestimated the population, whilst in others it was the other way round, as shown in Fig. 2. In the case of the differences in population five years after the toll removal, the forecasts observed were made around five years before the toll removal. The reason was to avoid the influence of this event, but accounting already for the influence of the infrastructure. The mismatches after the toll removal in all cases seemed to correspond to an underestimation of the population growth, represented in red in Fig. 2.

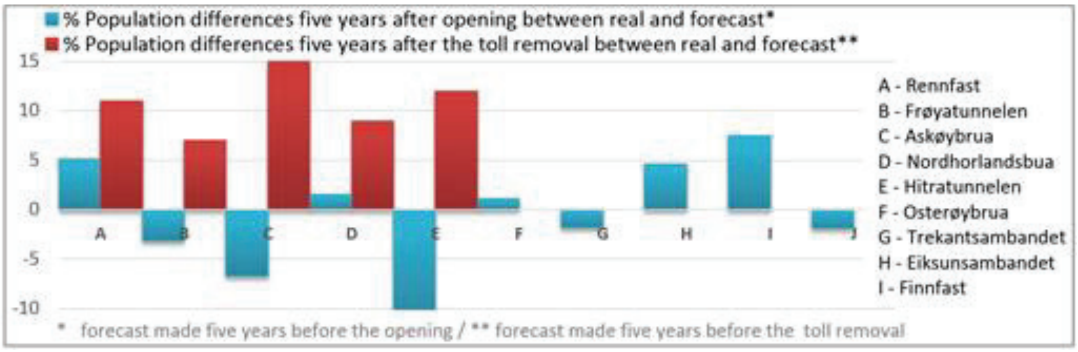

Fig. 2. Mismatches between forecast and real population (%), five years after the opening of the fixed link and five years after its toll removal.

The precision of the forecasts might have been affected by several factors. In order to disregard the fact that the fixed links were not the cause of the mismatches, we observed also the differences in areas with similar characteristics that did not get a fixed link connection. These areas presented positives and negatives differences up to |9|% for the period after the openings. Conversely, in all the control areas after the toll removal the differences between forecast and real were lower than 5%.

3. Methodology

Our methodology consisted of determining a multiple linear regression, which allowed us to identify potential variables that might have affected the population growth. The general equation for the regression model was (1).

$$\hat{Y} = b_0 + b_1 X_1 + b_2 X_2 + \cdots + b_p X_p \quad (1)$$

In (1) b_0 represented the intercept and b_i the regression parameters for the variables X_i. All the variables observed are explained in 3.1. In general, there is no clear answer on the number of independent variables, or which ones are best to include (Howell, 2010). However, the number of parameters in the regression should be lower than the sample size in order to obtain a model estimation. This was a limitation given our low sample size. In order to try to overcome it, different combinations were tested to observe the significance of the parameters, the correlations, and the overall performance of the model.

Two different dependent variables in four time periods were tested. The first dependent variable was the difference in forecast population before the opening of the fixed link and the real population. The second dependent variable was the difference in population between the ages of 20 and 49, in order to observe potential differences for part of the working age group. We analysed only up to 49 years old, as it was expected that this group more likely changed the permanent residence. Henceforth, this is referred to as working age population. The four time periods observed were two and five years after both the opening of the infrastructure and the toll removal, when possible. The decision was based on trying to capture the short- and medium-term effects, as in previous studies by Díez Gutiérrez et al. (2015).

3.1. Independent variables

The independent variables were variables not included in traditional forecasts. Several of them, shown in Table 1, were tested to try to explain the differences between real and forecast population.

Fixed links triggered direct changes in travel cost and time. These might have caused population relocation as the accessibility of the affected area improved. The cost values were considered in 2015 reference prices, the cost before the opening referred to the ferry ticket price, and the cost after to the toll fee. The difference in percentage cost was also considered as a potential variable in the model. Regarding the travel time values, the time was measured as the driving time from the main activity centre in the affected municipality to the nearest urban district in the mainland. The travel time in the before situation included waiting time for the ferry service, which equalled to half of the frequency in rush periods. Two extra variables regarding travel time were tested. On one hand, one categorical variable for the travel time after the opening classified in four groups, up to 15 minutes of travel time, between 15 and 30, between 30 and 45, and more than 45 minutes. These time intervals to the urban district might have influenced the decision of moving to the newly connected area. On the other hand, one dummy variable that represented if the travel time between the main activity centre and the urban district became within commuting time. The possibility of keeping the job in the urban district and moving to the island in a time lower than 45 minutes might have been a potential reason for relocating.

Real population, size, and density of the affected municipalities and urban districts were considered as potential determinants in the relocation decision. These variables were considered to capture the welfare and lifestyle of the area. These values were based on annual registrations. In the particular case of urban districts before 2000, the data were based on interpolation, as census was only registered every ten years.

The higher housing prices in the mainland might have generated a relocation to the affected municipalities within commuting time where the housing prices were lower. We used the difference in housing prices between these areas as another variable in the model. The estimation of the housing prices was based on the sales of residential dwellings in the corresponding areas. In order to avoid fluctuations, we used the smoothing method based on the medium average of three values.

The number of jobs it might have also been an important consideration for relocations, as they were considered as indicators of the labour market and the offered services. Regarding the variables involving number of jobs, we analysed all types of jobs, and those in the retail industry at municipality level. We estimated the relative values dividing the number of jobs by the population in each particular area. This better reflected the rate of jobs per individual from a zonal perspective.

Table 1. Independent variables considered for the regression model (9 NOK = 1 €).

Independent Variable description	**Code**	**Units**	**Type**
Travel cost before the opening	Cost_b	NOK	Numeric, continuous
Travel cost after the opening	Cost_a	NOK	Numeric, continuous
Difference in travel cost before and after	Cost_diff	%	Numeric, continuous
Travel time before the opening	TT_b	min	Numeric, continuous
Travel time after the opening	TT_a	min	Numeric, continuous
Difference in travel time before and after	TT_diff	%	Numeric, continuous
Travel time after the opening in ranges	TT_a_categoric	min	Categorical, ordinal 1: 0 - 15 2: 15 - 30 3: 30 - 45 4: >45
If the settlement in the affected municipality gets within commuting time (<45) with the closest urban district in the mainland	TT_commuting	0-1	Dummy
Size of the affected municipality	AM_size* AM_size**	km^2	Numeric, continuous
Real population in the affected municipality	AM_population* AM_population**	ppl	Numeric, continuous
Population density in the affected municipality	AM_density* AM_density**	ppl/km^2	Numeric, continuous
Size of the nearest urban district in the mainland	UD_size* UD_size**	km^2	Numeric, continuous
Real population of the nearest urban district in the mainland	UD_population* UD_population**	ppl	Numeric, continuous
Population density in the nearest urban district in the mainland	UD_density* UD_density**	ppl/km^2	Numeric, continuous
Differences in housing prices between the affected municipality and the closest municipality/ies in the mainland	Hous_diff* Hous_diff**	kr	Numeric, continuous
Differences in total number of jobs between the affected municipality and the closest municipality/ies in the mainland	Jobs_diff* Jobs_diff**	jobs	Numeric, continuous
Relative differences in total number of jobs between the affected municipality and the closest municipality/ies in the mainland	Jobs_rel_diff* Jobs_rel_diff**	jobs/ppl	Numeric, continuous
Differences in number of jobs in the retail industry between the affected municipality and the closest municipality/ies in the mainland	Retail_diff* Retail_diff**	jobs	Numeric, continuous
Relative differences in number of jobs in the retail industry between the affected municipality and the closest municipality/ies in the mainland	Retail_rel_diff* Retail_rel_diff**	jobs/ppl	Numeric, continuous
* five years before the opening of the fixed link / ** the opening year of the fixed link			

It is worth mentioning that out of all the independent variables, those that were in continuous development over time, i.e. the population, the housing price and the number of jobs, were observed at two different years. Their values from five years before the opening were used to model the dependent variables after the opening of the new infrastructure, assuming that the construction works of the fixed link did not affect them. Whereas, the values on the opening year were used as input to the dependent variables after the toll removal.

4. Results

In the regression models tested for the periods after the opening of the fixed links, the sample consisted of the ten cases. We tested the significance of the independent variables in several models considering the whole sample and three samples according to the type of fixed link. In spite of that, no parameters were found significant. Therefore, the differences between the forecast and real population might have been the consequence of other factors not related to the infrastructure, such as local policies.

Unlike the periods after the opening, the sample was six for the period two years after the toll removal, and five for five years after. Thus, the dependent variables were not studied separately for the different fixed links. Several regression models for estimating the difference between forecast and real population were estimated. Table 2 shows the most relevant models.

Table 2. Regression models for the two dependent variables after two and five years from the toll removal of the fixed links.

	A (n=6)		B (n=5)		C (n=6)		D (n=5)	
MODEL 1	*b*	*(sig.)*	*b*	*(sig.)*	*b*	*(sig.)*	*b*	*(sig.)*
(Constant)	560,522	(-0,335)	-76,818	(-0,734)	1222,881	(0,436)	**349,354**	**(0,114)**
TT_a	**-22,611**	**(-0,052)**	-1,893	(-0,510)	**-39,122**	**(0,150)**	**-10,479**	**(0,036)**
Cost_b	**19,241**	**(-0,100)**	5,142	(-0,220)	30,614	(0,276)	**10,573**	**(0,054)**
Hous_diff	**0,529**	**(-0,069)**	0,095	(0,281)	0,905	(0,211)	**0,283**	**(0,044)**
R2	0,910		0,654		0,961		0,997	
MODEL 2	*b*	*(sig.)*	*b*	*(sig.)*	*b*	*(sig.)*	*b*	*(sig.)*
(Constant)	**2036,433**	**(0,051)**	130,587	(0,689)	**4025,990**	**(0,071)**	**1355,054**	**(0,126)**
TT_a_categoric	**-540,513**	**(0,059)**	-20,067	(0,827)	**-862,040**	**(0,094)**	-247,525	(0,223)
Cost_b	5,287	(0,388)	1,846	(0,584)	2,847	(0,654)	1,519	(0,685)
Jobs_rel_diff	**830,345**	**(0,181)**	-25,946	(0,925)	**1232,943**	**(0,188)**	2423,106	(0,384)
R2	0,898		0,303		0,985		0,902	
MODEL 3	*b*	*(sig.)*	*b*	*(sig.)*	*b*	*(sig.)*	*b*	*(sig.)*
(Constant)	**1501,607**	**(0,165)**	43,707	(0,727)	**1355,054**	**(0,184)**	1126,902	(0,269)
TT_a	-9,760	(0,374)	**2,548**	**(0,197)**	-247,525	(0,254)	-5,513	(0,481)
Hous_diff	0,258	(0,488)	**0,095**	**(0,183)**	1,519	(0,838)	0,029	(0,918)
Retail_rel_diff	-2609,419	(0,776)	**-3128,447**	**(0,129)**	2423,106	(0,533)	1292,979	(0,863)
R2	0,551		0,887		0,876		0,643	
MODEL 4	*b*	*(sig.)*	*b*	*(sig.)*	*b*	*(sig.)*	*b*	*(sig.)*
(Constant)	-257,941	(0,275)	56,628	(0,806)	3393,292	(0,261)	**2224,582**	**(0,172)**
TT_a	**5,444**	**(0,098)**	3,234	(0,272)	-766,430	(0,285)	-453,297	(0,208)
AM_population	**0,028**	**(0,086)**	-0,013	(0,335)	**0,103**	**(0,148)**	**0,033**	**(0,191)**
UD_population	**0,007**	**(0,017)**	**0,002**	**(0,194)**	-0,007	(0,486)	-0,006	(0,254)
R2	0,989		0,698		0,990		0,972	

A: Total population differences between the real and the forecast (2 years after the toll removal)
B: Total population differences between the real and the forecast (5 years after the toll removal)
C: Working age population differences between the real and the forecast (2 years after the toll removal)
D: Working age population differences between the real and the forecast (5 years after the toll removal)

Model 1 included the travel cost before the opening, the travel time after, and the difference in housing prices between the municipality in the affected area and in the mainland in the opening year. The independent variables aimed to reflect the extra population to be added to the forecast made some years before the opening. Since this might influence the estimation of the toll for the fixed link, the cost variable is referred to the initial situation with the ferry service. The travel cost could have been already reflected in the housing prices as a discount in the affected municipality, despite that, the hypothesis that their parameters were equal could be rejected with a significance level larger than 45%. Hence, other factors may have been related to the differences in local housing prices. The hypothesis that the cost parameter equalled zero could only be rejected with a confidence level greater than 80% when the independent variable represented the difference between forecast and real working age population five years after the toll removal, and total population two years after. The travel time parameter was significant with a confidence level larger than 85% for all independent variables except for the total population after five years of the toll removal variable. The parameter for the difference in housing prices was significant with a confidence level larger than 90% for the total population two years after and the working age population 5 years after, and 70% for the other independent variables.

Model 2 included the travel cost before the opening, the travel time after, and the relative difference in total number of jobs per person between the municipality in the affected area and in the mainland in the opening year. The hypothesis that the cost parameter equalled zero could not be rejected with a confidence level larger than 50% for any of the independent variables. The travel time treated as categorical variable pretended to illustrate that the decision of commuting, and hence the residence respect to the job location, varied little within those ranges, so it was not a continuous relationship. The hypothesis that the travel time parameter equalled zero could be rejected with a confidence level larger than 90% for the total and working age population two years after the toll removal. The relative difference in number of jobs reflected directly the labour market, and the services and opportunities the area offered to its inhabitants. Conversely, comparing the absolute number of jobs might not have revealed that in an area with more jobs the opportunities to get a job may have been more difficult due to competition among more people. In this case, there was no correlation with the cost of the toll. The hypothesis that the job parameter equalled zero could be rejected with a confidence level larger than 90% also for the total and working age population two years after the toll removal.

Model 3 included travel time after the toll removal, the differences in housing prices, and the relative difference in the number of jobs in the number of retail jobs per person. These differences were between the municipality in the affected area and in the mainland in the opening year. Including the retail jobs instead of the total might have helped to explain potential differences in the structure of the settlements, whether these were based more on rural or urban activities. The three parameters were only significant with a confidence level higher than 80% when considering the total population 5 years after the toll removal as independent variable. Nevertheless, the hypothesis that the job parameter and the housing prices parameter were equal could not be rejected with a confidence level larger than 80%.

Model 4 included the travel time after the toll removal, the population in the affected municipality and in the closest urban district in the opening year. According to the limitations of the maximum number of dependent variables, any of the monetary variables were included in this model. The travel time parameter was significant with a confidence level larger than 70% for all the independent variables. The population parameter was observed to be more significant than the population density parameter of both settlements. The hypothesis that the population in the affected municipality parameter was equal to zero could be rejected with a confidence level larger than 80% for all the independent variables except for the total population after 5 years of the toll removal variable. In the case of the population in the closest urban district parameter, this was significant with a confidence level larger than 80% for the total population.

The overall performance of the models where the independent variable was the difference in total population five years after the toll removal represented a low r-square value. One reason might be the low sample size or that other factors not included in this study affected more these differences, for example local demographic policies. The models for the other independent variables indicated that the parameters that affected the most were related to travel time after the toll removal, cost before, population in the two areas, and the differences in housing prices and in relative total number of jobs per person. At this respect, both model 1 and 4 have a high rsquare value, meaning that the models fitted the data reasonably well.

5. Discussion

In this study, we observed the differences between the forecast and real population in the areas affected by fixed links. We studied only ten cases, since this type of infrastructures is limited. Nevertheless, it could have been interesting to widen the type of case studies. There are other infrastructure investments that also change dramatically the accessibility in terms of time and cost within two areas, even if they got a permanent connection before. The inclusion of more cases might benefit a better understanding of the variables that affect the population mismatches.

The methodology used only aimed to identify potential variables that might have affected the mismatches between the forecast and the real population after the opening of the fixed links and after its toll removal. The regression models used are only valid for two and five years after the toll removal, hence, these should not be used to predict the extra population in future fixed links. Nonetheless, further research could be focused on including the significant parameters into the forecasts using time dependent models. Given the actual forecast population model, these parameters are only interesting to include for up to five years after the toll removal, since actual forecasts include the population patterns from the previous five years.

We assumed that the differences in population were caused by the fixed links. The control areas of the studied cases did not present significant mismatches between forecast and real population after the toll removal. Despite that and given the sample size, the mismatches might have rather been related to external factors, for example policies or GDP development.

1) Do fixed links affect population in the connected areas?

The forecasts at municipality level in Norway are based on births, deaths, migrations at national level and five years of migrations patterns within regions. The forecasts do not include potential changes caused by infrastructures. The opening of the studied fixed links did not generate extra population with respect to the forecast years before. On the other hand, Díez Gutiérrez et al. (2015) and Andersen et al. (2015) did find there was an extra population growth in some fixed links some years before the opening when comparing the population development of similar areas without the new connection. Conversely, we found mismatches between the forecast and real population after the toll removal on the fixed links.

Before the opening of the fixed links, the newly connected areas had little interaction with the mainland, as the low traffic volumes on the ferries indicated compared to the traffic on the fixed links. After the improvement in accessibility, more people have probably changed their destinations for some trips since the traffic volumes increased. This improved interaction might have been in both directions, i.e. people travelling to the urban area for shopping or private trips, and people travelling to the islands for leisure trips, for example. However, the extra population over the forecast did not move to the affected area until the toll removal. The improvement in travel time might have not been enough to change the residence location, as the commuting trips might get quite expensive with the toll. Therefore, the extra population might have come from residents of the urban areas that decide to move, keeping their jobs, as the cost of commuting was reduced.

