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The traffic effects of fixed links: short and long-run forecast accuracy

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Abstract

Economic and financial appraisals of road projects depend on reliable traffic forecasts, and there is a need for knowledge of how traffic reacts to changes in the transport network. In the article, the authors study the effects on traffic of fixed links constructed in Norway and the extent to which planners have been able to forecast those effects with an acceptable degree of accuracy. The main finding is a substantial underestimation of traffic in the long term. Initially, the differences between the forecast traffic and actual traffic were relatively small, but the differences increased over time. In the long term, actual traffic might be twice as high as the forecast traffic. This finding deviates substantially from findings from other countries, where overestimation of traffic on tolled, at least in the short term, seems to have been the norm.

Keywords: Fixed links; bridges; tunnels; traffic forecasts; optimism bias; transport appraisal

1. Background

Transport infrastructure binds countries and regions together. Trips that in the past might have taken days or even weeks can now be carried out in a matter of hours. Due to the well-developed state of the transport system in most

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countries in the developed world, transport improvements are normally marginal. Hence, travel time reductions today are usually measured in minutes rather than in hours.

However, in some cases, new roads may deliver significant improvements by reducing generalized costs and changing travel patterns. Fixed link projects (i.e. bridges and tunnels) that replace ferry connections, may reduce travel times across fjords and from island communities to the mainland by more than 30 minutes, as well as giving round-the-clock access to national and international markets. Such projects have the potential to have a wide range of regional impacts, such as improved market access, the entry of firms, increased competition, access to a wider range of goods and services, and changes in settlement patterns. These impacts make traffic forecasting more challenging than in projects in which changes in travel times are more marginal.

Although fixed links may be considered exotic, several bridge and tunnel projects are currently being considered, planned, and implemented in a number of European countries. Around the Scottish coast and its island communities, members of the Scottish Parliament and local interest groups regularly call for tunnels and bridges to be built in order to connect islands to the mainland and to each other (Cope, 2018; Grant, 2019; Shetland News, 2019). The Faroe Islands have invested considerable sums in bridges and tunnels, and are currently in the process of constructing further tunnels to connect the islands to the capital, Tórshavn (Sovik, 2018). In Denmark, the construction recently started on the Fehmarnbelt Fixed Link, which will link Rødbyhavn in Denmark and Puttgarten in Germany (Femern, 2019). In Finland, a high-speed rail tunnel linking Finland and Estonia under the Baltic Sea looks set to go ahead after the project has secured EUR15 billion in funding (Stone, 2019). In Italy, plans for a 3 km bridge to connect the island of Sicily to the Italian mainland regularly reappear on the political agenda.

All of the above-mentioned plans and projects will require huge investments as well as financial and engineering skills. The appraisal of the projects will include an estimation of necessary future capacity; the social benefits generated by the schemes, and, as fixed links often are financed party by user fees, an assessment of potential revenues. The historical performance of past projects can guide the appraisal and give an indication of the likely effects of future schemes. In this respect, the Norwegian experience can provide valuable knowledge to other countries that are planning projects that will significantly reduce travel times.

In this paper, we study the effects on traffic of fixed links. We assess the accuracy of fixed link forecasts and calculate the traffic growth from ferry to fixed link as well as the annual traffic growth thereafter. The paper is based on data from tunnels and bridges opened for traffic between 1970 and 2013. We investigate whether the effects of traffic on fixed links have been in line with expectations. We start with a comparison of traffic forecasts for the first five years of operation with real traffic. Thereafter, we compare traffic in the final year of ferry traffic with traffic on the fixed link. Finally, we examine whether the traffic growth in the projects has been larger than the traffic growth on other roads. The focus of this paper is on the effects of traffic, so that past projects can guide the appraisal of future ones. We briefly discuss some of the reasons for our findings, but we do not study the potential cultural, economic and political impacts of the links.

