Determinants affecting ferry users' waiting time at ferry terminals

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Abstract

The paper develops a model to examine how different factors influence ferry users' waiting time at the terminals. The estimations are based on interviews of 10 952 Norwegian ferry travellers just after they boarded the ferries. The interviews were conducted in 2013 at 16 of the most important ferry connections in Norway. The average headway and waiting time at the terminals were 52 and 15 minutes, respectively. By comparison, average sailing time at the services in question was 38 minutes, indicating that waiting-time costs at the terminals make up a large proportion of ferry users' time costs. The model's results show that the users' waiting time at the terminals increases concavely with the ferries' headway and distance travelled to the terminals, that is, the marginal effects of these factors diminish when their values increase. The first result indicates that the proportion of ferry users arriving randomly at the terminals decreases with the ferries' headway. The model also reveals that a large proportion (20%) of the waiting times at the terminals is due to the travellers being unable to board their desired departure because of the ferries' capacity restrictions. Other variables, like the mode of transport travellers' used to get to the terminals, their income, and how often they used the service, influence waiting time significantly in the hypothesised directions, even though some (e.g. income and trip frequency) have very moderate influences on waiting time.

Keywords: Capacity problems; Ferry services; Headway time; Public transport; Waiting time

1. Introduction

Public transport is characterised by limited capacity and fixed schedules. Each year, more than 50 billion journeys are made by such modes of transport in the European Union (UITP, 2015). One of the most important factors influencing user satisfaction with public transport is departure frequency; see for example, Jansson (1993), Mathisen and Solvoll (2010), Nathanail (2008) and Jørgensen and Solvoll (2018). The importance of frequency is related to the negative convex relationship between the length of the time interval between each departure (i.e. headway) and frequency. Thus, increased frequency reduces travellers' hidden waiting time (i.e. time due to being unable to depart or arrive when they want) and their waiting time at the terminals (i.e. the time from arriving at the terminal until the time of departure). Empirical studies have suggested that travellers' time cost per hour is significantly higher when waiting at the terminals than when on the means of transport (Small, 2012). Hence, reducing travellers' waiting time is crucial when public transport systems are designed (Ingvardson, Nielsen, Raveau, & Nielsen, 2018).

The inconveniences for the travellers of relying on scheduled transport can, thus, be divided into two groups. The first group and perhaps the most significant one is "hidden waiting time costs" that are costs related to the disadvantages of not being able to travel when they want because they must adapt to the modes' departure - and arrival times. The second group is open waiting time or waiting time costs at the terminals. Both cost categories depend on headway time (i.e. the length of the time interval between each departure), punctuality, and reliability (Andersen & Tørset, 2017).

The primary focus of this article is, however, on the relationship between waiting time and headway. This relationship has been investigated in a number of previous studies, and it was early established that travellers arrive randomly to terminals when headway is short. Expected waiting time ($E(W)$) on these short-headway services can therefore be expressed as $E(W) = 0.5 \cdot HE$, where HE is the length of the time interval between each departure. However, studies that have aimed to identify the threshold for how long headway can become before travellers plan their arrival to the terminal according to schedule have produced varying results. In an early study of the bus and underground rail services in London in the 1950s, Welding (1957) argued that travellers did not find it worthwhile to time their arrival to the terminal when headway was shorter than 10 minutes. Recent studies of bus travellers in Austin, Texas (W. Fan & MacHemehl, 2009), and Trondheim, Norway (Nygaard & Tørset, 2016), found that travellers stop arriving randomly at the terminal when headway exceeds 11 and 10 minutes, respectively. However, travellers by rail (Harris, 2016) and ferry (Andersen & Tørset, 2017) have been observed to accept headways of 15 and 20 minutes, respectively, indicating that travellers by these modes have higher thresholds than travellers by bus before planning the trip according to schedule.

When studying the relationship between headway and waiting time, O`Flaherty & Mangan (1970) found that expected waiting time in minutes for bus travellers in Leeds, during peak, could be described as $E(W) = 1.79 + 0.14 \cdot HE$. The slope of 0.14 suggests that a 1-minute reduction in headway reduces expected waiting time by as little as 8.4 seconds. Later, Salek & Machemehl (1999) used bus line headway to predict waiting time among bus travellers in Austin, Texas, and found the following relationship: $E(W) = 2.0 + 0.30 \cdot HE$. As such, their model predicts that a 1-minute reduction in headway reduces waiting time by 18 seconds.

The aforementioned studies assume a linear relationship between headway and waiting time; this, however, is unreasonable because as headway increases, a greater proportion of travellers will plan their trips according to the timetables. Hence, a nonlinear relationship between headway and waiting time is more likely (Jørgensen & Solvoll, 2018).

By using data from 45 Norwegian ferry services, Knudsen (1995) found the following non-linear relationship between average waiting time (AWT) and HE: $AWT = 20(1 - e^{-0.023 \cdot HE})$. This model suggests that AWT increases concavely with HE. However, the model will never generate an AWT greater than 20 minutes. Considering that AWT is greater than 20 minutes on several Norwegian ferry services (see Table 1), this is a major weakness of the model. Therefore, we are not surprised that Andersen and Tørset (2017) found that actual average waiting time for five Norwegian ferry services where higher than the estimated waiting time on the same services by using the model developed by Knudsen (1995).

Norway has a long coast with many fjords and inhabited islands that make ferry transport an important part of the Norwegian transport infrastructure (Jørgensen & Solvoll, 2018; Mathisen & Solvoll, 2010). According to our review of the literature, the knowledge gaps regarding determinants that influence ferry travellers' waiting time at terminals are worth closer inspection. First, the aforementioned studies have tended to focus on headway as the only factor explaining waiting time at terminals, also studies dealing with ferry transport (Jørgensen & Solvoll, 2018). Our study shows that many other factors, like distance to the terminals and mode of transport used to travel to the terminals, influence travellers' waiting time. In this manner, we can infer how such exogenous factors of the ferry operators' influence on waiting time at the terminals. As Table 1 reveals, such factors vary considerably between ferry terminals in Norway.

Second, characteristics of the ferry services distinguish them from other public transport services (e.g. rail and bus). The departure frequency among the services typically has large variations and, in general, a large proportion of very low-frequency services. The low frequency of services implies that the consequences for passengers of not being able to board at their desired departure time due to capacity restrictions can be great. Our work also addresses this problem by estimating the relationship between average waiting time for all travellers and headway and the hypothetical relationship between waiting time and headway if all the travellers have reached their planned departures. In that manner, our model enables us to infer the consequences on waiting time of increased frequency and the consequences of increasing ferry size. Frequency and ferry size increase transport capacity, and thereby the number of travellers who make their planned departures; thus, these factors are important instruments for decision-makers who want to influence the quality of ferry services.