Another possible source of extra population with respect to the forecast might have been people who came from different places in order to live and work in the newly connected areas. The accessibility improvements might have promoted benefits to the companies due to the agglomeration effects. Part of these might have been specialisation of some companies and expansion of the labour markets, triggering an increase in the number of jobs. Moreover, the number of companies might have increased in the long term, and it may have coincided with the toll removal.

2) What are the variables affecting changes in population density in areas affected by fixed links?

The travel time was a significant variable in explaining the differences between the forecast and real population after the toll removal on the fixed links. According to the regression models, the higher travel time to the urban district, the lower were the mismatches. This might be explained by how proximity to the urban district may affect the attractiveness, and hence the nearer it is, the more attractive it is for people to move the residence to the newly connected area.

The cost of the toll also represented a significant variable. Its parameters in the regression models showed that the higher the cost the higher the difference between the forecast and real population. Thus, a higher cost generates more consequences in terms of residence location. The number of people willing to pay after the toll removal is higher when the toll is more expensive.

The relative difference in the number of total jobs was also an important variable that might have helped to explain the extra population not accounted for in the forecasts after the toll removal. The larger difference the greater the development or rapid growth in population in the affected municipalities compared to the forecast. This is in accordance to Vickerman (1998), who stated that infrastructure investments may lead to regional economic growth if there is a development potential in the industries affected.

The parameters for the population in both the affected municipality and the urban district were significant as well. The extra population growth not accounted for in the forecasts was greater if the original populations were larger. The larger number of inhabitants may reflect more services and higher welfare, as consequence, the attractiveness of these areas might increase. Conversely, high-density areas in the urban districts might not be the ideal residence location for families; hence, these may prefer to move towards less populated zones within commuting time.

3) Can changes in population development explain the under/overestimation of traffic on the fixed links?

The traffic on the fixed links might be generated by different purposes. Commuting trips represent an important share of the traffic. When the input to the traffic volumes estimations does not consider the adequate population that move to the affected areas or the correct number of job positions in the different areas, the consequence might be an under/overestimation of the commuting trips, and hence the traffic volumes. The potential bias in the future traffic volumes might play a crucial role in the decision of the toll fee.

6. Conclusion

The policy implications of this paper are related to the fact that population development is affected by infrastructures, especially by those that considerably reduce travel time and cost. The future population projections could include population changes according to the travel time, cost, and differences between the connected areas in terms of housing prices, relative number of jobs and population. The impacts on population are clearer when the toll of the infrastructure is removed. This is an important finding for decision makers, as they should take into account the great impact that the toll generates.

Further studies might be oriented to corroborate the significance of these variables in other fixed links and other infrastructures that dramatically change the connections between settlements. Moreover, a detailed study on the population changes over time, based on age cohort, would allow a better combination of the traditional method and the new variables, meaning a more accurate prediction of population.

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Paper 3

Journal of Transport Geography 68 (2018) 215–223

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

The impact of fixed links on population development, housing and the labour market: The case of Norway

Stig Nyland Andersen[a,b,*], María Díez Gutiérrez[a], Øyvind Lervik Nilsen[a,c], Trude Tørset[a]

[a] Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
[b] Norwegian Public Roads Administration, Nygaardsgaten 112, NO-5008 Bergen, Norway
[c] Rambøll Norway, Fjordgaten 15, NO-3103 Tønsberg, Norway

ARTICLE INFO

Keywords:
Ferry replacement
Fixed link
Population
Housing market
Regional development

ABSTRACT

This study compares 11 fixed link projects in Norway, linking islands to the mainland. The fixed links substantially increase the accessibility between the islands and the mainland. Thus, interaction between the islands and the mainland increases. Large infrastructure improvements may not only affect the transport patterns but also the population and companies in the connected areas. We apply a difference-in-difference method to analyse the impacts from the increased accessibility. The findings indicate growth in housing prices, population, commuting and employment on the islands. The growth rates of these variables depend on the case characteristics. Urban cases appear to promote larger growth on the island. The contribution of this paper to the literature is that while there have been several studies that have involved single projects, a comparison of several cases that combines assessments of housing and labour markets is still rare in the literature.

1. Introduction

Transport projects strive to improve economic and social conditions. Network improvements increase accessibility, as travel time and distance to surrounding areas decrease. According to Vickerman (1998), network improvements may promote regional development and cohesion as more jobs are within commuting distance. Reductions in travel time promote new opportunities for people, as communities become more integrated. Hence, the labour market widens and becomes more optimised (Louw et al., 2013). This finding provides the potential for more interactions between areas. The impact on society from transport investments, such as population development and labour market changes, has previously been recognised in the literature (Baldacchino, 2007; Banister and Berechman, 2001; Bråthen, 2001; Bråthen and Hervik, 1997; Coppola et al., 2013; Geurs and van Wee, 2004; Knowles, 2006; Wu et al., 2017). These impacts on society are of crucial importance when assessing the long-term effects of transport investments.

Wegener (2004) divides the urban change process of transport projects into four categories by how fast the changes occur. Goods transport and travel patterns may change immediately. The change in the number of people living and/or working in an area is a rapid process. The development of workplaces, such as factories and office buildings, and residential buildings changes slowly. The transport network and zoning change at a very slow pace. Banister and Berechman (2001) emphasise the importance of an increase in accessibility at a network scale as a key factor in promoting economic growth. Hence, projects linking two previously disjointed networks promote larger growth than an additional link in an established network. Fixed link projects are suitable examples of such projects.

Fixed link projects are defined as bridges or tunnels replacing a ferry service. Ferry services constitute barriers in the transport network. In contrast to the remainder of the road network, ferry connections are open for traffic only at scheduled arrival times. Thus, ferry connections are characterised by the inconvenience associated with low frequencies and waiting times, particularly outside peak hours. This circumstance provides less flexibility for the travellers who are dependent on the ferry. Furthermore, ferry services may involve capacity restraints, as the number of vehicles on each departure are limited. A fixed link removes these barriers, reducing travel time and substantially increasing capacity. Furthermore, flexibility increases as the fixed link is open 24/7 and is normally less influenced by bad weather conditions than the ferry. These special projects are very interesting to analyse due to the clearly defined affected area, as they involve islands that acquire a connection to the mainland.

The impact on fixed links has previously been studied in a number of papers. Díez Gutiérrez et al. (2015) analysed two Norwegian ferry replacement projects joining smaller towns/settlements to a city with more than 50,000 inhabitants. The connected areas experienced an

* Corresponding author.
E-mail addresses: stig.andersen@vegvesen.no (S.N. Andersen), maria.diez@ntnu.no (M. Díez Gutiérrez), oyvind.lervik.nilsen@ramboll.no (rset).

https://doi.org/10.1016/j.jtrangeo.2018.03.004
Received 29 June 2017; Received in revised form 20 February 2018; Accepted 13 March 2018
Available online 07 April 2018
0966-6923/

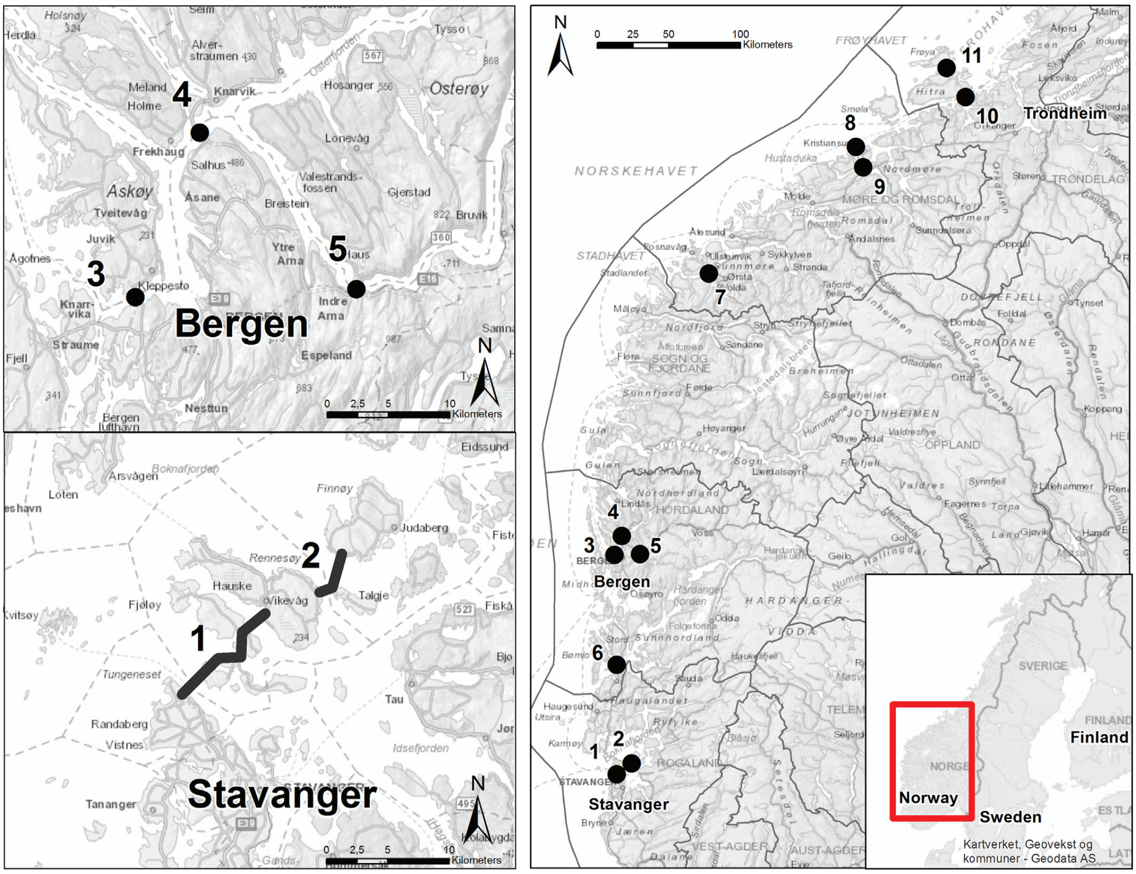

Fig. 1. Location of the cases in this study. The excerpts to the left show the projects around the cities of Bergen and Stavanger. County borders are also highlighted. Numbers in the maps according to Table 1.

Table 1
Case characteristics. Population figures refer to the population at the time of the opening of the fixed link. Travel time is calculated between the closest towns on the mainland and the island, including the estimated waiting time for the ferry.

No.	Name	Year of opening/toll removal	Population in opening year		Travel time between island and closest town on the mainland		Ferry ticket	Toll fee on fixed link
			On the island	Of the closest town on mainland (name of town)	Before opening	After opening		
1	Rennfast	1992/2006	2600	135,500 (Stavanger)	150 min	25 min	€16.40	€15.50
2	Finnfast	2009	2800	190,000 (Stavanger)	90 min	50 min	€8.54	€23.30/17.80
3	Askøybrua	1992/2006	18,500	191,000 (Bergen)	30 min	15 min	€9.20	€6.40
4	Nordhord-landsbrua	1994/2005	21,400	195,000 (Bergen)	40 min	30 min	€7.80	€7.20
5	Osterøybrua	1997/2015	7000	200,000 (Bergen)	96 min	42 min	€7.00	€7.00
6	Trekant-sambandet	2001/2013	10,800	11,000 (Stord)	60 min	30 min	€8.54	€11.20
7	Eiksund-sambandet	2008/2014	22,500	5500 (Volda)	50 min	30 min	€7.00	€8.54
8	Krifast	1992/2012	22,500	20,600 (Molde)	145 min	78 min	€4.40	€8.70
9	Atlanterhavs-tunnelen	2009	5400	17,000 (Kristiansund)	45 min	20 min	€10.90	€10.30
10	Hitratunnelen	1994/2010	4200	6000 (Orkanger)	152 min	88 min	€8.50	€5.30
11	Frøya-tunnelen	2000/2010	4100	6000 (Orkanger)	212 min	116 min	€18.40	€5.30

increase in population and housing prices. However, four fixed link projects in rural areas observed by Andersen et al. (2016) did not have significant effects on population numbers and the labour market after opening. Engebretsen and Gjerdåker (2010) did not find a strong impact on settlement, trade and employment when analysing the Triangle link in Norway. However, the link had a strong impact on commuting. Meijers et al. (2012) analysed the Westerschelde tunnel in the Netherlands, finding impacts on both population and employment; however, the impacts are considered distributive effects rather than growth at the regional level. Matthiessen (2004) analysed the Öresund Bridge linking urban areas in Denmark and Sweden. This study reports slow development towards an integrated urban region. These studies show that fixed links contribute to changes in society to varying degrees.

This paper contributes to the research on the interactions between transport and the impacts on society, specifically for fixed link projects. While existing studies typically analyse only one or a few cases, this paper investigates and compares 11 fixed link projects in Norway regarding population development, housing and the labour market. Much of the previous research on this topic focuses on the regional scale, while our contribution lies in a more detailed, meso-level approach.

The study focusses on the changes experienced on the connected islands. The methods currently used in Norway to assess fixed link projects do not include changes in population due to infrastructure improvement. By analysing cases with different characteristics, this paper can also contribute with recommendations as to when changes to population development and labour market should be expected to occur in future fixed link projects. This paper empirically investigates whether transport investments affect the indicators of changes to society, in this paper defined as changes to the housing market, population development and the labour market. We address the following research questions in this paper:

1) How do fixed links affect population development and the labour market on the connected island?
2) How do the case characteristics influence these changes?

Norway has replaced many ferry connections with fixed links over the past 60 years along the whole coast of Norway. We have analysed 11 of these ferry replacement projects located along the western coast of Norway. The western coast of Norway has been chosen due to the plans for investing in many new fixed link projects in this part of the country (Statens Vegvesen, 2018).

The analysed projects substantially improve accessibility between the islands and the mainland. The islands consist of one or more municipalities, which provide us access to data recorded at the municipality level. Other municipalities in the region may also be influenced by the fixed link, both for the mainland and the surrounding islands. However, the scope of this paper is limited to the islands that become connected to the mainland. This scope is limited to a focus on whether the fixed links will promote growth on the island, as is normally expected by decision makers in Norway.

An important feature when conducting case studies is to compare the case against an alternative path of development. What would occur if the fixed link had not been built? This comparison is often lacking in other case studies. In this paper, we utilise the difference-in-difference method (Lechner, 2011).

The analysed cases are presented in Section 2. Section 3 describes the data used in this study, and Section 4 describes the methods used in the analysis. The results are described in Section 5, with a discussion following in Section 6. Finally, the conclusions and policy implications are summarised in Section 7.

2. Description of the cases

Fig. 1 shows the locations of the 11 ferry replacement projects studied in this paper. The cases have different characteristics regarding population on the island, population on the mainland, travel time reduction, travel time to the closest town after opening and a change in monetary cost. The differences in characteristics promote a better understanding of the impact that accessibility has on the population and the labour market. Table 1 presents the most important characteristics of each case.

The cases are located within four of the five counties on the western coast of Norway. Three of the largest cities in Norway are located in this area and are labelled with names in Fig. 1.

Most of the fixed link projects connect sparsely populated areas on the islands to more dense areas on the mainland. However, there are exceptions. In case 8, the city is located on the island, while the mainland is more rural. This finding may provide different results, as the fixed links open for more interaction with the surrounding rural areas, and the results may provide indications regarding whether redistributive effects from the city to the surrounding rural areas appear. In this case, the closest city is used in Table 1. Case 6 and case 8 are also part of a triangular connection, connecting islands and the national road network. In these two cases, the affected areas are defined as the island that obtained a fixed link. Cases 10 and 11 can be characterised as rural areas on both the island and the mainland.

Travel times were reduced substantially in all cases. The fixed links connected many islands to the town on the mainland within a reasonable commuting time of 45–50 min. However, cases 8, 10 and 11 have a travel time of more than 60 min to the closest town.

A toll fee as part of financing the investment costs normally replaces the ferry ticket. The relative change in direct cost varies from 0.62 to 2.72 times the corresponding ferry ticket. The toll period normally ends after 10–15 years, depending on the time needed to repay the investment cost. Despite the toll fee, fixed links represent a substantial increase in accessibility, as time savings are large. Thus, areas connected by a fixed link serve as excellent cases to study the joint interaction between transport investments and changes to society.

3. Data

The analysis of the cases is based on multiple data sources, which are presented in Table 2 and described in the following text.

3.1. Traffic volume data

Average annual daily traffic (AADT) was collected before and after the opening of the projects. The before data were based on counts provided by the ferry companies, while the after data were collected from counts on the fixed links by the Norwegian Public Road Administration. The traffic volumes used are the sum of all vehicle types.

3.2. Population data

Population data consisted of the total number of people residing in

Table 2
Variables and observed period.

	Variable	Observed period
1	Traffic volumes	(1989–2015)
2a	Population	(1985–2015)
2b	Population relocation patterns	(1985–2014)
3	Housing market (square metre price)	(1993–2014)
4a	Employees	(2000–2015)
4b	Commuting patterns	(2000–2015)

each municipality who are registered in the national database. People residing temporarily and thus not registered in the correct municipality may influence the data. However, these errors are considered minor errors (Statistics Norway, 2016). We analysed changes in the total population. We also observed migration and population relocation patterns. The latter consist of the total number of people moving from one municipality to another.