The paper is organized as follows. In Section 2, we provide some background information on ferry traffic in Norway and the reasons why the Norwegian Government has invested heavily in fixed links. In Section 3, we review relevant literature for this study. In Section 4, we present the data used and outline our research questions. In Section 5, we present the results, followed by some conclusions in Section 6.

2. Ferries and Fixed Link Projects in Norway

Historically, maritime transport was the dominant mode of transport within and between parts of Norway, a country with a deeply rooted seafaring tradition. However, with the development of the road network, the car took over the role of the boat as the primary mean of transport. Many of the routes for large passenger boats were closed down, but ferry connections across fjords and to the islands off the coast were established to link up the entire road network.

The need for and possibility to construct fixed links have changed considerably in recent decades. After World War II, a special permit was needed to buy a car in Norway because the government wanted to reduce the consumption of imported goods due to limited access to foreign currency. The aim was to keep private consumption down and investment rates high. Because of this policy, there were only 18 cars per 1000 citizens in 1948. Persons who owned a car faced restrictions in terms of mileage (Kustomrama, 2018). Car rationing was lifted in 1960 and thereafter the need for new and better roads increased. At the same time, the technology for the construction of bridges and tunnels made great progress. As the construction of bridges became relatively cheaper, a large number of bridges were built in the 1970s. Eventually, tunnel technology made similar progress and following the opening of Norway's first subsea road tunnel, the Vardø Tunnel in 1982, a large number of ferry connections were replaced by tunnels in the 1980s and 1990s. The links were normally financed by a combination of government funds and road tolls.

Ferry transport is still an important part of the Norwegian transport system. Today, Norway has some 115 ferry connections served by over 200 ferries along its 29,000 km coastline. The ferries annually carry more than 20 million vehicles and the same number of passengers in addition to the drivers. There are large differences in traffic levels. The busiest connections carry more than 5,000 vehicles per day while others carry less than 50 vehicles (Statens vegvesen, 2016). Ferry connections are considered part of the road network and formal responsibility for their operation lies either with the state or with the regional road authorities. Private companies operate the ferries based on competitive tenders.

Ferry transport implies costs to both operators and users. The total operating costs are partly paid by motorists and passengers through ferry tickets[1], and partly through public subsidies. The annual subsidies to state and regional ferry connections are over EUR 300 million. In addition to the fares, the users face several inconvenience costs. For example, the connections represent barriers to movement as they are only open parts of the day and at scheduled times. Limitations in terms of the frequencies in the schedules, as well as waiting times and capacity restrictions all add up to less flexibility when travelling by ferry than when using the rest of the road network. In a survey of almost 11,000 Norwegian ferry travelers, Hanssen et al. (2019) found that average headway times and waiting time at the ferry terminals were 52 minutes and 15 minutes respectively. By comparison, the average sailing time was 38 minutes, indicating that waiting times at the terminals accounted for a large proportion of ferry users' total time spent travelling. The huge costs to both the users and the authorities is part of the reason why replacing ferries with fixed links continues to be an attractive option.

Although bridges and tunnels have replaced more than 100 ferry connections since World War II, Norway still has ambitious plans for fixed links. The Ryfast subsea tunnel between the City of Stavanger and Strand Municipality is set to open towards the end of 2019 and will be 14,300 metres long and run 292 metres below sea level. The Rogfast tunnel in the county of Rogaland is planned to open in 2026. With a length of 26,700 metres and a maximum depth of 392 metres, it will be the longest and deepest subsea road tunnel in the world. Rogfast is part of the ambitious plan to develop the E39 road along the west coast to a coastal highway without involving ferries. Replacing the seven ferry connections on the E39 with fixed links may reduce travel time by up to a half (Statens vegvesen, 2018). To estimate the effects of these projects, it is necessary to know how past schemes have performed.