The aim of this article is, therefore, to derive how headway and 26 other variables influence Norwegian ferry travellers' waiting time at the terminals. This study is based on data from the National Ferry Data Bank and an extensive user survey conducted on 16 of the most important ferry connections in Norway in 2013. Our unique dataset contains information from almost 11 000 respondents. The remainder of this paper is organised as follows. Section 2 defines the variables and data used in the study and forms the hypotheses for the econometric model specification. Section 3 outlines the econometric model in more detail, tests its statistical properties, and presents and discusses its results. Section 4 provides the concluding remarks.

2. Data sources, variable definition, and hypotheses

2.1 Data sources

Our analysis is based on data from two sources. The first, and primary, source of data is a traveller survey conducted on 16 highway ferry connections in Norway in 2013. These services amounted to nearly 40% of the total number of vehicles transported nationally by ferries. The purpose of the survey was to gather information about ferry users and their travelling habits, and the results are presented in Denstadli et al. (2013). The survey was conducted by distributing a questionnaire onboard the ferries. The population of the study was all the travellers aged 16 years or older, and they were not informed in advance about the survey. Everyone in this group was supposed to receive the questionnaire. However, this plan was difficult to achieve on services with short sailing times. The questionnaire had 16 questions. The nine questions used in this study are in the Appendix.

In total, 14 621 travellers answered the questionnaire. After deleting observations with missing values on one or more of our selected variables, our dataset comprised 10 952 observations. Although calculating a response rate was not possible (Denstadli et al., 2013), the general feedback from those who distributed the questionnaires was that most of those asked were willing to participate. To improve the representativeness of the dataset, questionnaires were distributed on 2 days during week 17 (April 22–April 28) and during weeks 27 and 28 (July 1–July 14). Normally, a greater number of representative responses is received by interviewing travellers over two periods (i.e. spring and summer) and 2 days than when interviews are limited to one period or one day (Denstadli et al., 2013).

The second source of data is the Norwegian Ferry Data Bank, developed and maintained by the Norwegian Public Roads Administration (NPRA, 2017). The ferry operators report the data, and the public roads administration checks them and makes corrections until it considers the data quality to be satisfactory (NPRA, 2017). From the database, we drew data on traffic volume and the total number of departures in 2012. Table 1 provides data and information regarding the 16 ferry services included in our analysis.

The unweighted average headway time and waiting time on the 16 ferry services are 106 and 19 minutes, respectively. The longest average headway is 721 minutes on Bodø-Moskenes, whereas the shortest is 25 minutes on Moss-Horten. Additionally, the longest average waiting time is 78.7 minutes on Bodø-Moskenes. Although the service with shortest average waiting time (Fodnes-Mannheller) is not the service with lowest headway, Table 1 suggests a positive correlation between average waiting time and headway: travellers tend to wait longer for ferry services with few daily departures. Table 1 also reveals that the average unweighted waiting time is 18.7 minutes, whereas the average unweighted sailing time is 38.1 minutes. This indicates that average waiting time is approximately half of average sailing time. For three crossings, waiting times at terminals are longer than the actual sailing time. That time values per hour of waiting time tend to be higher than time values per hour of in-vehicle time (see e.g. Mark Wardman, 2001; M. Wardman, Chintakayala, & de Jong, 2016) indicates that waiting times at terminals can be a significant proportion of ferry users' time costs. If, for example, time values per hour for the ferry users are 20% higher at the terminals than in the ferries, the time costs at the terminals are nearly 60% of the sailing time cost when the unweighted waiting times and sailing times from Table 1 are applied.[1] The proportion of vehicles unable to board the

[1] $\frac{18.7 \cdot 1.2 \cdot TK}{38.1 \cdot TK} \cdot 100\% = 0.59$ in which *TK* are passengers' time cost per unit of time in the ferries. The results in M. Wardman, Chintakayala, & de Jong, 2016 indicate that our multiplier of 1.2 is a conservative estimate.

desired departure varies from 2.2% to 13.3%. It is worth noting that the most trafficked service and the one with lowest headway have a relatively high number of left behind vehicles.

Table 1: Total annual traffic and average values of headway, waiting time, and sailing time at the 16 ferry connections.

Service name	*Traffic volume* [a]	*Remaining vehicles* [b]	*Headway* [c]	*Waiting time* [d]	*Sailing time* [e]
Anda-Lote	487	4.4%	42	10.4	10
Bodø-Moskenes	33	13.3%	721	78.7	210
Bognes-Lødingen	148	3.1%	124	23.4	60
Bognes-Skarberget	122	11.5%	97	23.4	25
Drag-Kjøpsvik	60	3.6%	175	24.5	45
Fodnes-Mannheller	650	3.7%	28	7.5	15
Halhjem-Sandvikvåg	920	4.9%	44	12.8	40
Halsa-Kanestraum	346	11.3%	45	12.2	20
Hella-Dragsvik	109	12.9%	69	16.9	10
Hella-Vangsnes	116	7.4%	73	16.7	15
Lavik-Oppedal	537	5.6%	43	10.8	20
Molde-Vestnes	778	6.4%	44	12.3	35
Mortavika-Arsvågen	1366	5.0%	36	8.3	25
Solavågen-Festøya	579	2.2%	38	8.0	20
Vangsnes-Dragsvik	48	8.5%	88	20.7	30
Moss-Horten	1754	12.4%	25	13.0	30

[a] Traffic is the number of vehicles (1000) in 2012. [b] Percentage of respondents that stood over at least one departure. [c] Average headway is minutes in 2012 (526 000) divided by the total number of departures in 2012. [d] Waiting time is the average waiting time in minutes reported by the respondents on each service. [e] Sailing time is the number of minutes it takes the ferry to sail between the terminals.

The locations of the ferry services used by the respondents is shown in Figure 1.