3.3. Housing data

Housing market data consisted of registered sold dwellings, collected from the Land Registry and Cadastre. A possible source of error was that the properties were registered after the sale occurred; therefore, for sales late in the year, they may have been registered in the following year. In addition, a low percentage of the properties lacked information about the size and/or the sale price. The average annual prices presented fluctuations. To observe potential trends, we used the central moving average method with three values to reduce the sensitivity of the data.

3.4. Employee and commuting data

Commuting data consisted of the number of people residing in one municipality and working in another within Norway. The population of the register-based employment statistics consisted of persons between 15 and 74 years old, with one or more working hours per week, including the self-employed. Employee data use the same data source. The dataset has several data sources; therefore, it is possible to observe the consistency. Nonetheless, a possible source of error is delays in the registration of the self-employed. Additionally, employees working for companies with several locations may be incorrectly registered as employed by the wrong establishment (Statistics Norway, 2015).

4. Method

The analysis uses the difference-in-difference method (DiD-method) to analyse the impact of the fixed link. First, the DiD-method will be described; this will be followed by a description of how control areas used in the DiD-method are selected.

4.1. Difference-in-difference

The variables in this paper are analysed using the principle of the non-parametric difference-in-difference method (DiD-method) (Lechner, 2011). This method compares the development of an affected area to a control area, assuming that the development of the variables was similar in both areas before the project. The benefit of the method is to explain external factors that may influence the development, such as interest rates or gross domestic product (GDP). Hence, the results from the analysis could be related to the actual infrastructure improvement.

Eq. 1 shows the formula used to calculate the DiD-values.

$$\mathrm{DiD} = |\mathrm{Y}_t^{\mathrm{A}} - \mathrm{Y}_{t_0}^{\mathrm{A}}| - |\mathrm{Y}_t^{\mathrm{C}} - \mathrm{Y}_{t_0}^{\mathrm{C}}| \tag{1}$$

Y_t is the variable analysed in the affected area (A) or in the control area (C). t_0 relates to the opening year of the fixed link, and t is the number of years after opening. In this study, when data were available, we observed the opening of the ferry replacement projects at six time intervals: immediate (t: 1), short term (t: 3), medium term (t: 5) and long term/toll removal (t: 10, 15 and 20).

Furthermore, the analysis also includes a test to determine if the affected area or control area experiences a trend break in the analysed variables at the time of opening. We used the hypothesis in Eq. (2) with time series data five years prior to opening to test whether the assumption of similar trends was met. The hypothesis was tested using the test statistic described in Eq. (3).

$$H_0\colon\ \beta_1 = \beta_2\ \ i.\,e.\ \ \beta_1 - \beta_2 = 0 \tag{2}$$

$$t = \frac{b_1 - b_2}{\sqrt{S_{b_1}^2 + S_{b_2}^2}} \sim T\,(n_1 + n_2 - 4) \tag{3}$$

where:

b_1 is the slope of group 1
b_2 is the slope of group 2
${s_{b1}}^2$ is the standard error of b_1
${s_{b2}}^2$ is the standard error of b_2
n_1 is the number of observations in group 1
n_2 is the number of observations in group 2

4.2. Selection of control groups

The DiD-method uses control areas to control for an alternative development without the infrastructure improvement. An important assumption of the DiD-method is that the affected areas and control areas have similar developments before the opening of the fixed links. Control areas were defined using two different approaches. The variables housing prices, employment and commuting use a control group, while traffic volumes and population development use a simulated trend. The two approaches are described in Fig. 2.

The control group method uses the development on islands with similar characteristics such as industry composition and a ferry connection to the mainland during the whole period of analysis.

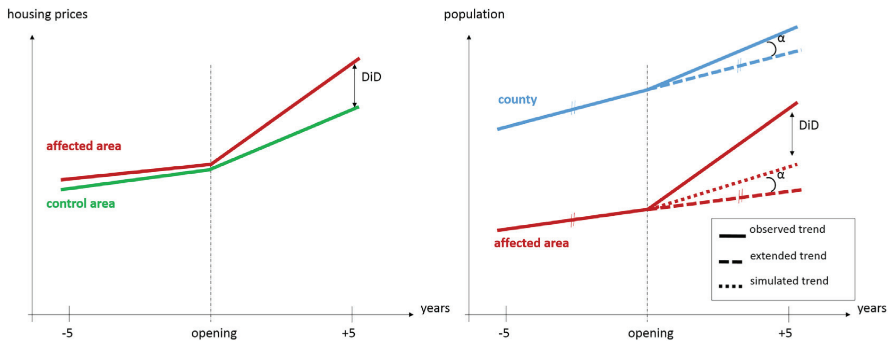

Fig. 2. Difference-in- difference using a) a control group or b) a simulated trend. The control group here is the adjusted trend in figure b.

Furthermore, the municipalities are selected from different islands in the same county as the affected area. The control groups consist of 1–4 municipalities with similar development to the affected area in the five years prior to opening. The test in Eq. 2 is used to test for similar development between the affected area and the control group prior to opening. This approach is described in Fig. 2a).

The simulated trend extends the trend line from the five years before opening through the period of analysis. To explain external factors, we use the development in the county as a whole. The change in trend between the six years before and six years after was analysed (α in Fig. 2b), and the extended trend was adjusted according to this trend change to provide a simulated trend as described in Fig. 2b). Traffic volumes uses only the extended trend, due to a lack of data on regional traffic development.

The motivation behind the use of a simulated trend was the lack of a control group with a similar trend before the opening of the fixed link as shown in Fig. 2a). The synthetic control group method, as described by Abadie et al. (2010), was tested as a third alternative. However, this method did not provide better results than the control group method.

5. Results

5.1. Traffic data

Table 3 shows the development in traffic volumes. The table also shows the AADT on the ferry the year immediately before the opening to provide the magnitude of the traffic volumes on the stretch.

Table 3
Traffic volumes, DiD-values compared to extended trend.

	Fixed link project	AADT on the ferry, the year before opening	DiD-values Years after opening					
			1	3	5	10	15	20
1	Rennfast	260	265	198	225	374	1003[a]	1384[a]
2	Finnfast	396	59	88	108	–	–	–
3	Askøybrua	2970	72	92	111	183	416[a]	569[a]
4	Nordhordlandsbrua	4760	20	47	62	90	198[a]	233[a]
5	Osterøybrua	560	183	204	251	377	474	–
6	Trekantsambandet	942	89	85	106	144	–	–
7	Eiksundsambandet	960	112	124	153	–	–	–
8	Krifast	1490	35	46	50	78	59	123
9	Atlanterhavstunnelen	890	132	160	176	–	–	–
10	Hitratunnelen	940	355	390	418	564	861	–
11	Frøyatunnelen	340	33	21	103[a]	143[a]	191[a]	–

[a] Observed after toll closure.

All cases experienced a substantial increase in traffic during the first years after opening. The immediate increase ranged from 20% to 285%. This immediate increase may be caused by the large increase in accessibility, which may trigger changes in the destination patterns. An example of this may be more private trips from the island to the mainland. Case 1 experienced a slight decrease from year 1 to year 2 after opening, but the reason for this is not clear.

After the initial years, the traffic growth stabilises at a higher growth rate than before the opening. The changes may be due to long-term factors other than changes in the destination pattern. These changes may be due to factors such as growth in population and employment. An increase in the population provides a higher potential for interactions with the mainland and hence may explain the further growth in traffic.

Toll removal also induces a second impact on the traffic volumes for those cases with available data. This removal may further promote the changes observed during the toll period, due to the reduction in generalised cost represented by the toll removal.

5.2. Housing market

Table 4 presents the DiD-values for housing price development. Cases 1, 8 and 10 are not analysed due to limitations in the data.

All cases except case 6 experienced a positive development in the square metre price. However, case 6 did not satisfy the similar trend assumption, which made the DiD numbers uncertain. Furthermore, this case involves a triangular connection also linking two parts of the mainland together. This finding may make the areas on the mainland more attractive regarding the expense of growth on the island. Case 4 experienced a decrease in the DiD-values in years 19 and 20 after opening. This finding may be due to a large growth in the control group and is considered to have been caused by a trend change in the control group. The negative DiD-value for case 3 in year 1 is due to a peak in the housing prices for the control area.

The results from Table 4 show that most of the islands had a higher square metre price than before, suggesting that the increased accessibility provided by the fixed link matters in terms of residential location attractiveness. All the cases appear to have a positive effect as well, but the size of these effects varied among the cases. The cases that experienced the highest increase in housing prices are localised close to large cities (on a Norwegian scale). Cases 2, 3, and 4 obtained fixed link connections to the second or third largest city regions in Norway, while case 7 obtained a connection to two smaller cities.

Table 4
Development in housing prices.

	Fixed link project	Similar trend before? (*t*-value)	Trend break in affected area? (*t*-value)	Trend break in control area? (*t*-value)	DiD-values Years after opening					
					1	3	5	10	15	20
1	Rennfast	Not analysed due to data limitations								
2	Finnfast	Yes (1.05)	No (1.32)	No (1.08)	1.0	15.6	33.7	–	–	–
3	Askøybrua	Yes (0.51)	Yes (10.96)	No (−1.28)	−11.5	36.1	53.5	128.9	294.1[a]	159.7[a]
4	Nordhord-landsbrua	Yes (−1.98)	No (1.19)	Yes (−3.96)	7.0	16.7	35.0	78.2	62.3[a]	−96.1[a]
5	Osterøybrua	No (2.60)	Yes (3.15)	Yes (3.64)	*24.5*	*44.3*	*−8.1*	*−23.2*	*−61.1*	–
6	Trekant-sambandet	No (3.93)	Yes (4.82)	Yes (6.69)	*−13.1*	*−7.1*	*−4.0*	*−6.9*	–	–
7	Eiksund-sambandet	Yes (2.11)	No (0.78)	No (−1.28)	6.1	14.3	22.1	–	–	–
8	Krifast	Not analysed due to data limitations								
9	Atlanterhavs-tunnelen	Yes (0.90)	No (−0.29)	No (−1.31)	−18.2	−1.6	5.5	–	–	–
10	Hitratunnelen	Not analysed due to data limitations								
11	Frøyatunnelen	No (−2.74)	Yes (3.24)	No (−2.17)	*5.8*	*41.9*	*24.1*	*−4.4*	–	–

Numbers in italic = Assumption of similar development before has not been met.
[a] Observed after toll closure.

Table 5
Population development.

	Fixed link project	Trend break simulated trend (*t*-test)	Trend break observed trend (*t*-test)	Population numbers in the closest town on the mainland in opening year	DiD-values Years after opening					
					1	3	5	10	15	20
1	Rennfast	No (0.804)	Yes (4.461)	135,500	0	2.4	6.1	16.0	21.5[a]	49.8[a]
2	Finnfast	Yes (2.868)	Yes (10.971)	190,000	1.6	7.0	11.5	–	–	–
3	Askøybrua	No (0.370)	No (0.603)	191,000	−0.7	−0.9	0.3	5.7	16.2[a]	30.7[a]
4	Nordhord-landsbrua	No(0.036)	Yes (3.201)	195,000	0.3	1.4	2.2	5.0	12.1[a]	20.8[a]
5	Osterøybrua	No (−0.655)	Yes (2.150)	200,000	0.3	0.5	2.2	4.2	9.9	–
6	Trekant-sambandet	No (0.388)	Yes (−5.886)	11,000	−1.0	−2.4	−3.2	−1.7	–	–
7	Eiksund-sambandet	Yes (33.232)	Yes (15.648)	5500	0.1	3.2	4.2	–	–	–
8	Krifast	No (2.093)	No (1.938)	20,600	0.5	0.2	0.2	0.9	2.3	8.2[a]
9	Atlanterhavs-tunnelen	Yes (5.304)	Yes (7.485)	17,000	0.1	1.2	1.9	–	–	–
10	Hitratunnelen	No (0.373)	No (−0.121)	6000	−0.3	−0.3	−0.3	2.5	6.2	17.5[a]
11	Frøyatunnelen	Yes (2.577)	No (−1.836)	6000	−0.6	−0.8	−2.7	−0.5	4.7[a]	–

[a] Observed after toll closure.

5.3. Population

Table 5 presents the DiD-values and trend breaks for population development.

Most of the cases experienced a growth in population after the opening of the fixed link. The DiD-values show that the increase differs between the cases. Cases 6 and 11 did not experience extra growth in population during the toll collection period because the population growth was lower than the growth for the entire county.

After toll removal, all cases with sufficient data experienced an additional growth in population compared to the simulated trend. This additional growth may indicate that the tolling suppresses some of the potential growth that the fixed link represents.

We also analysed relocation patterns for the cases with population growth. For the cases close to cities, a large proportion of people move from the nearby municipalities to the islands. For the remainder of the fixed links, a larger proportion of the people moving to the areas came from municipalities that were farther away from the affected areas. The reason why more people move from the mainland in cases close to cities may be due to access to new residential areas and lower housing prices on the island than the city area on the mainland. This finding is supported by the cases close to Stavanger (1 and 2) and Bergen (3, 4 and 5), where average square metre prices on the islands were 40–80% of the equivalent prices in the cities in the period of analysis. Conversely, the more rural cases reported similar prices on the island and mainland.

5.4. Employment

Data on the number of employees and on commuting to and from the affected area are available only for cases 2, 7 and 9 due to data being available only from 2000. The DiD-values for employment are presented in.

Table 6, while data for commuting from and to the affected area are presented in Table 7 and Table 8, respectively. Note that similar trends are only found in some of the observations.

Cases 2 and 7 experienced an increase in the number of employees five years after opening. Only case 2 experienced extra growth in the number of employees; however, the results are uncertain due to the development not being similar to the control group before the opening.

The commuting patterns show an increase in commuting both to and from the islands in all cases after five years, which may indicate a widening of the labour market. However, the similar trend conditions were only met for commuting to the island in cases 2 and 9.

Table 6
Development in number of employees (Source: (Nilsen et al., 2017)).

	Fixed link project	Similar trend before? (*t*-value)	Trend break in affected area? (*t*-value)	Trend break in control area? (*t*-value)	DiD-values Years after opening		
					1	3	5
2	Finnfast	No (−3.389)	Yes (−2.752)	Yes (−2.954)	*2.3*	*−5.7*	*6.1*
7	Eiksundsambandet	No (−3.220)	No (−2.006)	Yes (−5.740)	*2.4*	*8.1*	*11.4*
9	Atlanterhavstunnelen	Yes (−0.478)	No (−0.558)	No (−0.797)	−0.6	3.0	−1.1

Numbers in italic = Assumption of similar development before has not been met.

Table 7
Commuting from the island to the mainland. (Source: (Nilsen et al., 2017)).

	Fixed link project	Similar trend before? (*t*-value)	Trend break in affected area? (*t*-value)	Trend break in control area? (*t*-value)	DiD-values Years after opening		
					1	3	5
2	Finnfast	No (−5.518)	Yes (−2.649)	No (−0.420)	*5.2*	*10.3*	*19.6*
7	Eiksundsambandet	No (−3.046)	No (−1.356)	No (−0.701)	*−2.9*	*−7.1*	*3.4*
9	Atlanterhavstunnelen	No (−4.343)	No (−0.966)	Yes (−5.950)	*7.5*	*22.8*	*24.2*

Numbers in italic = Assumption of similar development before has not been met.

Table 8
Commuting to the island from the mainland. (Source: (Nilsen et al., 2017)).

	Fixed link project	Similar trend before? (*t*-value)	Trend break in affected area? (*t*-value)	Trend break in control area? (*t*-value)	DiD-values Years after opening		
					1	3	5
2	Finnfast	Yes (−1.459)	No (−1.521)	No (−2.128)	2.6	−13.4	7.9
7	Eiksundsambandet	No (−3.349)	No (−1.465)	No (−1.361)	*0.1*	*2.5*	*5.0*
9	Atlanterhavstunnelen	Yes (−0.384)	No (−1.833)	No (−0.798)	6.2	40.8	12.1

Numbers in italic = Assumption of similar development before has not been met.

6. Discussion

The cases in this paper represent a large increase in the accessibility between the islands that the projects connect and the mainland. The improvement in accessibility provides more opportunities for people to interact between the newly connected areas. The question raised in this paper is how this substantial increase in accessibility may affect the society on the island, represented by growth in population and the housing and labour markets. Furthermore, we question how the characteristics of the connected areas and travel time reductions influence the magnitude of these changes.

6.1. How do fixed links affect population development and the labour market on the connected island?

The results from the analysis show immediate growth in traffic the first year after the opening. These results were expected, as the increased accessibility provides easier access across the fjords. However, the more interesting part in this setting is the change from low or no annual growth to a large growth rate in the years after the opening. This increased growth rate indicates that long-term processes may be present since the traffic continues to grow. Similar changes are also found in previous studies including a few of the same cases (Andersen et al., 2016; Díez Gutiérrez et al., 2015).

The housing market experienced an increase in housing prices after 3 years, in all the cases with sufficient data. This increase in housing prices on the connected islands indicates an increased demand for housing on the island, as the islands become more attractive for residential settlements. The growth is also larger in the cases connected to cities. These findings are also in line with previous studies (Andersen et al., 2016; Christophersen et al., 2000; Díez Gutiérrez et al., 2015; Laakso, 1997). The importance of accessibility with respect to housing prices and residential location has been highlighted in numerous studies (e.g., (Osland, 2010; Wegener, 2004)). The growth in housing prices may have started even before the opening. However, the smoothing method used also averages out a bit of the trend break observed in the raw data in some of the cases.