3. Literature review

The accuracy of ex ante forecasts in road projects has been the subject of many studies, but studies of traffic forecast accuracy involving large samples are relatively rare. Probably the most comprehensive study to date was conducted by Nicolaisen and Driscoll (2014), who examined 12 studies of road and rail projects in different countries in the 1970s and found that following completion of road projects the amount of traffic was consistently higher than forecast.

In a previous study, two of the authors of the present article compared the accuracy of traffic forecasts in road projects financed with and without road tolls (Welde and Odeck, 2011). In a sample of 25 Norwegian projects, they found that traffic on roads without tolls was some 20% higher than forecast in the first whole year after opening.

[1] As an example, a ferry ticket for an HGV for a distance of 12 km is currently about EUR 118 (May 2019), whereas a ticket for passenger car is about EUR 16

The forecasts for the 25 projects with road tolls appeared to be more accurate, as outturn traffic on average was just 2.5% lower than forecast. However, there was a high degree of variation between the projects. Actual traffic ranged from only 65% of the forecast traffic to 45% above forecasts. Although underestimation of traffic can have negative economic consequences for projects that are funded by user payments, Welde and Odeck (2011) found that after five years the actual traffic exceeded the forecast traffic. In their follow-up study with data from 68 toll road projects, Odeck and Welde (2017) found that on average actual traffic exceeded forecast traffic by 4% in the first whole year of operation after opening and that the level of underestimation increased over time.

The fact that actual traffic in toll-free road projects in Norway is higher than forecast is in line with the findings from most international studies. However, while Norwegian studies have found that forecasts for toll roads have underestimated the traffic, the opposite has been found in most international studies. For example, Morgan (1997), Vassallo (2007), Bain (2009), Li and Hensher (2010), and Baeza and Vassallo (2012), all found that forecasts for toll road projects overestimated the traffic. Such overestimation of traffic has led to several cases of bankruptcy. A few years ago, AECOM – the engineering design firm that had prepared the traffic forecasts for several Australian toll projects – agreed to pay AUD 280 million to the toll companies' creditors (Stacey, 2015).

It can be challenging to provide traffic forecasts for fixed link projects. First, the transport models used to prepare the forecasts are based on a number of assumptions, one of which is unchanged land use. That is problematic because fixed link projects are often aimed at increasing areas for housing and commercial development (i.e. changed land use). Tveter et al. (2017) evaluated the extent to which transport projects affected settlement patterns in Norway and found that fixed links had clear impacts on settlement patterns on islands connected to urban areas and on the utilization of natural resources on islands. Changes in settlement patterns and increased populations normally lead to more traffic, in contrast to the assumption of unchanged land use. In a study similar to that conducted by Tveter et al. (2017), Nyland Andersen et al. (2018) found that fixed link projects in Norway had led to growth in house prices, population and employment. These effects may be difficult to forecast and lead to traffic impacts beyond those that can be estimated by conventional transport models. Furthermore, the effects of traffic in terms of large reductions in travels times may be difficult to forecast. While ordinary road projects rarely result in travel time reductions of more than 10–15 minutes, fixed links can reduce travel times by up to one hour per trip. Ferries imply constraints on travel behaviour, due to the lack of 24-hour services and because of limited capacity. Hence, road users may be willing to pay for not having to consider these inconveniences. This effect may be difficult to capture through ordinary transport models. Economic appraisals of projects that lead to large changes in the transport system thus face special issues and those responses for the appraisals may experience difficulties in revealing the true ex ante benefits. Bråthen and Hervik (1997) studied the effects of inconvenience costs and found that road users' willingness to pay for travel time reductions in fixed link projects was significantly higher than assumed in the original cost–benefit analyses. The users of the ferries hence attached higher costs to their travel time due to the inconvenience of relying on ferries.