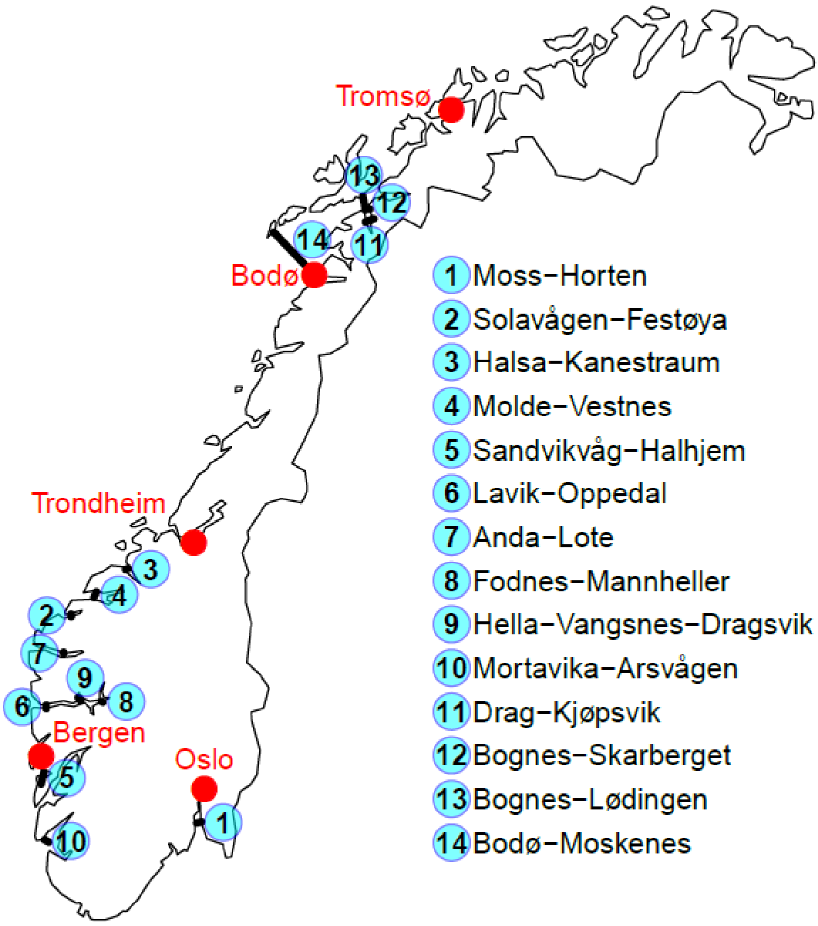

Figure 1: Locations of the ferry services included in the study. No. 9 comprises three ferry services (Hella-Dragsvik, Hella-Vangsnes, and Vangsnes-Dragsvik).

2.2 Variable definition and hypotheses

Waiting time (WT)

WT is the dependent variable and the self-reported waiting time at the ferry terminal from each respondent, that is, the number of minutes the respondent had to wait at the ferry terminal after the time when they arrived and before being able to board the ferry.

Headway time (HE)

Headway time (*HE*) is the time span in minutes between departures at the time when the respondent arrives at the ferry quay. For example, if the respondent arrives at 2:05 pm and the ferries' timetable shows departures at 2:00 pm and 2:15 pm, *HE* is 15 minutes.

A reasonable assumption is that for high- and low-frequency ferry services, users' waiting time at the terminals will increase when headway increases, but the tendency to arrive randomly will be lower when headway increases because a greater proportion of travellers will plan their trips according to the timetables (Jørgensen & Solvoll, 2018). This phenomenon suggests that waiting time increases concavely with headway, that is, the marginal effect on *WT* of increasing *HE* diminishes.

Distance from start of trip to ferry terminal (DT)

Under reasonable assumptions, the uncertainty in travel time from where the trip starts to the ferry terminals (measured by the standard deviation, σ_T) increases concavely with trip distance[2], leading to higher uncertainty in arrival times at terminals for long-distance travellers. This trend is in the direction of a longer waiting time for travellers who start their trips far away from the ferry quays, especially when using low-frequency services.[3] Consequently, *WT* increases with *DT*, probably concavely.

Transport mode *used to get to ferry terminals (M1*, *M2,* and *M3)*

These trip characteristics of the respondents are characterised by the dummy variables *M1*, *M2*, and *M3* as follows:

- *M1* = *M2* = *M3* = 0 if he/she arrives to the terminal by private car or a van, either as a driver or passenger, or if the alternative 'Other (please specify)' in the questionnaire was used.
- *M1* = 1 if he/she arrives to the terminal by foot, cycle, or motorcycle/moped, *M1* = 0 otherwise.
- *M2* = 1 if he/she arrives to the terminal by bus, *M2* = 0 otherwise.
- *M3* = 1 if he/she arrives to the terminal by truck (truck driver), *M3* = 0 otherwise.

A large proportion of the travellers arriving at the ferry terminals by foot or cycle probably live near the terminals and are regular users of the ferry services, suggesting that they have on average a shorter waiting time than those who arrive by private cars. The same situation applies to bus passengers because the local buses' timetables are coordinated with the ferries' departure times and buses are granted boarding priority if demand exceeds ferry capacity. By contrast, truck drivers often use the ferry terminals to rest to fulfil the resting restrictions. Consequently, they often have a deliberately longer 'waiting time' at the terminals than private car users.

[2] Suppose ET_i is the expected driving time for kilometer i to the ferry quay and $ET = ET_1 + ET_2 + \cdots + ET_n$ is total expected driving time and n is total trip length in kilometer to the ferry quay. When we assume the T_i values are independent with identical distributions, we obtain $\sigma_T = \sigma_{T_1} \cdot \sqrt{n}$, where σ_{T_1} and σ_T are standard deviations of driving time per kilometer and driving time for the total trip to the ferry port, respectively.

[3] For high-frequency ferry services (headway less than 30 minutes), a large proportion of travellers will arrive randomly to the terminals, and *DT* will have little influence on waiting time.

In summary, based on the aforementioned reasoning, bus passengers and cyclists have the lowest waiting time at the ferry terminals, whereas truck drivers have the highest. Forming a clear presumption regarding the difference in waiting time for pedestrians, cyclists, and bus passengers is difficult.

Travellers' income (IN)

A traveller's income is described by the dummy variable *(IN)*, such that *IN* = 1 if his/her income exceeds 500 000 NOK (≈ €53 000), *IN* = 0 otherwise. Travellers' value of travel time per unit increases with their income, see for example, Gunn (2008) and Button (2010). This phenomenon indicates that high-income travellers have stronger incentives to save travel time than low-income travellers; thus, they plan their trips more thoroughly by investigating the details of the timetables before starting the trip. We, therefore, expect that *WT* decreases with the travellers' income.