Additional population growth due to the opening of a fixed link is not evident in all the analysed cases. Only the cases connecting the islands to the most populated areas experienced additional population growth according to the results. This finding is in accordance with the findings in previous studies (Andersen et al., 2016; Díez Gutiérrez et al., 2015; Meijers et al., 2012).

We also find indications of growth in employees and commuting to and from the island due to the fixed link. However, similar trends before are only found for commuting to the island. The data do not provide an explanation of the reasons for this growth. However, various factors may cause this growth in commuting. People may move from the mainland and retain their job there. In addition, people on the island may get new jobs on the mainland or vice versa. Furthermore, firms may establish new or increase the activity on the island, attracting more workers from the mainland. These findings support that fixed links appear to connect the labour market closer to the mainland. This finding is also in accordance with interviews with firms on these islands, reported in (Nilsen et al., 2017).

The toll removal provides an additional impact on the analysed variables. Both the traffic volumes and population growth are affected by the toll removal. Traffic volumes get another immediate increase, and the annual growth rate is higher than the situation with toll collection. Population development also experiences additional growth due to the toll removal. However, the toll removal did not influence housing prices as much as expected. The two cases with sufficient data did not experience further growth in the housing prices due to the fixed link. This finding may indicate that much of the potential growth effect from the fixed link was realised within the tolling period. The findings are also uncertain due to potential external effects in the control groups, as one of the control areas experienced sudden growth in the last two years. Overall, the cases with available data experience additional growth to both population and traffic when removing the toll. This finding may indicate that the full potential of growth is restricted to an extent during the tolling period.

6.2. How do the case characteristics influence the changes?

Combining the results from the housing prices and population growth may explain the causal relationship in the cases close to a city. A fixed link connects new areas to the city, available for residential or commercial development. The housing prices on the newly connected island tend to be lower than those on the mainland, providing new opportunities for cheaper housing on the island. However, the people moving to the island need to travel longer distances to be able to work in the city or utilise services only found in the city centre. This relationship is supported by the commuting results, which indicate an increase in commuters from the island to the mainland. Furthermore, the moving patterns also show that much of the population growth originates from the mainland in these cases. This finding is also in accordance with the mechanisms described in Wegener (2004).

The cases around the cities of Bergen and Stavanger (cases 1–5) experience significantly larger growth in population, housing prices and traffic volumes than the more rural cases in this analysis. Two characteristics appear to influence this additional growth. First, the connected island is located close to a large city, and the travel time between the city and the island is within an acceptable commuting time of approximately 45 min. Thus, the fixed links connect the island to the larger labour market on the mainland. The second characteristic is the relative difference between housing prices on the island and the mainland before opening. The fixed links joins the island with lower housing prices, providing access to more land for development close to the city. These two case characteristics contribute to the understanding of the differences observed between rural and urban cases in this paper.

The rural cases did not experience growth of the same magnitude as those close to cities. The fixed links positively affected growth in housing prices, while the results indicate only small or no additional population growth due to the fixed link during the tolling period. However, after the tolling period ended, these cases also experienced an additional increase in population. Much of the same process as described above for the urban cases may explain these findings but with lower magnitude than projects close to cities.

If we draw a line between cases close to cities or rural areas, the general trend is that fixed links promote growth in housing prices and population. The magnitude of the changes varies according to the characteristics of the fixed link and surrounding areas and appears to be affected by the population level on the mainland. However, other parameters may also influence the magnitude. The difference in square metre price between the mainland and the island can also influence the attractiveness of the island for development and population growth, as the housing costs are initially lower on the island. Travel time to the closest town on the mainland may also influence growth, and the availability of jobs may affect the attractiveness of an area.

6.3. Limitations and further research

Suitable cases for this analysis are limited in the Norwegian context due to data being available only on a municipality scale and due to limited availability of older time series. The method used assumes that the control group can represent how the development would have been without a fixed link. To meet this assumption, the development before the opening needs to be similar in the affected area and the corresponding control area. However, the control area may be affected by other factors than the affected area due to different characteristics. To avoid this issue, we chose control areas with similar population levels and industry composition in the same county. Furthermore, control areas close to the affected area may mutually influence one another, and this situation will exclude certain municipalities as control groups. Therefore, we consider the control areas as a suitable fit for the alternative development.

We also consider the simulated trend as a suitable alternative path of development for population. The population development changes more slowly, and the method provides indications of whether the affected island attracts a larger proportion of the population growth than the remainder of the county. Furthermore, the use of the county in the simulated trend also involves the affected municipality. This use may provide a bias in the results. However, the proportion of population in the affected municipality is less than 5% for all cases except case 8 (9%). Due to this low proportion of the county population, we consider this to be a minor bias in the results. Furthermore, a positive DiD-value in the population variable shows that the island attracts a larger proportion of the population in the county than before the fixed link was built.

The construction time for these projects is normally 3 to 5 years. This finding may provide an anticipatory effect on the region, resulting in the development beginning prior to opening. Indications were found for the population in (Díez Gutiérrez et al., 2015). This finding may underestimate the DiD-values to an extent due to the contingent growth prior to the opening not being represented.

The cases in this study provide valuable information on some of the impacts fixed links have on the society on the connected islands. The transport model currently used in assessment in Norway does not include the impact from transport investments on society (e.g. population and employment numbers). Thus, the findings in this paper suggest that the methods should be expanded to include these impacts in future assessments of large projects such as fixed link projects. However, development of such a method is outside the scope of this study and remains for future research.

The scope of this study is to analyse the changes to society on the islands that obtain a fixed link connection. Our focus is on how the connected islands are affected by a fixed link connection. However, how these projects affect the surrounding areas and the region may be an interesting topic for future research. Engebretsen and Gjerdåker (2010) argue that these effects are redistributive effects rather than growth on a regional level. We agree that this may be the case on a regional scale, as the analysis of population relocation indicates that the observed population growth originates from the mainland. This finding may be analysed more in depth through the movement patterns in future studies. During our work with these cases, it appears that the cities expand towards the newly connected areas. This finding is also relevant to studies in the future. However, this paper will provide a strong foundation for further analysis on whether the growth on the islands happens at the cost of less growth elsewhere in the region or is actually additional growth for the region.

7. Conclusion

This study analyses changes in population, housing and the labour market due to a fixed link replacing a ferry service. The large impact on accessibility represented by the fixed link induces traffic growth, both immediate growth and a higher growth rate in the following years. The results show that one of the underlying reasons for this increased annual growth rate is that the islands become more attractive as residential locations. This finding is reflected by the large growth in housing prices and population on the connected islands. Furthermore, we find indications of increased commuting to and employment on the connected islands. The magnitude of these changes may vary according to the characteristics of the connected mainland. We find that islands close to cities experience larger growth in population and housing prices than islands connected to rural areas. Based on these findings and our knowledge of the Norwegian assessment methods, we recommend developing these methods to explain changes to society in future assessments of fixed link projects, particularly for projects close to cities.

Acknowledgements

This research is part of the "The E39 Coastal Highway Route" project by the Norwegian Public Roads Administration and co-funded by Norwegian University of Science and Technology, Rambøll Norway and The Research Council of Norway. We would also like to thank Helge Sandvik and Mahmoud Ebrahimi in the Norwegian Public Roads Administration for help with collecting data on traffic volumes.

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Paper 4

Case Studies on Transport Policy 7 (2019) 57–63

Contents lists available at ScienceDirect

Case Studies on Transport Policy

journal homepage: www.elsevier.com/locate/cstp

Generated and induced traffic demand: Empirical evidence from a fixed link toll removal in Norway

María Díez-Gutiérrez[a,*], Stig Nyland Andersen[a,b], Øyvind Lervik Nilsen[a,c], Trude Tørset[a]

[a] Norwegian University of Science and Technology, Høgskoleringen 7A, Trondheim 7491, Norway
[b] Norwegian Public Roads Administration, Askedalen 4, Leikanger 6863, Norway
[c] Rambøll Norway, Fjordgaten 13, Tønsberg 3103, Norway

ARTICLE INFO

Keywords:
Fixed link
Toll removal
Generated traffic
Induced traffic
Destination choice

ABSTRACT

Large infrastructure projects may significantly improve accessibility. Nevertheless, many such projects have toll schemes, and the total benefits may not be realised until the tolls have been removed. In response to toll removals, the traffic volumes on the corresponding infrastructure may change because of generated or induced traffic, the former being related to changes in travel patterns and the latter to new traffic. Predicting the consequences in advance can improve traffic forecasts and, thus, the assessment of infrastructure projects. Using the case of an island, this study analysed the traffic counts and a panel data survey of 132 respondents before and after toll removal. A mixed logit model was estimated to detect the role of the toll in users' destination choice. The results showed that the toll did not affect destination choice significantly. Therefore, extra traffic may have resulted from route change, transportation mode change, or other potential structural changes. There were no clear indications of potential induced traffic, although this factor should be studied further.

1. Introduction

Transportation infrastructure investments are important in national budgets; consequently, they should be carefully assessed. Small changes in traffic volumes represent substantial impacts on the benefits of a project (Mackie, 1996; Cervero, 2002). Therefore, accurate traffic forecasts play a crucial role in achieving the most effective prioritisation of projects and, thus, the allocation of funds towards greater societal benefit. This study used empirical data to identify the traffic effects that would result from removing the toll at the Osterøy Bridge, which is a fixed link on the west coast of Norway, and will contribute to the scarce body of literature of ex-post studies after toll removal in projects of this type.

In transportation analyses, decisions of where, when, and how people travel are mostly based on generalised costs (GC). The GC of a trip is the sum of the value of the trip's distance, time, and direct costs (Ortuzár and Willumsen, 2011). Consequently, projects that significantly change the GC may have substantial effects on traffic demand. This is the case for ferry replacement projects, in which a ferry service is replaced by a bridge or a tunnel, joining areas previously separated by geographical barriers. These projects, considered large infrastructure projects, drastically change the accessibility conditions of the connected areas. These projects represent significant travel time savings and dismiss the need for considering ferry schedules and weather conditions that could affect the availability of the connection, as well as overcome potential capacity problems. Despite a reduction in travel time, the toll cost may supress potential travel demand and thus may not present their full benefits before eventual toll removal (Baldacchino, 2007). For example, in the case of the Øresund bridge, lowering the toll to half of the current amount would quadruple traffic volumes (Matthiessen, 2004). In Norway, the average toll rates for ferry replacement projects are two to eight times higher than other tolls (Odeck and Kjerkreit, 2010), indicating their greater potential effects.

Despite the importance of predicting traffic effects on transportation assessments, previous ex-post evaluations of ferry replacement projects have shown significant inaccuracies. Some examples are the Channel Tunnel between England and France, for which the forecast traffic five years after opening was overestimated by more than 50% (Flyvbjerg et al., 2003), or the Øresund Bridge between Sweden and Denmark, which also overestimated the predicted traffic in the first year after opening by approximately 20% (Knowles and Matthiessen, 2009). In contrast, two Danish fixed links, the Great Belt and the Sallingsund Bridge, exceeded forecasts by more than 70% and 20%, respectively (Knowles and Matthiessen, 2009; Skamris and Flyvbjerg, 1996). In Norway, despite Odeck and Welde (2017) having revealed good traffic forecasts in toll road forecasts, Tørset et al. (2013) noted the

* Corresponding author.
E-mail address: maria.diez@ntnu.no (M. Díez-Gutiérrez).

https://doi.org/10.1016/j.cstp.2018.11.007
Received 9 January 2018; Received in revised form 6 October 2018; Accepted 16 November 2018
Available online 17 November 2018
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weaknesses of ferry replacement projects. The traffic volumes after the opening of Eiksundsambandet were more than double those projected by simulations (Samferdselsdepartementet, 2000). For Trekantsambandet, the traffic in the first year was 14% above forecasts (Odeck and Welde, 2017). Consequently, there is a need for improved knowledge of traffic effects triggered by these transportation projects.

The extra traffic from a transportation network change can be divided into generated and induced traffic demand (Litman, 2015), both of which should be included in transportation assessments (Johnston et al., 2001; Ponnu et al., 2015; Seeherman and Skabardonis, 2016). Generated traffic refers to existing traffic that modifies its route, destination, or transportation mode. Variations in a route towards a new or updated road are likely to occur when a new project minimises total travel expenses (Knorr et al., 2014). Changes in destination because of a transportation project may occur for activities that can be transferred to other areas. Davidson et al. (2014) highlighted the need for further research on changes in users' destination choice. Based on a stated preference survey, Davidson et al. (2014) found that users' destinations are less likely to change as a result of a transportation project, which is consistent with a study by Fox et al. (2011) that also found that destination choice is less likely to be changed than users' mode choice. Nonetheless, certain trip purposes may influence the sensitivity of destination choice because, for example, the mechanisms behind the decision process for grocery shopping differ from those underlying occasional shopping (Suel and Polak, 2017). Several examples of changes in transportation mode can be found in the literature. The hypothetical introduction of a toll in the Netherlands would lead to a shift from private car usage to public transportation for more than 15% of respondents (Ubbels and Verhoef, 2006); in New Zealand, the percentage was as great as 21%, including both walking and public transportation (O'Fallon et al., 2004).

In addition, large transportation projects may lead to traffic effects because of structural changes, e.g., changes in land use (Holl, 2006), territorial cohesion (Stepniak and Rosik, 2013), and labour markets (Louw et al., 2013). Other indirect effects, such as urban and economic growth, could also trigger increased interaction between the areas adjoined by the project (Vickerman, 1998; Holved and Preston, 2005). Disregarding the spatial distribution of the benefits of a project could result in undesired policy outcomes (Metz, 2017). The body of international literature on structural changes for fixed links is large; some examples of studies include those by Jensen-Butler and Madsen (1996), Bråthen and Hervik (1997), Wang and Meng (2004), Hay et al. (2004), Meijers et al. (2012), Díez Gutiérrez et al. (2015), Wu et al. (2017), and Nilsen et al. (2017). Andersen et al. (2018) and Tveter et al. (2017) presented some of these changes for the same studied case, and thus, this study did not focus on potential structural changes.

Unlike generated traffic, induced traffic demand can be explained based on the principles of latent travel demand, specifically, when caused by greater expected costs compared with the expected benefits of a trip (Van Der Loop et al., 2016). If latent travel demand exists, more trips are expected after the GC have been reduced because of a transportation project. Although induced traffic may be an important part of the total traffic for projects that significantly change the GC, traditional four-step transport models do not account for this traffic type (Schiffer et al., 2005).

Some researchers in the field of induced and generated traffic have assumed that all extra traffic is induced traffic (Cervero, 2003) and have used changes in vehicle miles driven (VMD) as an indicator. Nonetheless, changes in VMD do not allow for identification of the origin of the extra traffic because such changes only account for the extra distance driven. In contrast, this study identified each component of the origin of extra traffic. This approach can expand the knowledge of user reactions towards toll removal and thus improve traffic forecasts.

Under these premises, the aim of this study was to identify the generated and induced traffic for a case study by observing travel behaviour before and after the removal of the toll scheme. Therefore, the research questions addressed are as follows:

1) How much generated traffic follows a fixed link toll removal?
   a. How did toll removal affect the *route choice*?
   b. How did toll removal affect the *destination choice*?
   c. How did toll removal affect the *transportation mode choice*?
2) How much induced traffic is generated by a fixed link toll removal?
   a. How did toll removal affect the *trip frequency*?

This study analysed the traffic changes based on counts for both available connections from the island to the mainland. In addition, 132 responses from a panel revealed preference survey on the island in relation to changes before and after the event were studied regarding destination choice, mode choice, and trip frequency.

The case study is further defined in Section 2. The data are described in Section 3, and the methodology is further explained in Section 4. The results are presented and discussed in Section 5. Section 6 presents the conclusion and areas for further study.

2. Case study

Osterøy is an island on the western coast of Norway with a population of approximately 7000. The island is close to the city of Bergen, the second largest city in Norway, with more than 200,000 inhabitants. Fig. 1 shows the island and other nearby areas defined according to municipality or district borders and geographic localisation.

Osterøy was connected to the mainland before 1997 by two ferry services, one on its west coast (blue connection) and another to the south (red connection). The former is still operated by a private company with a price of EUR 5.80 (2016 base price) and headway of 30 min. The average travel time between the island and Bergen using this connection is 65 min (including 15 min of waiting time, equivalent to half of the headway).

The southern ferry was replaced by a bridge in October 1997. An electronic toll was implemented until 2015 to finance the infrastructure and the connecting roads on the island (Samferdselsdepartementet,

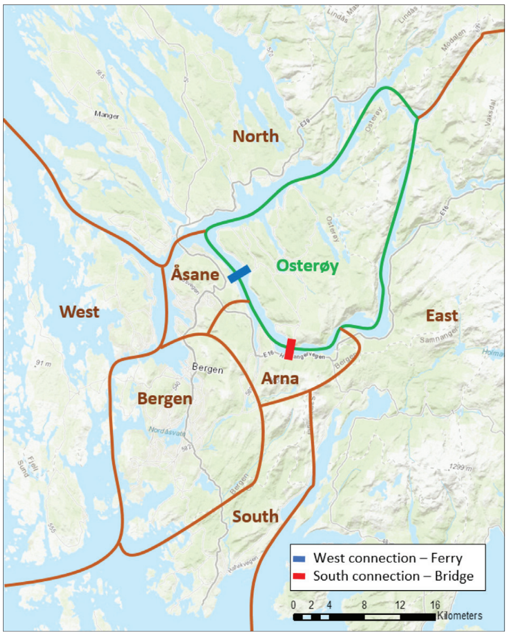

Fig. 1. Localisation and destination zones.