There are examples outside Norway of the challenges of estimating the effects of fixed links on traffic. One of the projects for which the effects are best documented is the Øresund Bridge between Sweden and Denmark. The combined road and rail bridge opened in 2000 and linked two geographical areas that had been in contact with each other for thousands of years, albeit with poor transport connections. After the opening, the traffic was some 20% lower than expected, but after three years, the traffic had increased and exceeded the forecast percentage. A similar project was the Great Belt fixed link between Zeeland and Funen in Denmark, which opened in 1997. Already one year after opening, the traffic was more than 70% higher than planned (Knowles and Matthiesen, 2009). COWI (2002) examined this effect further and found that the traffic increase was mainly due to induced traffic, which in turn was due to increased economic activity because of the construction of the bridge. Although both of above-mentioned large-scale projects experienced higher volumes of traffic than planned, the traffic increase had different causes. The Great Belt fixed link allowed longer commutes and led to more leisure and business traffic internally in Denmark, while the Øresund Bridge had far less leisure traffic but a large number of commuters who made use of differences in living costs and labour costs between Sweden and Denmark. The results for the traffic levels are thus similar, but the reasons differ.

While the Øresund Bridge has led to social and economic integration between two countries, the Channel Tunnel between Britain and France has not fully lived up to expectations. Traffic was 80% lower than expected one year after opening. Anguera (2006) suggested that the British economy would have been better off without the Channel Tunnel, and Thomas and O'Donoghue (2013) found that the tunnel had only a limited impact on the spatial economy of the trans-frontier zone between the county of Kent in the UK and Nord-Pas-de-Calais region in France.

The Confederation Bridge linked the Prince Edward Island off the coast of New Brunswick in Canada to the mainland in 1997. Vehicle traffic to the island immediately increased by almost 70%, but stabilized thereafter. In an ex post study of the effects of the bridge, Baldacchino and Spears (2007) concluded that the bridge had not had a significant impact on the local economy and population.

Skamris and Flyvbjerg (1997) studied the accuracy of traffic forecasts for fixed link projects in Denmark and documented the differences between forecast traffic and actual traffic for the Lillebælt Bridge, the Sallingsund Bridge, and the Farø Bridge. They found that the differences ranged from 32% below the forecast amount to 27% above them. Skamris and Flyvbjerg concluded that due to the high level of uncertainty regarding costs, execution time, and traffic, the results of cost–benefit analyses of such projects would be highly unreliable.

4. Data and methodology

The data for our study were derived from 38 fixed link projects that were opened for traffic in the period 1970–2013. Together, the projects represent more than 80% of all fixed link projects in Norway during that period. All projects have been partially funded through tolls. In most of the projects, the toll collection has ended, but it is still ongoing in six of the projects. The data are incomplete, as we only have traffic forecasts for 23 projects, although we have real traffic data for all 38 projects.

Our traffic data were collected from different sources. Data relating to traffic before opening and to traffic forecasts were taken from parliamentary records for the time of the formal decision to build. The Norwegian Parliament must formally approve all projects financed by tolls and as part of this process, the underlying economic assumptions are scrutinized to ensure that toll revenues will be sufficient to ensure that the projects are financially viable.

Data on actual traffic and traffic development after the projects were opened for traffic were derived from three sources: (1) paying road users who passed through the toll stations, according to annual reports from the toll companies; (2) continuous traffic counts on the road network; and (3) traffic counts recorded in the National Road Database (NRDB), which contains estimates of traffic on all roads. The NRDB contains data from both counted traffic and estimated traffic. Comparisons of real traffic based on traffic counts and estimated traffic source from the NRDB show small differences.

We address the following research questions:

1. How accurate were the traffic forecasts for the first whole year of traffic after opening?
2. How accurate were the forecasts for Years 3 and 5?
3. What changes occurred in traffic between the last year of ferry traffic and the first full year of operation in a fixed link?
4. What was the annual traffic growth since the opening of the fixed link?