Trip frequency (TF)

Ferry users' trip frequency is described such that *TF* = 1 if they use the service less than one time per week (non-frequent users), *TF* = 0 otherwise. Non-frequent users of a ferry service have less incentive to remember its timetables than frequent users. This lower incentive indicates a longer waiting time for non-frequent users, especially for low-frequency services, where most of the users do not arrive randomly at the terminals.[4]

Gender (GE)

GE = 1 if male, *GE* = 0 if female. If one accepts that women generally are more risk averse than men (Eckel & Grossman, 2008), and thereby accept lower threshold probabilities of not being able to reach the planned ferry departures points in the direction of higher waiting times for women. On the other hand, causes higher risk aversion for women that they will plan their trip and investigate timetables more thoroughly than men in order to maintain appointments. The latter suggests lower waiting times for women. Hence, forming any clear presumption about whether male ferry users have a shorter or longer waiting time at the terminals than their counterparts is difficult.

Trip purpose (PU)

PU = 1 if the trips are work related, *PU* = 0 otherwise. In general, a reasonable assumption is that it is more important for business travellers to maintain appointments than for other groups of travellers; thus, they will have more safety margins, which indicates likely longer waiting times for them.

[4] If the headway between the departures is longer than, for example, 45 minutes, a large proportion of frequent travellers will not arrive randomly to the ferry quays.

Notably, business travellers' travel time has the highest value (Button, 2010), which indicates the opposite; thus, forming any clear assumptions based on a priori reasoning alone is difficult.

Month of travelling (MO)

Because July is the busiest tourist month in Norway, we introduce this dummy where $MO = 1$ if the journey occurred in July, $MO = 0$ otherwise. As the capacity problems on the ferries are most prominent in July while tourists generally know less about the timetables than other travellers, we reasonably assume the highest waiting times are in July.

Weekend travelling (WE)

This dummy is defined such that $WE = 1$ if the journey occurred on Saturday and Sunday, $WE = 0$ otherwise. For some services, leisure travel is definitely the highest on these days, but truck traffic is significantly lower during the weekends. These facts point in opposite directions with regard to waiting time meaning that how weekends affect waiting times at ferry quays is ambiguous.

Capacity problems on the ferries (Q1, Q2, Q3, and Q4)

During peak times, demand exceeds capacity at some ferry services, implying that not all users board their desired departure. The capacity problems are characterised by the dummy variables *Q1, Q2, Q3,* and *Q4* as follows:

- *Q1* = *Q2* = *Q3* = *Q4* = 0 if travellers can board their desired departure.
- *Q1* = 1 if travellers must stand over exactly one departure, *Q1* = 0 otherwise.
- *Q2* = 1 if travellers must stand over exactly two departures, *Q2* = 0 otherwise.
- *Q3* = 1 if travellers must stand over exactly three departures, *Q3* = 0 otherwise.
- *Q4* = 1 if travellers must stand over more than three departures, *Q4* = 0 otherwise.

Other things being equal, waiting time at the terminals (*WT)* is lowest in the first case and highest in the last.

Specifying each ferry service (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, and *S15)*

The topography across the 16 ferry services in question varies considerably; some are in sheltered waters, whereas others are in unsheltered stretches of open sea. Additionally, the manoeuvring difficulties to and from the piers vary significantly between the connections. Finally, the quality of the ferries operating the services varies considerably. All these factors imply that the ferries' ability to maintain their timetables varies considerably between connections, especially in rough weather. Hence, we expect great variations in the punctuality (the standard deviation of departure times) and proportion of cancelled departures (regularity) across the ferry services. Less reliable departure times will especially increase users' waiting times on low-frequency routes.[5]

In summary, several variables may affect ferry users' waiting time at the terminals that we have not been able to operationalise. Therefore, we have specified each of the 16 services by dummy variables as follows:

- $S1 = S2 = \cdots = S15 = 0$ if the respondents travel over the most trafficked ferry service in Norway (Moss-Horten).
- $Si = 1$ if they travel over service i, $Si = 0$ otherwise ($i = 1, 2, \ldots, 15$).

2.3 Summary statistics of the data set

Summary statistics of the aforementioned variables are presented in Table 2.

Table 2 shows, among other things, that average values for the respondents' waiting time, the ferries' headway when the respondents arrive at the terminals, and their travel distance to the terminals were 15.4 minutes, 52.2 minutes, and 189 km, respectively. Table 2 also shows that 89% of the respondents arrived at the ferry terminals by private car, 58% were men, and 86% travelled less than once per week on the service in question. Moreover, 27% of the respondents were business travellers, whereas nearly half of the journeys occurred in July. Finally, Table 2 shows that approximately 93% of the respondents could board at their desired departure[6], and 16% travelled on the most trafficked service in Norway, Moss-Horten ($S1 = S2 = \cdots = S15 = 0$).

[5] When most travelers arrive randomly at the terminals (headway less than 30 minutes), their expected waiting time is (fairly) independent of the ferries' punctuality but will increase with the rate of cancelled departures.

[6] This service level is far lower than the stated goal from the Norwegian authorities of 98%.

Table 2: Summary statistics of the data set (N = 10 952 observations).