Table 1
Characteristics of the areas in 2016.

	Arna	Åsane	Bergen	East	West	North	South	Osterøy
Population density (pop/km^2)	120.9	616.4	926.7	9.7	165.4	28.6	97.9	21.7
Employee density (number of employees/km^2)								
Total	45.4	202.6	577.9	3.6	38.7	8.6	26.9	6.1
Service sector	12.5	52.5	99.1	0.4	6.7	1.2	5.9	0.5
Leisure sector	1.7	25.5	162.1	0.3	4.8	0.8	2.4	0.3
Average travel time from Osterøy (min)	25	35	45	> 35	> 55	> 45	> 45	15

2007). Although several factors may affect the acceptance of a toll scheme (Jaensirisak et al., 2005), it is unlikely that some users chose an alternative route to avoid the toll, as users were already familiarised with this financing method in Norway. The toll of the bridge was equivalent to the previous ferry ticket, approximately EUR 6.20 (2016 base price). The average travel time between the island and Bergen was reduced from 95 min (including 20 min of waiting time) to 50 min. Regarding public transportation, the frequency of bus services did not change after toll removal.

In this case study, seven potential destinations from the island in addition to Osterøy were defined. The most relevant characteristics that might influence the number of trips to each area, population density, employee density, and travel time are detailed in Table 1.

3. Data

This study was based on two datasets: traffic counts at the south and west connections and a panel revealed preference survey. Data concerning the number of public transport passengers were not available.

The traffic counts corresponded to the average annual daily traffic (AADT) for light traffic from 1990 to 2017 at the connections between Osterøy and the mainland. Light traffic volumes were assumed to correspond to passenger cars with and without trailers, vans, and vehicles shorter than six metres. Data pertaining to traffic on the ferries were provided by the ferry company based on electronic ticketing (Statens vegvesen, 2014a). Traffic on the bridge was registered by the Norwegian Public Road Administration (Statens vegvesen, 2014b).

The panel data were collected by two surveys, one before and one after the toll removal on the fixed link to detect short-term changes. The first survey was sent by mail to all households on the island (3161) in March 2015. The total number of respondents who completed the first survey was 476, a 15.1% (476/3161) response rate, representing 6.1% (476/7842) of the municipality population. Nonetheless, the percentage of valid answers was reduced to 4.5% (352/7842) of the population. The respondents with valid answers were contacted in March 2016 by email or telephone to conduct the second survey. The final response rate for the valid panel data was 1.7% (132/7842) of the population.

The surveys were conducted among the residents of the island; however, other users could also be affected by toll removal. This was the case for residents outside Osterøy who travel there for shopping, leisure or private purposes; however, there are a small number of attractions on the island. There may also be commuters to the island; however, these users represented less than 5% (418/7842) of the municipality population. Therefore, it was assumed that most of the users influenced by toll removal were represented by the survey.

The most relevant socioeconomic characteristics of the respondents were compared with the population in the municipality to better understand the representativeness of the sample. The population between 18 and 24 years old was underrepresented in the sample; hence, students were underrepresented. The population older than 75 years old was also slightly underrepresented. However, the share of retired people was slightly overestimated, which might be compensated for by the number of respondents between 65 and 74 years old. The fractions of male and female respondents were 49 and 51%, respectively, nearly the same as in the total population.

In addition to socioeconomic characteristics, the respondents were directly asked whether toll removal affected them in terms of changing residence, job, or car ownership. For these variables, with only two possible answers, the margin of error of the sample for a 95% confidence interval was 8.4%. This measure indicates the deviation between the sample answers compared with those of the population for 95% of the cases. As an example, should 20% of the sample be affected by the toll removal, the proportion of the total population affected can be estimated by adding and subtracting the marginal error, i.e., between 11.6% (20–8.4) and 28.4% (20 + 8.4).

Respondents were also asked for the number of times and the main purpose for visiting the eight destinations on the last working day. However, some respondents reported their weekly trips instead, while others were confused about the classification of the trip purposes. Respondents also stated the number of times they used the ferry or the fixed link, the transportation mode, and who paid the toll or ferry ticket. Some of the valid answers are gathered in Table 2.

The number of times a destination was visited, stated in the questionnaire, corresponded with users' purposes. Some assumptions were made to estimate the number of trips per person. Trips made for work, private, leisure, and other purposes were counted as two trips, corresponding to the dotted arrows in Fig. 2. In the case of combined private and shopping trips, the trips were counted as three trips, corresponding to the dashed arrows in Fig. 2. A commuting trip was defined as one

Table 2
Survey responses.

	Before toll removal (2015)			After toll removal (2016)		
Answers from last working day	N	Mean	Max	N	Mean	Max
No. of commuting trips out of Osterøy	72	–	–	55	–	–
No of commuting trips in Osterøy	34	–	–	31	–	–
No. of shopping trips out of Osterøy	35	1.17	4	27	2.26	9
No. of shopping trips in Osterøy	47	1.09	2	31	1.77	5
No. of leisure trips out of Osterøy	52	1.25	6	60	1.37	5
No. of leisure trips in Osterøy	37	1.51	8	33	1.79	6
No. of bridge crossings (car)	61	1.38	8	41	1.44	4
No. of bridge crossings (public transport)	7	1.29	2	4	1.25	2
No. of bridge crossings (other transport mode)	0	0	0	0	0	0
No. of ferry crossings (car)	36	1.11	2	34	1.32	4
No. of ferry crossings (public transport)	11	1.46	3	10	1.1	2
No. of ferry crossings (other transport mode)	2	1.5	2	5	1.2	2

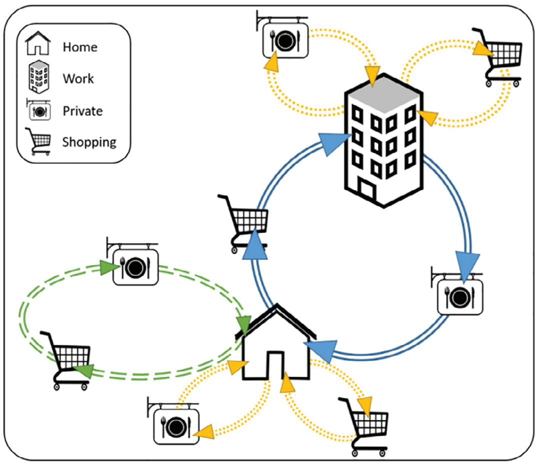

Fig. 2. Trip frequency description (each arrow is a trip).

from home to work and vice versa and was counted as two trips. If other activities were performed in combination with commuting, an extra trip was added, corresponding to the solid arrows in Fig. 2.

4. Methodology

Price elasticity is defined as the percentage change in demand (D) corresponding to a 1% change in travel cost. Price elasticity was used to relate the traffic effects from this case study to the toll removal of other fixed links. The formulation used to estimate elasticity in this study was the arc-elasticity, defined by Eq. (1) (Litman, 2013).

$$E_d^{arc} = \frac{lnD_2 - lnD_1}{lnGC_2 - lnGC_1} = \frac{\Delta lnD}{\Delta lnGC} \tag{1}$$

The travel cost was assumed to be the GC of an average trip using the fixed link, indicated in Eq. (2).

$$GC = tollfee + distance * valueofdistance + time * valueoftime \tag{2}$$

The average trip distance was assumed to be 30 km, estimated as the average distance between the island and the main urban districts of the three most visited municipalities outside of the island: Bergen, Arna, and Åsane. The average speed was assumed to be 50 km/h. The value of distance used was 0.30 EUR/km, corresponding to the official Norwegian value (Statens vegvesen, 2018). The value of time was assumed to be 12 EUR/h, based on an average of different trip purposes and lengths from a national value of time study (Ramjerdi et al., 2010).

In addition to price elasticities, this study used discrete choice models to estimate potential destination changes due to toll removal. Most discrete choice models are based on random utility theory (Ortuzár and Willumsen, 2011), which states that an individual (q) associates with each alternative (j) an index of preference, called utility (U_{jq}). It is assumed that the individual chooses the alternative that maximises his or her utility, according to the utility maximisation rule. The mixed logit model (ML) is one of the most versatile models because it can approximate any discrete choice model (McFadden and Train, 2000). The structure of the ML, Eq. (3), can be derived from the multinomial logit model by accounting for the random heterogeneity in the parameters for specific variables, the random heterogeneity in the preference for specific alternatives, and the correlation among alternatives.

$$U_{jq} = \sum_{k=1}^{K} f(\beta_{qk}) X_{jqk} + f(\beta_{jq}) + \varepsilon_{jq} \tag{3}$$

where k comprises the set of observed variables (X_{jq}) for each alternative and individual, $f(\beta_{qk})$ are the parameters for each variable, $f(\beta_{jq})$ are the parameters for each alternative, and ε_{jq} is the error term. Both types of parameters vary across individuals and represent heterogeneity in the population's preference; therefore, the parameters correspond to a density function. Eq. (4) shows the decomposition of the terms.

$$U_{jq} = \sum_{k=1}^{K} f(\beta_k + \nu_{qk}\sigma_k) X_{jqk} + f(\beta_j + \nu_{qj}\sigma_j) + \varepsilon_{jq} \tag{4}$$

where β and σ are the mean and standard deviation of the parameter (k) for alternative (j); ν represents a normal distribution (0,1) among individuals.

In this model, there is also an error term that cannot be estimated; therefore, no exact solution exists. Assuming that the error term is Gumbell-distributed, the probability of visiting each destination within the choice set is computed according to Eq. (5).

$$P_{jq} = \frac{exp(V_{jq})}{\sum_{i \in A(q)} exp(V_{iq})} \tag{5}$$

where i comprises the set of available alternatives (A) for each individual.

Scott and He (2012) stated that the choice set should be personalised for each individual because universal choice sets could disregard accessibility conditions, i.e., not all individuals can reach a destination within a reasonable amount of time to justify it as a daily trip. Despite that view, the choice set was considered to be universal because all of the destinations were accessible from the island by using public transportation in less than one hour when planned according to the corresponding timetables. Therefore, the choice set consisted of nine alternatives: seven destinations outside the island ('Arna', 'Åsane', 'Bergen', 'East', 'West', 'North', and 'South'), the island ('Osterøy'), and an alternative for those not travelling ('no trip').

The dataset for this model was created based on the panel data from the surveys. Therefore, a minimum of two observations per person were used, half of them corresponding to 2015 with a positive dummy variable for toll and the other half based on the 2016 survey without the dummy variable. In addition, a person travelling to two destinations for leisure purposes provided two observations, each one with a different selected destination, and a person travelling to one destination for leisure and shopping purposes also provided two observations. In total, 614 observations were used to estimate the model.

5. Results and discussion

The AADT in the western and southern connections are represented in Fig. 3.

For the western connection, the AADT changed from 964 to 768 at the opening of the bridge of the southern connection, which represented a trend shift, as after the event, the traffic presented a negative development. After toll removal in the southern connection, the AADT in the western ferry was also reduced from 519 to 455. For the southern connection, there was a significant change in the trend before and after the opening of the bridge, in addition to an immediate traffic increase of 112%, from 559 to 1187 AADT. Regarding toll removal, it was not possible to estimate potential breaks in the trend given the sparse data after the event, which corresponded to only two years. Nonetheless, the increase in traffic was 16%, representing an increase in the traffic counts from 3309 to 3839 AADT.

The price elasticity because of the toll removal at the Osterøy Bridge was −0.41, i.e., for a reduction of 1% in the travel cost, the traffic increased by approximately 0.41%. This value was slightly lower than the average national value developed following toll removal (Odeck and Bråthen, 2008), which was −0.56, although this value included variations from −0.03 to −2.26. Therefore, the value in our study was within the range. In the following subsections, the potential causes of

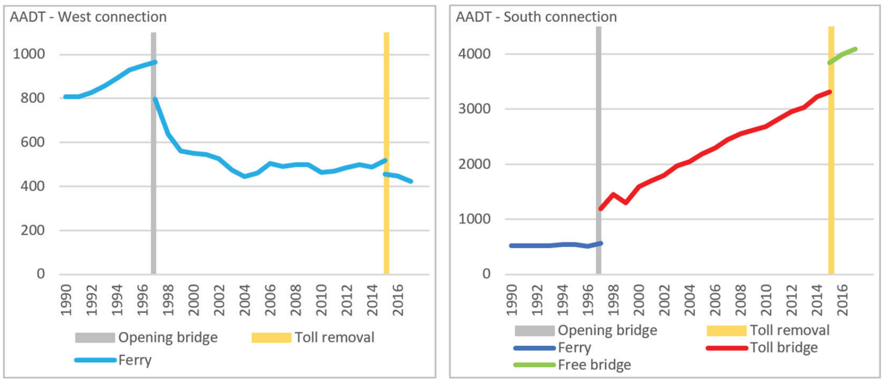

Fig. 3. Average annual daily traffic (light vehicles) on the western connection (left) and southern connection (right).

this increment due to changes in travel behaviour are analysed.

5.1. How did toll removal affect users' route choice?

Because there are only two connections out of/into the island, the changes in AADT in both indicate the potential route change. The experienced changes due to toll removal were a reduction of 64 vehicles on the ferry and an increase of 530 vehicles on the fixed link. Therefore, approximately 12% (64/530) of the traffic increase on the fixed link after toll removal was explained by a route change from the ferry connection.

In addition, whereas the ferry connection traffic showed a decreasing trend after the opening of the fixed link, the traffic for the fixed link increased every year, which could represent structural changes. The reduction in travel time because of the fixed link and other road improvements in the island, together with lower housing prices compared with the urban surroundings, may lead to a higher demand for housing, which could lead to potential population growth over time. These relocation effects may explain the trend, particularly for new residents who continue to work on the mainland and thus increase the number of commuting trips over the fixed link.

5.2. How did toll removal affect users' destination choice?

A mixed logit model was estimated to identify the variables that affected the destination choice for the residents of the island and the role of the toll for leisure and shopping trips. The variable pertaining to the toll was only present for respondents who completed a trip for the same purpose in both situations (with and without the toll). The model also accounted for travel time, including random heterogeneity, as well as potential trip combinations, i.e., if there were other trip purposes to the same area. Moreover, the model included parameters to account for potential correlations among the alternatives. Different model specifications were tested, including the socioeconomic characteristics of the respondents and zone characteristics. The results of the final model are presented in Table 3. The alternatives in the choice set were 1: 'Arna', 2: 'Åsane', 3: 'Bergen', 4: 'East', 5: 'West', 6: 'North', 7: 'South', 8: 'Osterøy', and 9: 'no trip'.

According to the results, the toll did not affect the users' decision regarding destination choice for any of the purposes, given that the hypothesis that the parameters of the toll variables equal zero could not be rejected with a confidence level greater than 95%. Thus, the increase in traffic on the fixed link was not because of a destination change. However, travel time did influence destination choice; there was taste heterogeneity for time among the sample because the standard deviation of the travel time coefficient was significantly different from zero at the 95% confidence level.

Table 3
Parameter estimates from the mixed logit model.

Variable	Alternative	Value	Std. error	*t*-test	Sig.
Constant_no trip	9	3.350	0.933	3.59	*
Constant_zone 2	2	3.190	0.880	3.63	*
Constant_zone 3	3	2.180	1.230	1.77	
Constant_zone 4	4	0.294	1.090	0.27	
Constant_zone 5	5	3.320	1.470	2.26	*
Constant_zone 6	6	2.980	1.120	2.66	*
Constant_zone 7	7	2.550	1.110	2.30	*
Constant_zone 8	8	3.950	0.777	5.08	*
Travel time	1–8	−0.116	0.039	−2.94	*
Sigma travel time	1–8	−0.038	0.008	−4.63	*
Toll for shopping trips	1–7	0.626	0.581	1.08	
Toll for leisure trips	1–7	0.751	0.507	1.48	
Workplace in the destination	1–8	2.060	0.483	4.26	*
Leisure in the destination for shopping trips	1–8	1.260	0.440	2.86	*
Sigma leisure in the destination	1–8	2.380	0.782	3.05	*
Shopping in the destination for leisure trips	1–8	1.270	0.338	3.75	*
Sigma shopping in the destination	1–8	1.730	0.499	3.48	*
Pensioners	1–3	1.670	0.489	3.41	*
Leisure employee density for leisure trips (if no workplace)	1–8	0.013	0.005	2.79	*
Shopping employee density for shopping trips (if no workplace)	1–8	−0.002	0.007	−0.30	
Correlation all zones	1–8	0.723	0.538	1.34	
Correlation zone out of the island	1–7	−1.780	0.548	−3.25	*
Correlation zone 1,2	1,2	−0.333	0.391	−0.85	
Correlation zone 1,3	1,3	3.070	0.796	3.86	*
Correlation zone 2,3	2,3	0.621	0.360	1.73	
Number of draws	1000				
Initial log likelihood	−1349.096				
Final log likelihood	−827.593				
Rho-square ($\rho^2(0)$)	0.387				

* Significant at the 95% confidence level.

Regarding the combination with other trips, if the respondent worked in the zone, there was a clear increase in the attractiveness of that zone. This variable was fixed, at least in the short-term; therefore, this variable only described how the location of the respondent's work affected the destination for other trips. At the same time, when the respondent made other trips to the area, the attractiveness to the area also increased. In the case of shopping trips, the sample presented random heterogeneity for the influence of leisure trips in the zone, i.e.,

Table 4
Trip frequency according to a national survey (Hjorthol et al., 2014) and the two surveys in 2015 and 2016.