The reason for using traffic (measured in average annual daily traffic) for the first full year of operation instead of traffic in the opening year is that the opening year may be characterised by sightseeing traffic and seasonal variations. Additionally, we are concerned with how traffic develops in the years after fixed link projects open. The international literature has shown somewhat differing results as to whether traffic ramp-up takes place (e.g., George et al., 2003; Bain and Polakovic, 2005; Bain, 2009).

The change in traffic following the last year of ferry traffic is considered important because given that a ferry connection normally suppresses travel demand, we would expect a strong increase in traffic once a bridge or a tunnel replaces a ferry. However, in Norway, it is customary practice to set the toll rate for the fixed link at 40% above the ferry ticket and therefore the net traffic increase will be a result of a trade-off between the effects of reduced travel time and increased user charges. Hence, the net traffic increase may be difficult to estimate.

It may be extremely difficult to perform an ex ante estimate of long term traffic developments that are due to changes in land use, population, and other indirect effects. In a review of fixed links worldwide, Laird (2011) found traffic increases of up to 22 times the ferry traffic.

In order to compare traffic before and after opening, we use the most common formula for assessing the forecast errors, namely percentage error:

$$Y_i = \frac{x_i - \hat{x}_i}{\hat{x}_i} * 100$$

where $\hat{x}_i$ is the traffic forecast for project i, and x_i is the real traffic. If Y_i is negative, it implies that traffic has been overestimated, while the opposite is the case if Y_i is positive.

The mean percentage error, $\bar{Y}$, measures the average forecast error in a portfolio of projects:

$$\bar{Y} = \sum_{i=n}^{n} Y_i$$

The mean percentage error is a suitable measure of forecast accuracy at portfolio level, because it will reveal systematic errors. At the portfolio level, errors in both directions cancel each other out and the mean should ideally be close to zero. A high value of the mean percentage error is therefore an indication of systematic error or bias.

In addition, we include one further measure of forecast accuracy, which is commonly reported in the literature, namely the mean absolute percentage error:

$$|\bar{Y}| = \frac{1}{n}\sum_{i=1}^{n} |Y_i|$$

The advantage of the mean absolute percentage error is that it provides a measure of the absolute size of the deviation from the forecasts. If there are large numbers of large underestimates and overestimates in a sample, the mean percentage error may give an unrealistically positive result for forecast accuracy, as the value may be zero or close to zero. The mean absolute percentage error is not balanced by large positive and negative deviations. On the contrary, the larger the forecast inaccuracies are, the larger $|\bar{Y}|$ will be.

Effects on land use and population normally take years to materialize and then their impact on traffic levels may be large. The financial appraisals of projects rely on traffic estimates for decades into the future. We therefore measured the annual traffic growth, represented by r in the following equation, after the opening of the fixed link, but without including the one-off impact of the change from ferry to fixed link:

$$r = \left(\frac{AADT_{t1}}{AADT_{t0}}\right)^{1/(t_1 - t_0)} - 1$$

where, $AADT_{t1}$ is traffic in 2018, $AADT_{t0}$ is traffic in the first full year after the opening of the fixed link, $t1$ represents the latest year for which traffic data is available (in our case 2018), and $t0$ is the first full year after the opening of the fixed link.

Table 1 lists the descriptive statistics for the sample used in our study.

The first fixed link opened in 1970 (the Sotra Bridge) and the last in 2013 (the Hardanger Bridge). Traffic forecasts have generally been based on an assumption of a strong traffic increase when a ferry service was terminated, but traffic in all of the studied projects is significantly higher today.

Table 1: Descriptive statistics for tunnels and bridges opened for traffic between 1970 and 2013

	N	Minimum	Maximum	Mean	St. dev.
Opening year	38	1970	2013	1990	13
Ferry traffic in the last year of ferry traffic (AADT)	38	107	2783	644	616
Traffic forecast (AADT) for Year 1	23	195	5000	1351	1339
Real traffic (AADT) Year 1	23	276	5583	1411	1338
Traffic today	38	411	27600	5347	6084

5. Results

In the following, we present our results with respect to the research questions stated in Section 4.