	Definition	*Mean*	*S.D.*	*Min/Max*
Dependent variable				
WT	Waiting time (minutes)	15.4	27.1	0 / 660
Trip characteristics				
HE	Headway time (minutes)	52.2	108.9	15 / 1 440
DT	Distance from start of trip to ferry terminal (km)	188.5	423.1	0 / 14 947
M1	Arrival to ferry terminal, $M1$=1 if by foot, cycle or motorcycle/moped, $M1$=0 if otherwise	2.5%		0 / 1
M2	Arrival to ferry terminal, $M2$=1 if in bus, $M2$=0 if otherwise	5.3%		0 / 1
M3	Arrival to ferry terminal, $M3$=1 if in truck or trailer, $M3$=0 otherwise	3.0%		0 / 1
	Arrival to ferry terminal, $M1 = M2 = M3 = 0$ if other (please specify) or in a car or in a van	89.2%		
PU	Trip purpose, PU = 1 if work related trip, PU = 0 otherwise	26.5%		0 / 1
MO	Month of travelling, MO = 1 if July, MO = 0 otherwise	48.9%		0 / 1
WE	Weekend travelling, WE = 1 if journey occurred on Saturday or Sunday, WE = 0 otherwise	12.4%		0 / 1
Traveller characteristics				
IN	Income, IN=1 if income > 500 000 NOK, IN=0 if otherwise	32.6%		0 / 1
TF	Trip frequency, TF=1 if respondent travel less than once a week with the ferry service, TF=0 if otherwise	85.7%		0 / 1
GE	Gender, GE=1 if male, GE=0 if female	58.1%		0 / 1
Variables indicating capacity problems				
Q1	$Q1$=1 if travellers must stand over one departure, $Q1$=0 otherwise	6.2%		0 / 1
Q2	$Q2$ =1 if travellers must stand over two departures, $Q2$=0 otherwise	0.7%		0 /1
Q3	$Q3$=1 if travellers must stand over three departures, $Q3=0$ otherwise	0.3%		0 / 1
Q4	$Q4$=1 if travellers must stand over more than three departures, $Q4=0$ otherwise	0.1%		0 / 1
	$Q1 = Q2 = Q3 = Q4 = 0$ if travellers do not stand over a departure	92.8%		
Name of the ferry service				
S1	Anda-Lote, $S1$=1 if travelled here, $S1$=0 if otherwise	6.8%		0 / 1
S2	Bodø-Moskenes, $S2$=1 if travelled here, $S2$=0 if otherwise	3.8%		0 / 1
S3	Bognes-Lødingen, $S3$=1 if travelled here, $S3$=0 if otherwise	4.4%		0 / 1
S4	Bognes-Skarberget, $S4$=1 if travelled here, $S4$=0 if otherwise	5.3%		0 / 1
S5	Drag-Kjøpsvik, $S5$=1 if travelled here, $S5$=0 if otherwise	2.3%		0 / 1
S6	Fodnes-Mannheller, $S6$=1 if travelled here, $S6$=0 if otherwise	8.7%		0 / 1
S7	Halhjem-Sandvikvåg, $S7$=1 if travelled here, $S7$=0 if otherwise	9.3%		0 / 1
S8	Halsa-Kanestraum, $S8$=1 if travelled here, $S8$=0 if otherwise	5.0%		0 / 1
S9	Hella-Dragsvik, $S9$=1 if travelled here, $S9$=0 if otherwise	3.1%		0 / 1
S10	Hella-Vangsnes, $S10$=1 if travelled here, $S10$=0 if otherwise	3.1%		0 / 1
S11	Lavik-Oppedal, $S11$=1 if travelled here, $S11$=0 if otherwise	6.9%		0 / 1
S12	Molde-Vestnes, $S12$=1 if travelled here, $S12$=0 if otherwise	9.8%		0 / 1
S13	Mortavika-Arsvågen, $S13$=1 if travelled here, $S13$=0 if otherwise	6.5%		0 / 1
S14	Solavågen-Festøya $S14$=1 if travelled here, $S14$=0 if otherwise	7.9%		0 / 1
S15	Vangsnes-Dragsvik, $S15$=1 if travelled here, $S15$=0 if otherwise	1.1%		0 / 1
	Moss-Horten, $S1 = S2 = \cdots = S15 = 0$ if travelled here	16.1%		

2.4 Data deficiencies

The respondents' self-reported or perceived waiting time (*WT*) at terminals and distance driven to the ferry terminals *(DT)* are probably the most uncertain. The question asking the driver about waiting time is open to interpretation (question 6 in Appendix). Most of the travellers probably reported the time span from when they arrived at the terminals to when they boarded the ferries, but some are likely to have reported the time span between when they arrived at the terminals to when the ferries departed; thus, the latter group will report higher values of *WT*. Moreover, studies have indicated that respondents tend to overestimate the number of minutes they wait (Y. Fan, Guthrie, & Levinson, 2016), in particular, when waiting time was longer than expected (Daskalakis & Stathopoulos, 2008). Applied to our case, this information indicates that the ferry users overestimate waiting time when they are unable to board their desired departure.

Two of the ferry services (Bognes-Lødingen and Bodø-Moskenes) have a prebooking arrangement, and this requires that the travellers show up at least 45 minutes before departure to get their tickets. This means that for those who used the prebooking arrangement, the waiting time is at least 45 minutes. Unfortunately, we have no data on which travellers who used the prebooking arrangement as the questionaire did not contain such a question. So, in our model the effect of the prebooking arrangement is captured by the dummy variables *S2* and *S3* for the ferry services Bodø-Moskenes and Bognes-Lødingen, respectively.

The question asking the respondents about the distance from the start of their trip to the ferry terminal is also subject to interpretation because some who travelled more than one day from home to the ferry terminals may report the total distance from the trips' origins to the terminals, and others may report their driving distance the day they boarded the ferries. In addition, the self-reported values of income *(IN)*, trip frequency (*TF*), and trip purpose *(PU)* are uncertain, but to a lesser extent than *WT* and *DT*. We regard, however, the reported values of the dummies *Mi* (i = 1, 2, 3), *GE, MO, WE, Qi* (i = 1, 2, 3, 4), and *Si* (i = 1, 2, …, 15) as correct.

3. Model specification and estimation results

3.1 The model

To analyse how the characteristics of the ferry services and their users influence users' *WT* at the terminals, we use a modified linear model with *WT* as the dependent variable. All the dummy variables mentioned in Section 2.2, except for *Q1*, *Q2*, *Q3*, and *Q4*, were initially included as regressors in the model, that is, the estimated coefficients show the absolute changes in *WT* in minutes when the corresponding dummy variables change from zero to one. However, the main effect on WT due to capacity problems is not an increase in the waiting time by a fixed number of minutes, but an increase in *WT* by a fixed number of headway times. For example, if $Q2 = 1$, that is, the traveller has lost exactly two departures due to capacity problems, the increase in the waiting time for this traveller is approximately two times the headway time (HE). Therefore, we include the interaction terms of *HE* and the dummy variables *Q1, Q2, Q3,* and *Q4* as regressors, rather than the dummy variables *Q1*, *Q2*, *Q3*, and *Q4* themselves. Because *WT* is assumed to increase concavely with the continuous variables *HE* and *DT*, we include the powers of *HE* and *DT* with exponents between 0 and 1 as regressors, rather than *HE* and *DT* themselves.[7] Additionally, that the empirical distributions of *HE* and *DT* are highly right skewed, supports this choice of power functions of *HE* and *DT* as regressors.

The estimated coefficients of the dummy variables for July (MO), weekend (WE), and trip purpose (PU) are not significant at the 10% level; therefore, we exclude these regressors in our final model (3.1). Thus, the following model is employed:

$$WT = \alpha_0 + \alpha_{HE}HE^a + \alpha_{DT}DT^b + \alpha_{M1}M1 + \alpha_{M2}M2 + \alpha_{M3}M3 + \alpha_{IN}IN + \alpha_{TF}TF + \alpha_{GE}GE + \alpha_{Q1}(HE \cdot Q1) + \alpha_{Q2}(HE \cdot Q2) + \alpha_{Q3}(HE \cdot Q3) + \alpha_{Q4}(HE \cdot Q4) + \sum_{i=1}^{15} \alpha_{Si} \cdot Si \tag{3.1}$$

We choose the exponents $a = 0.08$ and $b = 0.29$ by finding the linear model with the smallest residual standard error (or equivalently smallest AIC)[8], when a and b are running through all the 10 000 possible combinations and are real numbers between 0 and 1 with exactly two decimals. It follows from the aforementioned hypotheses that $\alpha_{HE}, \alpha_{DT}, \alpha_{M3}, \alpha_{TF}, > 0$, $\alpha_{M1}, \alpha_{M2}, \alpha_{IN} < 0$ whereas the sign of α_{GE} is uncertain.