	National survey 2013/2014	Survey 2015	Survey 2016
Trip frequency	3.26	4.34	5.18

some respondents may have found the zone highly attractive for shopping if they were already visiting the zone for leisure activities, but others may not have felt the same way. Similar results were found for leisure trips.

Some characteristics of the zones affected their attractiveness; these characteristics were tested for those not working in the area. The employee density in the leisure sector was significant, although it was not relevant in the service sector, which could mean that shopping was less affected by the available choices because the options were very similar. The three closest zones were most attractive for pensioners, who travelled more often out of the island than did other users. In addition, there were some correlations among the zones visited out of the island, as well as between zones 1 and 3, because the null hypothesis that the parameters equal zero could not be rejected with a confidence level greater than 95%.

The model was based on a universal choice set, i.e., all individuals had the same set of alternatives within the destination choices. However, some activities could be highly specific and thus only available in a few areas. In such cases, the toll removal may have had no impact because of the inelasticity of the decision. This relationship could have affected the model results if it held for many respondents.

5.3. How did toll removal affect users' transportation mode choice?

The results of the surveys showed that 55 of the respondents were commuting out of Osterøy in both 2015 and 2016; 24 of them crossed the fixed link in 2016 by car, 2 more than in 2015. Thus, there was a transfer of 8% (2/24) in car traffic derived from public transportation. Nevertheless, data regarding the number of passengers using public transportation to the island could have better explained the potential changes because it would have covered all of the users of the bridge. A study of a toll removal in another city in Norway, Trondheim, also showed an increase of private car share due to a mode change from public transportation and soft modes (Meland et al., 2010). In our study, the share of the soft modes going out of the island was insignificant due to the long distances.

Another indirect aspect that may affect a transportation mode change is car ownership; increasing accessibility to more vehicles in the household could increase their use at the expense of a decrease in the use of other transportation modes. Nonetheless, only 3 of the respondents who changed the number of vehicles (58) in their households listed toll removal as the cause, representing 5% of those respondents.

5.4. How did toll removal affect the trip frequency?

Trip frequency was considered to be the number of trips per person per working day. Because the aim of this study was to discover the effect of toll removal on the fixed link, changes in trip frequency were only estimated for the respondents using it (n = 66). The average trip frequency determined from both surveys and the value at the national level are shown in Table 4.

In general, the values indicated by the two surveys were significantly greater than those at the national level. The difference may have been because the latter set also includes weekends in the estimation. Nonetheless, Hjorthol et al. (2014) noted that there could be selection bias given the low response rate at the national level. In addition, the traditional methods of maintaining trip diaries could cause an underestimation of short trips (Bohte and Maat, 2008; Wilson, 2004). In the survey, respondents did not have to specify the features of each trip but could write the total number, which could have overcome the potential problem of underestimating trip numbers in the national survey.

Given the differences between the surveys, changes in the number of times each respondent crossed the bridge were observed. The values decreased after the toll was removed; despite the apparent increase in trip frequency, the extra trips did not utilise the fixed link. This finding can be explained by the nature of the survey: the data corresponded to an arbitrary working day, and the differences thus may not have been because of the toll removal but because of other factors; for example, a person could participate in a leisure activity on Wednesdays but not on Thursdays. This justification is consistent with the responses from the survey; as in the case of commuting, there were large differences. Another factor could be potential occupation changes of respondents. Moreover, the low number of respondents using the bridge may have resulted in a high sensitivity to trip frequency changes.

6. Conclusion

This study contributes to the scarce literature of ex-post studies after the toll removal of fixed link projects, using the case study of a Norwegian island. The study provides a quantitative analysis of the short-term changes in traffic demand and its origin. The elasticity revealed an increase of 0.41% in traffic demand for a 1% GC reduction. Based on the traffic counts, the change in route accounted for 12% of this demand increase. Based on the surveys, 8% was the result of a change from public transportation to a private car. An analysis of the panel data indicated that the toll removal did not affect destination choice. There were no clear indications of induced traffic based on changes in the number of times the respondents crossed the Osterøy bridge. A follow-up study in a few years could provide further knowledge of traffic effects, adding long-term results.

Improved knowledge about the generated and induced traffic demand in the short-term can help identify potential sources of errors from traffic forecasts by transport models. For instance, transport models that predict significant changes in destination choice should be carefully revised. The fact that not all of the traffic increases could be explained may indicate that structural changes generate traffic, and thus, including changes in land use could also improve the transport models. Traditional four-step transport models do not include induced traffic, which is in line with the observed results. Nevertheless, given the weaknesses in capturing this type of traffic in this study, further research should focus on improving travel data collection to better identify changes in trip frequency.

Acknowledgements

This research was supported by the Norwegian University of Science and Technology, the Norwegian Public Roads Administration, Rambøll Norway, and the Research Council of Norway. The authors would like to thank Professor Elisabetta Cherchi for her valuable and insightful comments regarding the methodology.

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Paper 5

Transport Policy 77 (2019) 58–67

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

Perception of inconvenience costs: Evidence from seven ferry services in Norway

María Díez-Gutiérrez*, Trude Tørset

Norwegian University of Science and Technology, NO-7491, Trondheim, Norway

ARTICLE INFO

Keywords:
Ferry
Fixed link
Inconvenience costs
Partial proportional odds model

ABSTRACT

Transport projects are assessed mainly by cost-benefit analysis (CBA). Despite its wide use, this method has some weaknesses, such as using simulated traffic volumes as an input. These traffic volumes for future projects are estimated according to user travel patterns based on the new generalised costs (GC), which include travel time, distance, and direct costs. Nevertheless, many large transport projects dramatically change accessibility; thus, other factors could play important roles in the process. Notably, ferry replacement projects reduce travel times, eliminate waiting times, and provide a reliable and flexible connection 24/7. Some of these changes, known as inconvenience costs (IC), are not included in the GC.

This study contributes to the scarce literature on the IC concept and relates IC to the factors that different users value. The results, which are based on 9,878 answers from onboard ferry surveys in 2011 and 2016, revealed that inconvenience factors, such as trip planning and the lack of accessibility to family/friends, leisure activities and a broader labour market, are important. Thus, projects that improve these factors might trigger additional changes in user travel patterns. Four partial proportional odds models were estimated to relate the inconvenience factors to the trip and the socioeconomic features of users. The results showed that the waiting time, frequency of trips via the connection, trip purpose, gender, age and income played important roles in the perception of different factors. In addition, a quantification of the differences in the perceptions among the categories of the variables was described based on the average marginal effects (AME).

1. Introduction

Transportation projects generate changes in traffic volumes as a consequence of the variations in user travel patterns, i.e., where, when, and how people travel. Traditional estimations of these travel patterns are based on minimising generalised costs (GC), which are the sum of travel time, distance, and direct costs (Ortúzar and Willumsen, 2011). Nevertheless, many large transportation projects vastly modify accessibility conditions; thus, other factors can also affect user behaviour. Similar to the value of time, these additional factors can differ according to the trip characteristics or the user. Consequently, estimating travel patterns based only on the current GC and disregarding other factors might result in biased traffic simulations, leading to inaccurate cost-benefit analyses (CBA) (Flyvbjerg (2009); Ettema et al. (2013)).

Examples of large transportation projects include ferry replacements. Such projects refer to fixed links, bridges and/or tunnels that permanently join areas previously connected by ferry services; therefore, they eliminate the waiting time, reduce the travel time and provide a 24/7 connection. There is a growing interest in these projects, as seven ferries along the E39 Coastal Highway Route on the west coast of Norway are scheduled for potential replacement (Statens vegvesen, 2018a). Many other countries, such as Canada, Denmark, England, Italy, the Netherlands, and Scotland, have ferry services that could potentially be replaced in the future. Moreover, the similarities with other large infrastructure projects, in terms of accessibility changes, make this knowledge interesting to a broad international audience.

Fosgerau (2009) noted that users of a scheduled service have a cost associated with planning their trips, and replacing a ferry with a permanent connection can reduce this cost, which is not included in the current GC. There is also a lack of knowledge regarding the physiological effects of this replacement Knowles and Matthiessen (2009). Tørset et al. (2013) discussed the shortcomings of disregarding the extra benefit or reduction of the inconvenience cost (IC) perceived by the users of these projects. The concept of IC includes the lack of reliability due to capacity or weather conditions; the lack of flexibility to decide when to travel, as it depends on the ferry schedule; and the waiting time in the ferry quay (Bråthen et al., 2003). This study contributes to the limited literature on the IC concept by addressing the

* Corresponding author.
E-mail address: maria.diez@ntnu.no (M. Díez-Gutiérrez).

https://doi.org/10.1016/j.tranpol.2019.03.002
Received 7 September 2018; Received in revised form 29 January 2019; Accepted 5 March 2019
Available online 06 March 2019

following research questions:

1) How do trip characteristics affect the perception of IC?
2) How do socioeconomic characteristics affect the perception of IC?

A survey of seven Norwegian ferry services was conducted in 2011 and repeated for one service in 2016. The questions focused on the characteristics of the respondents, their trips, and their scaled opinions with respect to nine potential inconvenience factors, such as better accessibility to a broader labour market or family, shopping or leisure activities or reduced trip planning requirements. Respondents valued the importance of these factors when replacing the ferry service with a permanent connection. These factors were presented instead of the IC to facilitate respondents to value them. In total, 9,878 valid answers were analysed using ordered logit models in this study. These models relate the importance of different inconvenience factors to the characteristics of the trip and user.

A more detailed literature review is gathered in section 2. The description of the data is presented in section 3, and the methodology in section 4. The discussion of the results is given in section 5. Finally, section 6 presents the conclusions, policy implications, and further research.

2. Literature review

In recent years, Norwegian traffic simulations have been questioned because of the inaccuracy in capturing all the effects of ferry replacement projects (Hagen et al., 2010) (Ulstein et al., 2015). Ex post facto evaluations have shown that the traffic volume after the opening the Eiksundsambandet was more than double that based on simulations (Samferdselsdepartementet, 2000). For Trekantsambandet, the traffic in the first year was 14% above the forecasted load (Odeck and Welde, 2017). In the international context, several significant inaccuracies have also been observed. The traffic of the international fixed link of the Channel Tunnel between England and France was less than 50% of what was forecasted, even five years after the opening (Flyvbjerg et al., 2003). The traffic on the Øresund Bridge between Denmark and Sweden was only 80% of the simulated traffic during the opening year (Knowles and Matthiessen, 2009). In contrast, the traffic for two Danish projects, the Great Belt Fixed Link and the Sallingsund Bridge, exceeded the forecasted values by 73% (Knowles and Matthiessen, 2009) and 27% (Skamris and Flyvbjerg, 1996), respectively.

Traditional models do not account for the capacity limitations on the ferries; as a result, the simulation does not take into account that a person might need to wait for the next ferry Tørset et al. (2013). The implication of this shortcoming is that, assuming the rest is correct, the model will simulate traffic volume that is higher than the reality. In addition, the over/underestimation of this forecasted traffic may be partly explained by ignoring the IC in the transport models. These IC could be regarded as the monetary valuation of all disadvantages of being dependent on a frequency-based transport mode. IC are often related to factors that are easier to identify by users, such as inconvenience for trip planning, as well as lower accessibility to family or friends, leisure or shopping activities, jobs, and public and safety services. For example, inconveniences in the case of a night emergency due to the lack of nocturnal ferry services could delay access to the hospital or even firefighter services. Moreover, there might be inconveniences to access to the airport for early departures for the same reasons.

Norwegian transport models simulate ferry services based on GC, i.e., fare, travel time on-board, and waiting time, with waiting time being the most valuable component to the users (Ingvardson et al., 2018), highlighting the need for its accuracy. In the case of frequent ferry services (headway lower than 1 h), passengers are assumed to arrive at the ferry quay randomly (Jørgensen and Solvoll, 2018); thus, the waiting time is assumed equal to half the headway or 30 min for less frequent ferries. However, Andersen and Tørset (2017) proved that the open waiting time at ferry quays was lower than these values. This implies that passengers adapt their activities to the ferry schedule. Therefore, transport models might overestimate waiting times as more passengers will time their arrival at the station (Csikos and Currie, 2008). Nevertheless, there is a hidden waiting time encompassed in the remainder of the waiting time, this concept includes schedule inconvenience and synchronisation costs for long headway services (Furth and Muller, 2006). The first factor represents the time difference between the desired schedule and the real one, and the second factor is related to the stress of being on time. Laird (2012) demonstrated that reducing the headway for infrequent ferry services did not change the computed GC; however, user welfare was affected by improving trip scheduling. As hidden waiting time is part of the IC, considering only open waiting time in the GC when adding IC into the models could avoid double counting.

In Norway, the IC is included in the assessments in two different ways, depending whether the transport model is at the national or regional level. At the national level, the IC is added as a multiplying factor of 1.8 for the travel time on-board the ferry services (Statens vegvesen, 2018b). A potential shortcoming is that the IC might be perceived differently by different types of users according to trip characteristics. For example, the value of time is six times more for trips at work than for commuting trips (Samstad et al., 2010). In fact, new methods already split users according to socioeconomic group (Kouwenhoven et al., 2006). At the regional level, the IC is directly included in the CBA as a monetary value for the traffic volume estimated by the transport models (Statens vegvesen, 2018b). IC are a function of the number of persons in each vehicle type (light, heavy, and public transport) and a unit price that depends on the type of traffic (local or transit) (Bråten and Lyche, 2004). For ferries with frequencies lower than one departure per hour and no other modes available (or if they represent a long detour), the IC is multiplied by 1.5. An additional weakness of this method is that the IC might affect travel patterns, and as a consequence, disregarding IC in the estimation of the traffic volumes may lead to inaccurate volumes used as input in the CBA.

By contrast, the IC is related to changes in frequency and reliability in Canadian CBAs. Nevertheless, the simulated traffic volumes are obtained from travel demand elasticities (Litman, 2008), and the same approach is followed in Scotland (Fisher Associates, 2007). In England, Kouwenhoven et al. (2006) and Laird (2012) conducted stated preference surveys to include the value of the quality attributes of a ferry service, such as the frequency, reliability, and capacity problems, in the travel demand elasticity. Nevertheless, no studies have focused on the effects of the IC for different trip and user features, which is the aim of this study.

Large transport projects could also lead to structural changes, such as modifications in land use (Holl, 2006), territorial cohesion (Stepniak and Rosik, 2013), and labour markets (Louw et al., 2013). For example, ferry replacement projects could potentially lead to new housing relocation trends due to expansions of the housing market within the same travel time, as well as firm benefits due to agglomeration. Traditional CBAs do not account for these extra benefits, which are defined as wider economic benefits (WEB). In the case of labour markets (Legaspi et al., 2015) demonstrated that WEB were up to 8% of the CBA; nevertheless (Tveter, 2018), proved that agglomeration benefits in rural areas are minor, suggesting to add WEB only in urban areas. IC account for part of the WEB, in relation to the users, as it includes benefits for improved accessibility. Therefore, once IC are included in the GC of the transport models, WEB should be estimated only for firms or other external individuals not accounted for in the models to avoid double counting.

3. Data

A survey of seven ferries belonging to the national highway network and along the E39 Coastal Highway Route, as shown in Fig. 1, was

Fig. 1. E − 39 ferry locations (modified after (Statens vegvesen, 2018a)).

conducted. Some of the characteristics of these ferries are given in Table 1 for both survey years (2011 and 2016).

Some common features include the headway and the lack of capacity problems. Notably, Sognefjorden averaged approximately 30 light vehicles left behind each day. Bjørnafjorden and Moldefjorden had annual average daily traffic (AADT) approaching 1,800 light vehicles in 2011, and the rest of the ferries had approximately 1,000 vehicles. The share of heavy traffic was similar in all cases, representing approximately 18% of the total traffic. The price of the ferry for a conventional car in 2011 varied from approximately EUR 7 at Storfjorden to EUR 16 at Bjørnafjorden in 2011. Additionally, Bjørnafjorden experienced a traffic increase of 8% and price increase of 30% between the survey years.

The survey was a paper-based questionnaire distributed to the ferry passengers during two working days, Thursday and Friday, in November 2011. Passengers could complete the survey by themselves, although there were a couple of interviewers to help them. The survey was repeated only on the ferry with the greatest number of passengers, Bjørnafjorden, on two working days, Monday and Tuesday, in November 2016. Therefore, the number of respondents for this last year was lower, with a greater percentage of commuters, as the days corresponded to the beginning of the week. The data of both years were jointly treated, as the dissimilarities were linked to different samples rather than to trends in traveller perception or changes in ferry features.

The total number of valid answers was 9,878, accounting for

Table 2
Characteristics of the sample (N: number of respondents that belong to each category for the given variable; %: percentage with respect to the total sample).