5.1. Accuracy of traffic forecasts

We first look at the deviation between forecasts and real traffic in the first full year of operation after the opening of the fixed link. To gauge the accuracy, we use the measures presented in Section 4: the mean percentage error and the mean absolute percentage error. Table 2 presents the results.

Table 2: Mean percentage error and mean absolute percentage error of traffic forecasts on fixed links

	N	Minimum	Maximum	Mean	Traffic weighted mean	St. dev.
Mean percentage error, Year 1	23	-32%	59%	13%	4%	26%
Mean absolute percentage error, Year 1	23	1%	59%	23%	21%	17%

The impact on traffic of fixed links in Norway has been underestimated. On average, real traffic was 13% higher than forecast in the first full year after opening. In most cases, this means that the benefits of these projects have been underestimated. Moreover, the weighted average by traffic volume is only 4%, which shows that the precision is best for projects with the most traffic.

The accuracy of the forecasts varies substantially. The standard deviation is twice as large as the mean, indicating the uncertainty of developing forecasts for fixed links. As a portfolio of projects, the risk has not been downplayed, but the general inaccuracy of the forecasts may be a cause of some concern for the road authorities.

The mean percentage error detects only systematic forecasting errors. It provides a poor measure of forecast accuracy, since large overestimates or underestimates may even out the mean inaccuracies and mask large inaccuracies.

Table 2 shows the mean absolute percentage error, which in turn shows the general inaccuracy of the forecasts. Actual traffic deviated from forecasts by 23 vehicles on average, thus illustrating the uncertainty of this vital parameter in the appraisal of fixed links.

The above-presented results differ from some of those found in other studies. While traffic in toll projects in many other countries has been overestimated, optimism bias seem to have been less common in Norwegian fixed link projects and other toll road projects. Odeck and Welde (2017) suggested that the difference between the results for Norway and those of other countries is due to the organizational framework for toll financing. Whereas toll road projects in many countries are based on private companies that compete for the opportunity to build and finance new roads, the Norwegian arrangement is based on a clear separation between construction risk and traffic risk.

Since profit is not the motive for toll road financing in Norway, local authorities and interest groups may suggest tolling as a method to finance much needed road infrastructure faster than might otherwise be possible. The formation of a toll company is merely an administrative instrument that is not motivated by profits. The toll company uses private contractors to collect the tolls and for other services, but the revenue risk is not subject to competition. Therefore, there is no bidding process that results in the concession being awarded to the bidder with the highest traffic forecasts. This process reduces the risk of 'perverse incentives' that may tempt bidders to bias their forecasts in order to win the contract (Odeck and Welde, 2017, p. 11). Furthermore, traffic forecasts in all Norwegian road projects are developed using standardized transport models. Since these models are the responsibility of the Norwegian Public Roads Administration, it could be argued that since only one organization is responsible for overseeing the forecasting this leads to an accumulation of experience that benefits similar projects in the future.

Surprisingly, the forecast accuracy shows no improvement over time. Norway's organizational framework has been tried and tested over decades and provides a process through which potential toll projects can be appraised for social and financial viability. New projects can be benchmarked against a large reference class of projects that have already been completed or are in operation. Furthermore, over time transport models have improved. Hence, it could be expected that the accuracy of forecasts should also have improved over time, but as shown in Figure 1, there do not seem to have been any improvements in forecast accuracy in the period 1989–2013. A simple linear regression indicate that there has been an increasing number of underestimations in Norwegian fixed link projects ($t = 1.945$, $p < 0.10$), and possibly an upward trend to the errors.