The assumed influence of *Qi* (*i* = 1, 2, 3, 4) on *WT* in model (3.1) deserves further comment. When *Qi* increases from 0 to 1, *WT* increases by $(\alpha_{Qi} \cdot HE)$ minutes. If, for example, the headway at a service is 30 minutes, travellers' waiting time at the terminal will increase by approximately 30 and 60 minutes when they must stand over one or two departures, respectively. The aforementioned suggests that $\alpha_{Q1} \approx 1$, $\alpha_{Q2} \approx 2$, $\alpha_{Q3} \approx 3$, and $\alpha_{Q4} > 4$.

[7] From formula (3.1) follows $\frac{\partial WT}{\partial Z} = a\alpha_Z Z^{a-1} > 0, \frac{\partial^2 WT}{\partial Z^2} = \geq (< 0)$ when $a \geq (<) 1, Z = HE, DT$.

[8] AIC is Akaike information criterion, see Fox (2016).

The values of the parameters α_{Si} (i = 1, 2, …, 15) show how the waiting time in minutes at service i differs from the base service (Moss-Horten) when the values of the other explanatory variables are the same. As aforementioned, establishing any clear presumptions about the signs of α_{Si} is difficult, but a reasonable belief is that quite a few are significantly different from zero, because we have not been able to operationalise all factors that affect users' waiting time at the ferry terminals.

3.2 Model diagnostics and parameter values

The Breusch–Pagan test shows that the heteroscedasticity in the residuals is highly significant (p-value < 0.001). However, when using heteroscedastic robust standard errors from the estimators HC3 and HC4 (Zeileis, 2004) instead of the standard homoscedastic errors, all the regressors, except for the dummies for Bognes-Skarberget and Bognes-Lødingen, remain significant at the 5% level.

The normality plot of the residuals shows that the distribution of the residuals is far from normal. However, as we have more than 10 000 observations, the central limit theorem ensures that the inferences based on the least squares estimator are approximately valid (Fox, 2016). This validity is confirmed by obtaining p-values from permutation tests (Wheeler & Torchiano, 2016), because all the regressors, except for the dummies for Bognes-Skarberget, Bognes-Lødingen and Molde-Vestnes, remain significant at the 5% level when using these p-values.

Additionally, the residual plots confirm a linear relationship between the response variable *WT* and the chosen powers of headway (*HE*) and distance (*DT*). The residual plots of the categorical variables have the property that the centre of the boxes (for the box plots of the residuals at the various levels) is approximately the same for all the levels.

Finally, there is no significant correlation between the residuals and numeric regressors. In summary, the estimation results in Table 3 can be trusted.

Table 3: Multiple regression estimates.

Dependent variable: Waiting time at the ferry terminal			
Explanatory variable	Coefficient	t-value[a]	
Trip characteristics:			
$HE^{0.08}$	113.44	20.79	***
$DT^{0.29}$	1.15	10.51	***
M1	-7.05	-6.29	***
M2	-5.16	-6.51	***
M3	11.32	10.88	***
Traveller characteristics:			
IN	-0.71	-1.83	*
TF	0.97	1.86	*
GE	0.94	2.53	**
Interaction variables:			
HE·Q1	0.87	56.81	***
HE·Q2	1.84	36.39	***
HE·Q3	2.81	46.07	***
HE·Q4	4.95	36.63	***
Name of ferry service:[b]			
S1: Anda-Lote	-3.21	-4.02	***
S2: Bodø-Moskenes	15.42	8.31	***
S3: Bognes-Lødingen	-3.32	-2.93	***
S4: Bognes-Skarberget	-2.81	-2.79	***
S5: Drag-Kjøpsvik	-9.07	-6.02	***
S6: Fodnes-Mannheller	-0.49	-0.65	
S7: Halhjem-Sandvikvåg	-0.22	-0.30	
S8: Halsa-Kanestraum	-3.09	-3.47	***
S9: Hella-Dragsvik	-1.92	-1.76	*
S10: Hella-Vangsnes	-4.64	-4.12	***
S11: Lavik-Oppedal	-1.43	-1.80	*
S12: Molde-Vestnes	-1.53	-2.18	**
S13: Mortavika-Arsvågen	0.13	0.15	
S14: Solavågen-Festøya	-4.04	-5.36	***
S15: Vangsnes-Dragsvik	-0.82	-0.47	
Constant	-142.82	-19.79	***
Summary statistics: N = 10 952, R^2 = 0.56, F-statistic: 516, $df1 = 27$, $df2 = 10924$, p-value $< 2.2 \cdot 10^{-16}$			

[a] Level of significance: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.
[b] Ferry service Moss-Horten is the base value.

3.3 Further discussion of the estimation results

If we ignore the α_{Si} (i = 1, …, 15) parameters, all the other parameters in Table 3 have signs in line with our a priori assumptions and are significant at the 10% level or better, with most at the 1% level or better. It follows, for example, from the value of α_{HE} (= 113.44), that an increase in ferries' headway *(HE)* from 30 to 60 minutes will increase travellers' expected waiting time at the terminals

(WT) by 8.5 minutes. A further increase in headway by 30 minutes (to 90 minutes) will increase waiting time by only 5.2 minutes. Moreover, the value of α_{DT} $(= 1.15)$ suggests that when travellers' distance to the terminals *(DT)* increases from 0 to 100 km and from 100 to 200 km, expected waiting times at the terminals increase by 4.4 and 1.0 minutes, respectively. Although the α_{DT} parameter is significant at the 1% level, the estimation demonstrates that *DT* means little for waiting time when greater than 100 km.

The estimated coefficients of the dummies indicating the transport mode used to arrive to the terminals (*M1, M2, M3*) show that expected waiting times are 7.1 and 5.2 minutes shorter, respectively, for those who arrived by foot/cycle or bus than by private cars. Truck drivers have waiting times at the terminals more than 11 minutes longer than private car users. As aforementioned, truck drivers often have long stops at the terminals to comply with the resting restrictions. Because the resting requirements have remained unchanged since 2013 (Bergland & Pedersen, 2018), a reasonable assumption is that truck drivers still have longer waiting time at the ferry terminals than private car users.