Variable	Category				N	%
Trip characteristics						
Waiting time	Minimum	Maximum	Mean	Std. deviation		
	0 min	60 min	11.70	11.37	9,878	100%
Total travel time	< 30 min				277	3%
	30–60 min				1,050	11%
	60–120 min				1,946	20%
	> 120 min				6,605	67%
Trip frequency	> 7 times per week				405	4%
	4-7 times per week				717	7%
	1-3 times per week				1,424	14%
	1-3 times per month				3,106	31%
	1-5 times per year				3,731	38%
	< 1 time per year				495	5%
Mode	Car driver				5,895	60%
	Van driver				328	3%
	Truck driver				368	4%
	Car passenger				1,912	19%
	Public transport				1,183	12%
	Walking/cycling				98	1%
	Other				94	1%
Trip purpose	Commuting				2,188	22%
	Trip at work				2,388	24%
	Shopping				337	3%
	Private				3,262	33%
	Leisure				1,275	13%
	Other				428	4%
Overnighting out of home	No				4,703	48%
	Yes				5,175	52%
Socioeconomic characteristics						
Age	18–24				1,640	17%
	25–34				1,743	18%
	35–44				2,170	22%
	45–54				2,144	22%
	55–64				1,601	16%
	65–74				512	5%
	> 74				68	1%
Gender	Male				6,042	61%
	Female				3,836	39%
Profession	Student				1,082	11%
	Worker				7,877	80%
	Unemployed/Retired				919	9%
Personal income	< EUR 35,000				3,180	32%
	EUR 35,000 – EUR 50,000				3,513	36%
	> EUR 50,000				3,185	32%

Table 1
Ferry characteristics.

Ferry	Crossing time (min)	Headway* (min)	Approx. price in EUR (car)	AADT (light)	AADT (heavy)	AADT left behind (light)	N	%
2011								
1. Bjørnafjorden	45	30	16	2,066	389	8	3,303	33%
2. Sognefjorden	20	45	7.5	1,202	224	32	1,491	15%
3. Nordfjorden	10	45	7.5	1,101	191	2	1,008	10%
4. Voldafjorden	10	45	7.5	996	166	6	709	7%
5. Storfjorden	35	30	7	1,290	241	0	1,252	13%
6. Moldefjorden	35	30	10.5	1,678	347	0	1,291	13%
7. Halsafjorden	20	30	7.5	784	135	0	241	2%
2016								
1. Bjørnafjorden	45	30	21	2,178	478	13	583	6%

*Headway defined as time between departures.

approximately 30% of the total number of passengers during the surveying days at all locations. The characteristics of the sample are presented in Table 2. The categories were based on previous Norwegian travel surveys.

The waiting time on the ferry quays averaged approximately 12 min, representing less than half of the headway for all the ferries, which may indicate that most of the respondents knew the ferry schedule in advance and adapted their trips accordingly. More than 60% of the trips had more than 2 h of total travel time, and some of these trips might correspond to overnighting out-of-home trips. A comparison of the average travel time of commuting trips in this survey to that in the national travel survey showed that the trips involving ferry services are longer (Denstadli et al., 2013). Nonetheless, based on the differences among the ferry services in this study, those stopping close to a city had lower total travel times, likely due to having a larger share of commuting trips to the city. Conversely, ferries in rural areas, such as Bjørnafjorden, Sognefjorden, and Halsafjorden, had longer average trips. Most of the respondents took similar trips with a frequency of 1–3 times per month or 1–5 times per year. These frequencies corresponded to trips with greater travel times, i.e., more frequent trips corresponded to lower travel times.

The mode refer to the transport mode used to reach the ferry. Most of the respondents used cars, either as a driver or passenger, whereas only 10% used public transport. Approximately 3% of the respondents used a different mode often transport after taking the ferry, and most were car passengers. For ferries with at least one stop in a city, as was the case for Voldafjorden or Moldefjorden, passengers walked for part of the trip. Additionally, the availability of parking at one of the stops may have encouraged some car drivers to shift their transport mode.

The trip purposes were mainly distributed between commuting (22%), trips at work (24%), and private trips (33%), with 13% of trips for leisure and 3% for shopping. Previous surveys of trips on Norwegian ferries observed a similar trend (Denstadli et al., 2013), with a slightly lower share of commuter trips. This difference for commuter trips is likely that the ferries in this study encompassed a more heterogeneous sample that included more rural ferries not used for daily commuting.

Based on the obtained socioeconomic characteristics, the sample represented all ages and personal income types in almost even shares, whereas in the case of gender and occupation, the shares of workers and men were larger.

More detailed analysis of the survey was presented in Tørset (2012). The questionnaire collected personal perceptions or attitudes towards the ferry inconvenience factors. Nine factors were selected after discussions with the Norwegian Public Road Administration and other local parties to cover all potential inconvenience related to the dependency of the ferry services. These factors, described in Table 3, were presented to the users to facilitate the valuation of the IC based on the following five-point Likert scale (Likert, 1932): 1) unimportant, 2) of little importance, 3) moderately important, 4) important, and 5) very important.

Further studies could focus on analysing other types of ferries, for example, following the classification by Jørgensen and Solvoll (2018), who divided the Norwegian ferries into main state roads and other roads and subdivided roads according to the traffic level. Another potential classification could be obtained according to the location of the ferry in an urban or rural area, as suggested by Bråten and Lyche (2004).

Table 3
Inconvenience factors.

Less trip planning
Better accessibility to family and friends
Better accessibility to leisure activities
Better accessibility to a broader labour market
Better accessibility to safety services (police, firefighters, etc.)
Better accessibility to larger shops
Easier to establish long-term plans for residence relocation
More secure job position because of benefits for the firm
Better accessibility to public services (e.g., admin. offices)

4. Methodology

The inconvenience factors identified as most important by the respondents were further analysed and related to the trip and personal characteristics. Even though the respondents classified these factors according to a five-point scale, for modelling purposes, the importance of each factor was transformed to a three-point scale: 1) not important, 2) quite important, and 3) very important.

Borooah (2001) stated that some econometric models, such as multinomial or nested logit models, disregard the ordinal nature of the perception level because they only account for the categorical nature of the dependent variable. To avoid biased results, ordered discrete choice models have been suggested in the literature (O'donnell and Connor, 1996).

The ordered logit model (OLM) is based on a latent variable model, which uses a continuous, unmeasured latent variable Y*. This variable Y* assigns different values to each individual for different categories of the dependent variable. Y* includes an error term that is assumed to follow a logistic distribution. Because the estimation of this variable is not exact, the model relies on the probability of belonging to each categorical group. Nonetheless, this model is only valid when the assumption of proportional odds or parallel lines is met, i.e., each independent variable has an identical effect on each categorical level (Williams, 2006). Even if only one independent variable does not satisfy this assumption, the results might be biased. The Brant test (Brant, 1990) is used to statistically check the violation of this assumption. In this study, the assumption of proportional odds did not hold for all variables.

The generalised ordered logit (GOL) model overcomes the shortcoming of the assumption of proportional odds, as the parameters of each independent variable are different for each category of the dependent variable (Terza, 1985). This approach increases the complexity of the model, which might be unnecessary because not all variables violate this assumption. An intermediate model, the partial proportional odds model (PPO), is available in which some of the variables remain constant for different categories of the dependent variable and others vary (Peterson and Harrell, 1990). The probability is expressed by equation (1) according to Williams (2006):

$$P\,(Y_i > j) = g(\beta_j X_i) = \frac{\exp(\Phi_j + \beta'_1 X_{1i} + \beta'_{2j} X_{2i})}{1 + \exp(\Phi_j + \beta'_1 X_{1i} + \beta'_{2j} X_{2i})} \qquad j = 1,2,\ \ldots, M-1 \tag{1}$$

where M is the number of categories of the dependent variable, β'_1 is the vector of parameters that do not violate the proportional odds assumption, and X_{1i} is the vector of explanatory variables associated with them. Furthermore, β'_{2j} is the vector of parameters that violate the proportional odds assumption and differ for each category, and X_{2i} is the vector of associated variables. Φ_j are the cut-off points for the thresholds.

The PPO model is used in this study and estimated in STATA (StataCorp, 2017) based on the program written by Williams (2006). The independent variables considered in the models were continuous or categorical. The assumption of no multicollinearity was tested by transforming the categorical variables into dummies and building several linear regression models with one independent variable as the dependent variable. The tolerance values among the independent variables were larger than 0.20 in most cases, meaning that less than 80% of the variance of each variable was shared with others, i.e., the variable could not be predicted by the rest of the independent variables.

A marginal effect analysis is conducted to facilitate the interpretation of the models for the categorical variables. The marginal effects provide an approximation of the amount of change in Y* for a unit

Table 4
Perception of the inconvenience factors in the ferry trip.

No.	Description	Mean	Std. dev	N
1	Less trip planning	2.40	0.72	9,130
2	Better accessibility to family and friends	2.18	0.79	9,020
3	Better accessibility to leisure activities	2.03	0.78	8,697
4	Better accessibility to a broader labour market	1.96	0.84	8,679
5	Better accessibility to safety services (police, firefighters, etc.)	1.94	0.83	8,567
6	Better accessibility to larger shops	1.83	0.79	8,639
7	Easier to establish long-term plans for residence relocation	1.75	0.80	8,558
8	More secure job position because of benefits for the firm	1.74	0.81	8,320
9	Better accessibility to public services	1.64	0.73	8,449

change in the independent variable (Williams, 2012). It is based on the estimated model over a dataset in which some or all covariates are fixed at values different from what they truly are, i.e., the marginal effect for the variable female is the difference in probability for each observation assumed as female and as not female. The average marginal effects (AMEs) for each category of the explanatory variables belonging to the three perceptions of inconvenient levels are estimated based on the program written by (Long and Freese, 2014).

5. Discussion of results

The nine inconvenience factors related to the ferry service, rather than using a fixed connection, are presented in Table 4, which presents the mean value of importance given on the three-point scale, the standard deviation and the sample size.

The most important inconvenience factor, less trip planning (1), refers to the fact that users do not need to plan their trips according to

Table 5
PPO model and AMEs (model 1 – trip planning).

	Category	Model		AMEs		
Variable		P (Y > 1)	P (Y > 2)	Not inconvenient	Quite inconvenient	Very inconvenient
Travel characteristics						
Waiting time	–	0.010***	0.010***	–	–	–
Total travel time	< 30 min	0.004	0.004	−0.04%	−0.03%	0.07%
	30–60 min[b]	–	–	–	–	–
	60–120 min	0.395***	0.087	−3.98%	2.34%	1.64%
	> 120 min	0.389***	0.114	−3.93%	1.78%	2.15%
Trip frequency	> 7 times per week	0.505***	0.505***	−3.52%	−5.22%	8.74%
	4-7 times per week	−0.002	0.369***	0.02%	−6.55%	6.53%
	1-3 times per week	0.334***	0.334***	−2.45%	−3.50%	5.95%
	1-3 times per month[b]	–	–	–	–	–
	1-5 times per year	−0.582***	−0.582***	5.64%	5.92%	−11.56%
	< 1 time per year	−1.529***	−0.862***	19.20%	−1.84%	−17.36%
Mode	Car driver[b]	–	–	–	–	–
	Van driver	−2.509***	−2.509***	39.19%	11.15%	−50.34%
	Truck driver	−2.674***	−2.674***	43.07%	9.13%	−52.20%
	Car passenger	−1.832***	−5.339***	24.16%	39.47%	−63.63%
	Public transport	−2.499***	−2.499***	38.96%	11.26%	−50.22%
	Walking/cycling	−3.757***	−3.757***	66.62%	−6.65%	−59.97%
	Other	−3.323***	−3.323***	57.91%	−0.26%	−57.65%
Trip purpose	Commuting[b]	–	–	–	–	–
	Trip at work	0.180**	0.180**	−1.72%	−1.69%	3.41%
	Shopping	0.211	0.211	−2.00%	−1.98%	3.98%
	Private	0.113	0.113	−1.10%	−1.05%	2.15%
	Leisure	0.206**	0.206**	−1.96%	−1.93%	3.89%
	Other	0.179	0.179	−1.71%	−1.68%	3.39%
Overnighting out of home	No[b]	–	–	–	–	–
	Yes	0.008	0.008	−0.08%	−0.07%	0.15%
Socioeconomic characteristics						
Age	18–24	0.210**	0.210**	−1.76%	−2.03%	3.79%
	25–34	0.026	0.026	−0.23%	−0.25%	0.48%
	35–44[b]	–	–	–	–	–
	45–54	−0.150**	−0.150**	1.38%	1.45%	−2.83%
	55–64	−0.336***	−0.336***	3.27%	3.21%	−6.48%
	65–74	0.772***	0.772***	8.41%	6.88%	−15.29%
	> 74	−1.179***	−1.179***	14.19%	9.20%	−23.39%
Gender	Male[b]	–	–	–	–	–
	Female	0.172**	0.376***	−1.61%	−5.46%	7.07%
Profession	Student	−0.033	−0.033	0.30%	0.31%	−0.61%
	Worker[b]	–	–	–	–	–
	Unemployed/Retired	0.021	0.021	−0.20%	−0.20%	0.40%
Personal income	< EUR 35,000	0.049	0.049	−0.46%	−0.47%	0.93%
	EUR 35,000–50,000[b]	–	–	–	–	–
	> EUR 50,000	0.031	0.031	−0.29%	−0.29%	0.58%
Constant (Φ)	–	2.299***	0.394***			
N		9,130				
Log likelihood		−7303.3153				
Pseudo r^2		0.1782				

***Significant at the 0.01 level/**Significant at the 0.05 level/*Significant at the 0.10 level.
The variable satisfies the assumption of proportional odds.
[b] Base category for the explanatory variable.

the ferry schedule. After the replacement of a ferry, users would benefit from a permanent and reliable connection. Moreover, respondents may identify this factor as a decrease in the waiting time. Therefore, the cost of travelling might be reduced, which could lead to taking more trips.

In addition, changes in accessibility might also cause similar user reactions and induce changes in the existing travel patterns. Unlike the inconvenience factor related to less trip planning (1), respondents evaluate improved accessibility; however, it entails changes already included in the GC (travel time and distance) and extra factors related to the IC. Nevertheless, the valuation of accessibility to different activities provides insight regarding which are more important in ferry replacement projects and are more likely to trigger changes in user travel patterns. The accessibility factors were divided into six categories. The most important factors include better accessibility to family/friends (2), leisure activities (3), and a broader labour market (4). The latter represents commuter trips, and respondents ranked this factor as important because it may involve new job opportunities and better salaries due to firm competition. The accessibility to larger shops (6) was of minor importance, potentially because users already have access to shopping options, and these activities tend to be concentrated in the proximity of a user's residence.

Another factors related to accessibility includes access to safety (5) or public services (9); however, the locations of these services depend on policies or laws established by authorities. Therefore, a replacement for the ferry service might also require a change in the location of a fire station, for example, as these services should be within a certain radius of populated areas. Therefore, even if the accessibility to the current service locations improves, such locations may change.

For inconvenience factors of residence relocation (7) and more secure jobs (8), additional factors other than the accessibility conditions might alter the associated travel patterns, as these factors are related to land use. The residence location is also related to the housing market; moreover, users willing to move to the newly connected areas are affected by the permanent connection; however, these factors are not included in this study. For improved job security, factors related to firm agglomeration could affect this factor, and better accessibility to other firms could entail more competition, representing a threat rather than an improvement (Nilsen et al., 2017). These two factors, which were identified as long-term effects, might promote residence or firm relocation and trigger changes in the traffic demand (Andersen et al., 2018).

The four most important inconvenience factors for users, according to the ranking in Tables (1)–(4) and (4), are further analysed, and the outputs of the PPO models and the corresponding AMEs are presented in Table 5, Table 6, Table 7 and Table 8.

The model has two columns, the P (Y $<$ 1) column indicates the likelihood that a user perceives the inconvenience factor as 'not inconvenient' vs. 'quite inconvenient' and 'very inconvenient', and the P (Y $<$ 2) column indicates the perception of 'not inconvenient' and 'quite inconvenient' vs. 'very inconvenient'. The parameters that are significantly different from zero are indicated with *, **, or *** at the 0.01, 0.05, or 0.10 level, respectively. The parameters that are equal in both columns meet the proportional odds assumption, meaning there is no difference in perception between 'quite' or 'very' inconvenient. The AMEs columns represent the discrete change in probability between each category of the explanatory variable against the base category ([b] in the table) for the three inconvenience perception categories.

5.1. How do trip characteristics affect the perception of IC?

Users spending more *time waiting* for the ferry were more likely to perceive the inconvenience factors as inconvenient, as shown by the significance of its parameter in all models. Losing the ferry due to poor trip planning would lead into a significant waiting time, up to over 4 times the crossing time. The magnitude of the parameters among the models indicates that the waiting time was slightly less important than accessibility to a broader labour market (model 4), potentially because commuters adapted to the ferry schedule, as waiting time is a minor part of their total travel time.

The parameter for *total travel time* of the trip was significant at the 0.10 level for trips longer than 60 min in terms of the inconvenience related to trip planning (model 1) and the accessibility to leisure activities (model 3). Significance at the 0.01 level was found for trips longer than 120 min in terms of accessibility to a broader labour market (model 4). Travellers whose trips were longer than 60 min were more likely to perceive inconvenience related to trip planning (model 1) as quite or very inconvenient by approximately 4 percentage points relative to those whose trips were shorter than 60 min. This result might be because users travelling for more than 60 min were less used to ferry schedules, and thus, the total travel time might have been significantly affected by poor trip planning. In regard to the inconvenience related to accessibility to leisure activities (model 3), users whose trips were longer than 120 min were more likely to perceive it as not inconvenient by 10.95 percentage points relative to those whose trips lasted between 30 and 60 min. This result may be because the trip was perceived as part of the leisure activity. Regarding accessibility to a broader labour market (model 4), travellers whose trips were longer than 120 min were more likely to perceive the inconvenience as not inconvenient by 5.82 percentage points relative to those whose trips took between 30 and 60 min. This result might be because the trips for those travelling longer than 120 min were likely to be unrelated to work activities, and thus, the ferry crossing did not affect them in the same way as those who used the ferry for work purposes.