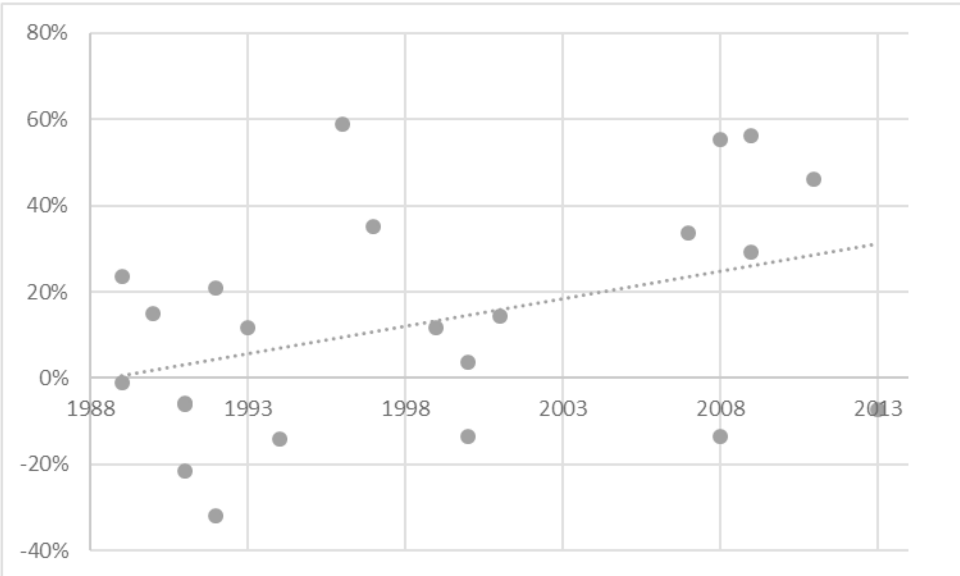

Figure 1: Development in the accuracy of traffic forecasts for fixed links

5.2. Accuracy over time

In a study of road projects implemented between 1996 and 2008, Odeck (2013) found that not only was traffic in the opening year underestimated, but also that the assumed annual traffic growth was underestimated; the latter was underestimated by over 1% per year. In our study, the traffic growth in fixed links was higher than assumed at the time of decision to build (Table 3). While traffic was underestimated by 13% one year after opening, the mean underestimation was double that in Year 3 and triple in Year 5.

Table 3: Mean percentage error of traffic forecasts three and five years after opening of the fixed link

	N	Minimum	Maximum	Mean	Traffic weighted mean	St. dev.
Year 3	23	-28%	91%	25%	22%	34%
Year 5	23	-19%	133%	39%	37%	44%

Table 3 also shows that that the minimum deviation (i.e. the biggest negative deviation) from traffic forecasts was reduced over time. In other words, traffic in Norwegian fixed link projects has experienced a 'demand ramp-up effect'.

5.3. Traffic increase from ferry to fixed link

Fixed link projects are based on, among other things, the existence of a latent travel demand that is suppressed by ferries with poor regularity, short opening hours, and/or low capacity. Therefore, in the economic appraisals of such projects, we normally assume a strong traffic increase from the last year of ferry operation to the first full year of operation in a fixed link (i.e. bridge or tunnel). The increase can be difficult to estimate, and more demanding than modelling changes in traffic, due to marginal improvements in travel times.

As shown in Table 2, traffic was underestimated in the first full year of operations. This is an indication that the increase from ferry to fixed link is difficult to estimate. Table 4 shows that the traffic increase from ferry to fixed link can be substantial: on average, traffic more than doubles when a fixed link opens.

Table 4: Increase in traffic from the last full year of ferry traffic to the first full year of the fixed link

	N	Minimum	Maximum	Mean	Traffic weighted mean	St. dev.
Increase from ferry to fixed link	38	12%	607%	116%	131%	113%

5.4. Traffic increase from ferry to fixed link

In recent decades, there has been a significant increase in passenger transport in Norway. Between 1980 and 2018 domestic road passenger transport increased by 124%, equivalent to 2.2% per year (Statistics Norway, 2018).