Although significant at the 10% level, the coefficients of the dummies signalling travellers' income (*IN*) and trip travel frequency on the ferry service in question (*TF)* show low influence on waiting time. Expected waiting time for travellers with an annual income greater than 500 000 NOK have a 0.71-minute (43 seconds) shorter waiting time than their counterparts, whereas low-frequency travellers have a 0.97-minute (58 seconds) longer waiting time than frequent travellers. Gender *(GE)* influences waiting time at the 5% level, but its influence is moderate. Expected waiting time for men is 0.94 minutes (56 seconds) longer than for women.

The estimates of $\alpha_{Q1}, \alpha_{Q2}, \alpha_{Q3},$ and α_{Q4} are 0.87, 1.84, 2.81, and 4.95, respectively. All have, thus, signs in line with what we expected, but the magnitudes of $\alpha_{Q1},$ $\alpha_{Q2},$ and α_{Q3} are somewhat lower than we supposed in Section 3.1. This difference may be because on short connections, ferries often take an extra trip to collect the remaining passengers, implying that the passengers do not have to wait until the next planned departure. Another reason may be that we tacitly assume that the headways between the next four departures are the same as the time span in minutes between departures at the time when the respondent arrives at the ferry quay. This suggests that these α-values overestimate (underestimate) the importance of not reaching the desired departure when arriving to the ferry quays before (after) the peak periods, that is, when frequency is highest.

The estimated parameters of the 15 categorical variables ($S1$, $S2$, …, $S15$) are meant to capture the total effect on users' waiting time at the quays of all the omitted explanatory variables, such as ferries' punctuality and regularity. Table 3 shows that 11 of the 15 connections have waiting times that differ significantly from the base service (Horten-Moss): ten have shorter waiting times than the base connection, varying from 1.4 to 9.1 minutes, and the eleventh ($S2$ = Bodø- Moskenes) is notable with a waiting time longer than 15 minutes compared with the base service. These results are reasonable. Table 1 shows, namely, that the base service is clearly the most trafficked, with the lowest headway leading to a larger proportion of travellers arriving randomly to the quays compared with the other services. Random arrival leads to longer waiting times (see Figure 2). Moreover, Table 1 shows that the proportion of travellers unable to board the desired departures is relatively high at the base service. This result also indicates a higher waiting time there. The service ($S2$) with significantly higher waiting time than the base service is in many ways an outlier: the proportion of tourists is high, the capacity problems are prominent during the summer, the trip length is very long (90 km), and the ferries must cross rough stretches of open seas. The last point leads to especially low regularity, which increases waiting time at the terminals.

The relationships between waiting time (WT) and headway (HE) are illustrated in greater detail in Figure 2. The top dotted line shows the relationship between waiting time and headway ($WT = 0.5 \cdot HE$) if the travellers arrive randomly to the terminals. The solid curve shows the actual relationship between waiting time and headway when all other explanatory variables have their average values. This curve confirms the concave positive association between these two variables: when HE increases from 20 to 60 minutes, WT increases by 16.4 minutes, whereas WT increases by only 9.7 minutes when HE increases from 60 to 100 minutes. Because the Q_i (i = 1, 2, 3, 4) variables also have their average values when depicting the solid line, it shows the actual relationship between WT and HE, taking tacitly into account that not all travellers could board their desired departure.[9]

To illustrate the consequences for the users of demand exceeding capacity for some departures, the bottom dashed curve in Figure 2 shows how users' expected waiting time would have been if all travellers boarded their desired departure; that is when $Q1$ = $Q2$ = $Q3$ = $Q4$ = 0. As expected, the vertical difference between the solid curve and this curve increases with headway. If, for example, HE = 30, the difference is 2.35 minutes; if HE is 60, it is 4.69 minutes. Although the difference is significantly lower than the headway (because the majority can board their desired departure), the curves signal that increased ferry capacity could have saved ferry users considerable waiting time at

[9] In our dataset approximately seven%.

the terminals, for example, when HE = 30 and HE = 60, they have saved on average 19% and 20%, respectively.

The vertical difference between the top dotted line and the solid curve clearly illustrates the importance for the ferry user of knowing the timetables, so they do not arrive randomly. For example, when headway is 20 minutes and 60 minutes, the expected reductions in waiting times are 3.1 minutes and 6.7 minutes, respectively.