The parameters for *trip frequency* in all models were significant at a 99% confidence level for almost all categories of the variable. Nevertheless, the perception of the inconvenience factors differed among those categories. Compared to the base category (1–3 times per month), frequent travellers ($>$ 1 time per week) were more likely to consider the different inconvenience factors as very inconvenient in spans of 6–9, 3–11, 7–15 and 12–15 percentage points for trip planning, accessibility to family and friends, leisure activities, and broader labour market, respectively. However, travellers whose trips were less frequent ($<$ 3 times per month) were more likely to perceive the inconvenience factors as not inconvenient by 6–19, 12–34, 12–32, and 18–36 percentage points for trip planning, accessibility to family and friends, leisure activities, and broader labour market, respectively. A potential reason behind these results may be that, as trip frequency decreased, users were less affected by ferry services.

The parameters corresponding to all categories of the *mode of transport* were significant at the 0.01 level for the inconvenience factors related to trip planning (model 1) and accessibility to a broader labour market (model 4). The main difference in perception was that those travelling by car in relation to the other modes were 50–64 percentage points more likely to consider the inconvenience factor as very inconvenient in regards to trip planning and 3–10 percentage points more likely in regards to accessibility to a broader labour market. A possible explanation to this result is that car drivers might have had to plan their own trips in contrast to car or public transport passengers or even truck drivers, as some companies plan the routes for them.

Concerning *purpose*, the parameters were significant with a confidence level larger than 99% for most of the categories with respect to the inconvenience factors of accessibility (models 2, 3, and 4). Users travelling for private purposes were 22.96 percentage points more likely to consider the accessibility to family and friends very inconvenient than commuters were. Travellers on shopping and leisure trips were more likely to perceive accessibility to leisure activities very inconvenient by 9.59 and 16.85 percentage points relative to travellers for work purposes. In contrast, commuters had greater likelihood of considering the accessibility to a broader labour market as very inconvenient by 7.88, 5.75, and 6.76 percentage points compared to private, leisure or other purposes, respectively. Therefore, these results showed that the purpose of the trip directly influenced the perception of

Table 6
PPO model and AMEs (model 2 – accessibility to family and friends).

Variable	Category	Model		AMEs		
		P (Y > 1)	P (Y > 2)	Not inconvenient	Quite inconvenient	Very inconvenient
Travel characteristics						
Waiting time	–	0.012***	0.012***	–	–	–
Total travel time	< 30 min	0.188	0.188	−2.94%	−1.30%	4.24%
	30–60 min[b]	–	–	–	–	–
	60–120 min	−0.005	−0.005	0.09%	0.03%	−0.12%
	> 120 min	−0.084	−0.084	1.40%	0.46%	−1.86%
Trip frequency	> 7 times per week	0.479***	0.479***	−6.12%	−4.75%	10.87%
	4-7 times per week	0.136	0.136	−1.92%	−1.19%	3.11%
	1-3 times per week	0.120*	0.120*	−1.70%	−1.04%	2.74%
	1-3 times per month[b]	–	–	–	–	–
	1-5 times per year	−0.705***	−0.705***	12.26%	3.15%	−15.41%
	< 1 time per year	−1.710***	−1.428***	34.22%	−5.99%	−28.23%
Mode	Car driver[b]	–	–	–	–	–
	Van driver	−0.168	−0.168	2.83%	0.88%	−3.71%
	Truck driver	−0.518***	−0.518***	9.41%	1.69%	−11.10%
	Car passenger	−0.126**	−0.126**	2.10%	0.69%	−2.79%
	Public transport	−0.060	−0.060	1.00%	0.35%	−1.35%
	Walking/cycling	−0.456**	−0.456**	8.18%	1.65%	−9.83%
	Other	−0.302	−0.302	5.26%	1.37%	−6.63%
Trip purpose	Commuting[b]	–	–	–	–	–
	Trip at work	−0.211***	−0.211***	4.36%	−0.01%	−4.35%
	Shopping	0.684***	0.094	−11.87%	9.84%	2.03%
	Private	1.132***	0.998***	−17.57%	−5.39%	22.96%
	Leisure	0.326***	0.326***	−6.13%	−1.11%	7.24%
	Other	0.415***	0.415***	−7.64%	−1.64%	9.28%
Overnighting out of home	No[b]	–	–	–	–	–
	Yes	0.238***	0.238***	−3.98%	−1.29%	5.27%
Socioeconomic characteristics						
Age	18–24	0.322***	0.322***	−5.26%	−1.95%	7.21%
	25–34	0.229***	0.229***	−3.81%	−1.28%	5.09%
	35–44[b]	–	–	–	–	–
	45–54	0.011	0.011	−0.20%	−0.05%	0.25%
	55–64	0.080	0.080	−1.38%	−0.38%	1.76%
	65–74	0.012	0.012	−0.22%	−0.05%	0.27%
	> 74	−0.601**	−0.601**	11.71%	0.48%	−12.19%
Gender	Male[b]	–	–	–	–	–
	Female	−0.095	0.097*	1.59%	−3.74%	2.15%
Profession	Student	−0.097	−0.097	1.60%	0.57%	−2.17%
	Worker[b]	–	–	–	–	–
	Unemployed/Retired	−0.061	−0.061	1.00%	0.37%	−1.37%
Personal income	< EUR 35,000	−0.012	−0.012	0.20%	0.06%	−0.26%
	EUR 35,000–50,000[b]	–	–	–	–	–
	> EUR 50,000	0.018	0.018	−0.29%	−0.10%	0.39%
Constant (Φ)	–	1.008***	−0.644***			
N		9,020				
Log likelihood		−9118.4669				
Pseudo r^2		0.0587				

***Significant at the 0.01 level/**Significant at the 0.05 level/*Significant at the 0.10 level.
The variable satisfies the assumption of proportional odds.
[b] Base category for the explanatory variable.

the related inconvenience factor, e.g., commuters perceived as more inconvenient the factor of accessibility to labour markets rather than to leisure activities. Therefore, asking users about the inconvenience of factors not related to their trip purpose might lead to biased results.

Regarding *overnighting*, the parameter was significant only at the 0.01 level for two of the four inconvenience factors (models 2, 4). Respondents who spent the night out of home were 4.58 percentage points more likely to perceive the accessibility to a broader labour market as not inconvenient than those travellers not overnighting. Additionally, they had 5.27 greater probability of perceiving accessibility to family and friends as very inconvenient. These users could benefit from a permanent connection that would allow a one-day visit instead of having to overnight due to a large travel time.

5.2. How do socioeconomic characteristics affect the perception of IC?

The parameter of the *age* variable was only significant at a 99% confidence level for some of the categories; however, it is interesting to mention that, for the perception of all the inconvenience factors, there was a similar trend. Respondents younger than 35 years old had a greater probability of perceiving the inconvenience factors as very inconvenient than users between 35 and 44 years old (base category), while older travellers were more likely to perceive them as not inconvenient. This might be because older people are more used to the existing infrastructures and might be less open to changes than younger people are.

The *female* parameter was significant at a confidence level over 95% for all inconvenience factors except for accessibility to family and friends (model 2). Women were more likely to consider accessibility to leisure activities and a broader labour market as not inconvenient than men by 9.30 and 5.37 percentage points, respectively. The opposite occurred concerning trip planning, where women showed a greater likelihood of perceiving it as very inconvenient by 7.07 percentage points.

Table 7
PPO model and AMEs (model 3 – accessibility to leisure activities).

	Category	Model		AMEs		
Variable		P (Y > 1)	P (Y > 2)	Not inconvenient	Quite inconvenient	Very inconvenient
Travel characteristics						
Waiting time	–	0.005***	0.005***	–	–	–
Total travel time	< 30 min	0.188	0.188	−2.82%	−1.34%	4.16%
	30–60 min[b]	–	–	–	–	–
	60–120 min	−0.144*	−0.144*	2.36%	0.71%	−3.07%
	> 120 min	−0.602***	−0.329***	10.95%	−4.13%	−6.82%
Trip frequency	> 7 times per week	0.318**	0.653***	−5.18%	−10.05%	15.23%
	4-7 times per week	0.110	0.612***	−1.90%	−12.35%	14.25%
	1-3 times per week	0.325***	0.325***	−5.28%	−2.11%	7.39%
	1-3 times per month[b]	–	–	–	–	–
	1-5 times per year	−0.621***	−0.621***	12.45%	−0.34%	−12.11%
	< 1 time per year	−1.449***	−1.449***	31.73%	−8.64%	−23.09%
Mode	Car driver[b]	–	–	–	–	–
	Van driver	−0.067	−0.067	1.27%	0.09%	−1.36%
	Truck driver	−0.689***	−0.689***	14.23%	−1.86%	−12.37%
	Car passenger	−0.027	−0.027	0.51%	0.05%	−0.56%
	Public transport	−0.077	−0.077	1.46%	0.10%	−1.56%
	Walking/cycling	−0.314	−0.314	6.17%	−0.08%	−6.09%
	Other	−0.367	−0.367	7.27%	−0.23%	−7.04%
Trip purpose	Commuting[b]	–	–	–	–	–
	Trip at work	−0.079	−0.079	1.63%	−0.18%	−1.45%
	Shopping	0.794***	0.477***	−14.00%	4.41%	9.59%
	Private	0.332***	0.332***	−6.40%	−0.13%	6.53%
	Leisure	0.806***	0.806***	−14.17%	−2.68%	16.85%
	Other	0.308***	0.308***	−5.96%	−0.07%	6.03%
Overnighting out of home	No[b]	–	–	–	–	–
	Yes	0.010	0.010	−0.19%	−0.01%	0.20%
Socioeconomic characteristics						
Age	18–24	−0.090	0.196**	1.66%	−5.80%	4.14%
	25–34	0.046	0.046	−0.82%	−0.12%	0.94%
	35–44[b]	–	–	–	–	–
	45–54	−0.199***	−0.199***	3.75%	0.20%	−3.95%
	55–64	−0.254***	−0.254***	4.83%	0.17%	−5.00%
	65–74	−0.526***	−0.526***	10.45%	−0.62%	−9.83%
	> 74	−1.133***	−0.110	23.98%	−21.76%	−2.22%
Gender	Male[b]	–	–	–	–	–
	Female	−0.491***	−0.287***	9.30%	−3.52%	−5.78%
Profession	Student	0.064	0.064	−1.23%	−0.05%	1.28%
	Worker[b]	–	–	–	–	–
	Unemployed/Retired	0.129	0.129	−2.44%	−0.16%	2.60%
Personal income	< EUR 35,000	−0.123**	−0.123**	2.38%	0.04%	−2.42%
	EUR 35,000–50,000[b]	–	–	–	–	–
	> EUR 50,000	0.106**	0.106**	−1.98%	−0.20%	2.18%
Constant (Φ)	–	1.612***	−0.554***			
N		8,697				
Log likelihood		−8983.0556				
Pseudo r^2		0.0526				

***Significant at the 0.01 level/**Significant at the 0.05 level/*Significant at the 0.10 level.
The variable satisfies the assumption of proportional odds.
[b] Base category for the explanatory variable.

The *profession* parameters were not significant with the exception of unemployed/retired people for the inconvenience factor of accessibility to a broader labour market. These respondents were less likely to perceive this factor as very inconvenient by 6.57 percentage points compared to those working, as they did not work. However, the unemployed might benefit more from better accessibility to a broader labour market than retired people, and having them aggregated might have masked the result for this particular inconvenience factor.

Regarding *income*, the parameters for all categories were significant at the 90% confidence level for the perception of the inconvenience factor regarding accessibility to leisure activities (model 3), and the parameter for the category with income larger than 50,000€ was significant at the 95% confidence level regarding the accessibility to a broader labour market (model 4). Respondents with higher income compared to those earning between 35,000€ and 50,000€ were 2.18 and 3.71 percentage points more likely to perceive as very inconvenient the accessibility to leisure activities and a broader labour market. These findings may be associated with the generalisation that people with higher salaries place a greater value on time, meaning that they are more willing to pay to save time when travelling and reduce any inconvenience generated by ferry services.

6. Conclusion

This study identifies factors beyond those currently included in the GC (travel time, distance, and direct costs) that are important for users travelling by ferry services. The most important factors, regarded as inconvenient factors, include trip planning and accessibility to family/friends, leisure activities and a broader labour market. Transportation projects improving these factors might trigger changes in the travel patterns of users and result in biased traffic simulations when disregarded. This study demonstrates that the perceptions of these inconvenient factors differ depending on trip characteristics, such as waiting time, trip frequency, and trip purpose, as well as on

Table 8
PPO model and AMEs (model 4 – accessibility to a broader labour market).

Variable	Category	Model		AMEs		
		P (Y > 1)	P (Y > 2)	Not inconvenient	Quite inconvenient	Very inconvenient
Travel characteristics						
Waiting time	–	0.004**	0.004**	–	–	–
Total travel time	< 30 min	−0.092	−0.092	1.78%	0.07%	−1.85%
	30–60 min[b]	–	–	–	–	–
	60–120 min	−0.136	−0.136	0.27%	0.01%	−0.28%
	> 120 min	−0.294***	−0.294***	5.82%	−0.05%	−5.77%
Trip frequency	> 7 times per week	0.100	0.515***	−1.98%	−9.95%	11.93%
	4-7 times per week	0.349***	0.623***	−6.57%	−7.93%	14.50%
	1-3 times per week	0.608***	0.608***	−10.83%	−3.31%	14.14%
	1-3 times per month[b]	–	–	–	–	–
	1-5 times per year	−0.812***	−0.812***	18.00%	−2.44%	−15.56%
	< 1 time per year	−1.590***	−1.590***	35.59%	−10.30%	−25.29%
Mode	Car driver[b]	–	–	–	–	–
	Van driver	−0.101	−0.101	−1.96%	−0.04%	2.00%
	Truck driver	−0.279**	−0.279**	5.61%	−0.35%	−5.26%
	Car passenger	−0.150**	−0.150**	2.99%	−0.11%	−2.88%
	Public transport	−0.192***	−0.192***	3.84%	−0.17%	−3.67%
	Walking/cycling	−0.582***	−0.582***	11.93%	−1.45%	−10.48%
	Other	−0.517**	−0.517**	10.55%	−1.15%	−9.40%
Trip purpose	Commuting[b]	–	–	–	–	–
	Trip at work	−0.219***	−0.219***	4.32%	0.09%	−4.41%
	Shopping	−0.072	−0.072	1.39%	0.08%	−1.47%
	Private	−0.401***	−0.401***	8.04%	−0.16%	−7.88%
	Leisure	−0.288***	−0.288***	5.72%	0.03%	−5.75%
	Other	−0.074	−0.341***	1.43%	5.33%	−6.76%
Overnighting out of home	No[b]	–	–	–	–	–
	Yes	−0.232***	−0.084	4.58%	−2.98%	−1.60%
Socioeconomic characteristics						
Age	18–24	0.225***	0.225***	−4.28%	−0.22%	4.50%
	25–34	0.074	0.074	−1.44%	−0.02%	1.46%
	35–44	–	–	–	–	–
	45–54[b]	−0.257***	−0.066	5.18%	−3.89%	−1.29%
	55–64	−0.647***	−0.431***	13.44%	−5.48%	−7.96%
	65–74	−1.251***	−0.849***	26.28%	−11.73%	−14.55%
	> 74	−0.727*	0.084	15.15%	−16.81%	1.66%
Gender	Male[b]	–	–	–	–	–
	Female	−0.271***	−0.271***	5.37%	−0.18%	−5.19%
Profession	Student	0.035	0.035	−0.70%	0.02%	0.68%
	Worker[b]	–	–	–		–
	Unemployed/Retired	−0.360***	−0.360***	7.41%	−0.84%	−6.57%
Personal income	< EUR 35,000	−0.026	−0.026	0.52%	−0.03%	−0.49%
	EUR 35,000–50,000[b]	–	–	–	–	–
	> EUR 50,000	0.192***	0.192***	−3.78%	0.07%	3.71%
Constant (Φ)	–	1.581***	−0.014			
N		8,679				
Log likelihood		−8570.9163				
Pseudo r^2		0.0961				

***Significant at the 0.01 level/**Significant at the 0.05 level/*Significant at the 0.10 level.
The variable satisfies the assumption of proportional odds.
[b] Base category for the explanatory variable.

socioeconomic features, primarily gender, age and income of users.

These findings provide a better understanding of the IC and could be used as background information to improve traffic simulations. The perception of the inconvenience factors differs with trip purpose; thus, a different IC should be determined for each purpose. Conventional transport models already divide trips by purpose, making it simple to implement a disaggregated IC for each type. In addition, the IC may be affected by the frequency at which users make their trips. To account for this disaggregation, a new input should be incorporated into transportation models to reflect the share of the trips for each user that uses ferry services. The socioeconomic features studied are already included in the transportation models, and thus, it is possible to disaggregate the IC with respect to gender, age and income.

Nevertheless, this study does not provide a quantitative factor for the different IC thus, a stated preference (SP) survey should be conducted to quantify the willingness of ferry users to pay for a permanent connection based on relevant trip and socioeconomic features. The results of this study could complement the values, as it quantified the difference in perception among the different categories of variables. Improved traffic simulations imply better input for the CBA and, thus, better assessments for prioritising transportation projects. Nevertheless, including the IC in the simulations should be done carefully to avoid double counting with hidden waiting time and when adding WEB to the assessments.

Acknowledgement

We would like to thank the Norwegian Public Roads Administration for the support in relation to the data collection process.

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