Table 5 shows that the average annual growth in traffic on the fixed links in our sample was much larger than the average growth in traffic elsewhere in Norway. The mean traffic growth between the first full year of the fixed link and 2018 was 5%, which shows that the long-term effects of fixed links on traffic can be considerable.

Table 5: Annual traffic growth rate from the first full year of the fixed link to 2018

	N	Minimum	Maximum	Mean	Traffic weighted mean	St. dev.
Annual traffic growth	23	2%	9%	5%	5%	2%

As traffic forecasts usually are based on general traffic growth, the gap between the forecast traffic and actual traffic will increase substantially over time. If the development in traffic using a growth rate of 2.2% is compared with the development using a growth rate of 5%, the difference will be 70% after 20 years, with a growth rate of 5% the traffic increases after a 20-year period by 165% $(1.05)^{20} - 1 = 1.65$. With a growth rate of 2.2%, the traffic increases by 54%, when using a similar calculation. Thus, the traffic is 70% higher with a growth rate of 5% than with a growth rate of 2.2%.

6. Conclusions

Economic and financial appraisals of road projects depend on reliable traffic forecasts. We need knowledge of how existing traffic is likely to react to changes in the transport network and of the implications a new road might have for potentially induced traffic. In this paper, we have presented the results of our study of the effects on traffic of fixed links and the extent to which planners have been able to forecast those effects with an acceptable degree of accuracy.

The main finding is a substantial underestimation of the impact on traffic in the long term. Initially, the difference between the forecast traffic and actual traffic is small, but the difference increases to almost 40% after five years. Our results suggest that this difference continues to grow. In the long term, the traffic growth on the fixed links will be higher than the overall growth rate; the actual traffic will be twice the forecast traffic after 20 years. This result deviates from results often found for other countries, where overestimation of traffic on toll roads, at least in the short term, seems to have been the norm.

We have not investigated the causes of the underestimation, but it seems that the reasons for the deviation between forecast traffic and actual traffic are related to uncertainty about both the one-time increase in traffic from ferry to fixed link and the annual traffic growth thereafter.

It is beyond the scope of this study to investigate the precise reasons why the effects of fixed links on traffic have been higher than forecast. However, several studies have documented that Norwegian transport planners have been cautious in their estimates, perhaps overly so (e.g. Welde and Odeck, 2011; Odeck and Kjerkreit, 2019). This has prevented overoptimistic estimates of proposed projects, but by downplaying the ex ante effects we risk underinvesting in infrastructure that may be beneficial to society.

Higher traffic than forecast could also be caused by higher than anticipated economic growth. Since the late 1990s, rapidly growing demand, particularly from Asian countries, has raised the prices of important Norwegian exports, while imported goods from the same countries have become relatively cheaper. Norway’s terms of trade have thus improved considerably. Household purchasing power and business profitability have increased. Such long periods of unprecedented and stable economic growth can influence travel demand in ways that might be difficult to foresee.

Large transport projects that lead to significant reductions in travel times may also lead to structural changes, such as changes in land use, new business activity, labour market effects, or increased population. Such effects are often the main purpose of fixed links, which frequently are aimed at promoting economic growth or maintaining settlement patterns in rural areas. Ironically, the transport models used to forecast traffic do not consider such effects. Tveter et al. (2017) argue that the assumption of unchanged population trends and settlement patterns might lead to systematic error in traffic forecasts and thereby underestimation of the benefits of fixed link projects.

Traffic growth on bridges and through tunnels within commuting distance of major towns and cities reflects a desired development in Norway. Many island communities have experienced large population growth, which is in line with political goals, and economic growth on many island communities has been large. However, increased traffic flows into cities and urban sprawl pose challenges in terms of congestion and pollution, thus leading to a common conflict of objectives within transport planning and policy. It is important that both traffic effects and spatial effects are documented and accessible to decision-makers when investment decisions are taken.

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