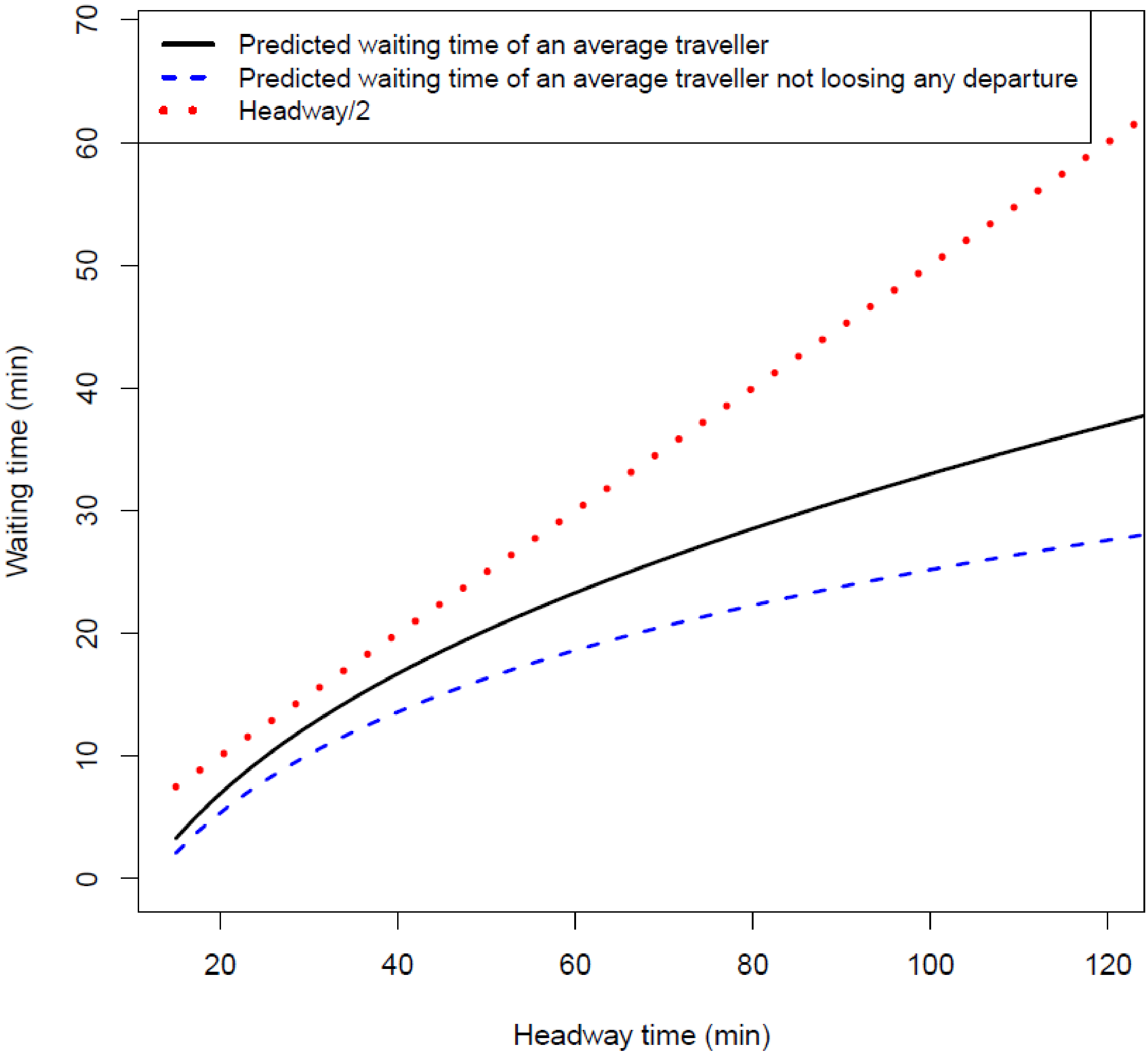

Figure 2. Relationships between predicted waiting time at the terminals and headway.

Finally and notably, our model enables us to discuss the authorities' possibilities to influence ferry users' waiting time by inferring the importance of the multiple correlation coefficient (R^2) of the model's explanatory variables that the authorities and ferry operators can control. The most prominent variable in this respect is, of course, headway *(HE)* or frequency, but the authorities' can also indirectly influence the proportion of travellers able to board their desired departure (the values of $Q1,\ Q2,\ Q3,$ and Q4) by increasing the transport capacity of each ferry. Omitting all these five controllable variables reduces R^2 from 0.56 to 0.27. This reduction in R^2 is significant but also reveals that exogenous factors for the authorities and ferry operators are important for travellers' waiting time at the ferry terminals.

4. Concluding remarks

In this paper, we develop a model to examine how different factors influence ferry users' waiting time at terminals. Special emphasis is placed on the relationship between waiting time and headway time because headway is the most important controllable variable for ferry operators and transport authorities that influences waiting time. This emphasis allows us to discuss to what extent a reduction in headway time can improve the welfare of ferry travellers by reducing their waiting time. The primary sources used in our analysis are nearly 11 000 answers to a survey conducted among travellers on the 16 most important ferry services in Norway in 2013 and data from the National Ferry Data Bank. The services were located across the country. According to our review of the literature, this is the first attempt to empirically study travellers' arrival behaviour at terminals for public transport services where headway, in general, is high and varies considerably between services. Our analysis also demonstrates the importance of a range of other explanatory variables on waiting time.

The most important finding is the concave relationship between waiting time and headway time, that is, the marginal effect on waiting time of increasing headway is diminishing. When, for example, headway is increased by 5 minutes from 15 to 20 minutes, expected waiting time increases by 3.7 minutes, whereas a similar increase from 55 to 60 minutes increases expected waiting time by only 1.5 minutes. In other words, all else being equal, a one-unit reduction in headway causes greater reductions in waiting time at the terminals for travellers on ferry services with short, rather than long, time intervals between departures. If we accept that hidden waiting time (*HT*) is half of the headway $(HT = 0.5 \cdot HE)$ the marginal effect on hidden waiting time of decreasing headway is constant. The above statements put together mean that the marginal benefits for ferry users of reduced headway are increasing. The marginal effect of increasing frequency is, however, somewhat different.[10] Another

[10] Let headway, $HE = \frac{O}{F}$ where *O* are opening hours and *F* frequency. Using the power relationship between waiting time *(WT)* and headway in formula (3.1) it can be deduced that $\frac{dWT}{dF} < 0$ and $\frac{d^2WT}{dF^2} > 0$. Hence, *WT* deceases convexly with *F*

thing worth noting is that optimal ferry frequency must not be decided from its influence on travellers waiting time costs alone, but also from the operating costs of ferry operators. This issue is thoroughly discussed in Jørgensen & Solvoll (2018).

Moreover, estimates suggest that 20% of travellers' waiting times at ferry terminals are due to them not being able to board their desired departure. This result means that increasing ferry size would cause fewer remaining vehicles and would, all else equal, reduce the average waiting time at the terminals (the solid curve in Figure 2 shifts downwards). The model also demonstrates the interrelationship between headway time and the importance of the travellers being able to board the ferries at their desired time. The diminishing effect on travellers' waiting time of increasing headway also implicates that the most prominent benefits for the travellers of increasing frequency are that they have greater flexibility in departure times (shorter hidden waiting time) and not that they have shorter waiting times at the terminals.

The model estimation also reveals the following. First, the distance to the terminal has little effect on waiting time when it is greater than 100 km. Second, travellers arriving to the terminal by foot or bus have a shorter waiting time than those arriving in private cars, whereas truck drivers tend to wait the longest. Third, income, gender, and trip frequency have a significant but relatively modest influence on waiting time.

Finally, our study, in line with all empirical studies, has limitations due to imprecise data, omitted explanatory variables, and misspecification of the model. The uncertainty in the data, especially the reported or perceived value of waiting time (WT) and distance driven to the terminals (DT), is earlier elaborated on in Section 2.4. Because ferry users tend to overestimate waiting time when they are unable to board the desired departure, our results may overestimate the waiting time increase due to capacity restrictions at the ferry services (the influence of the Q-values).

Admittedly, we could not operationalise all the important explanatory variables for users' waiting time at the terminals. As mentioned in Section 2.4, the effects on waiting time when the ferry users can use prebooking arrangement is scarcely dealt with due to lack of data. The most important omitted variable is, however, in our opinion undoubtedly the ferries' punctuality. If the ferry users accept certain threshold probabilities of not reaching their planned departures, it can easily be proved that waiting times at the terminals increase the lower the values of these thresholds and the higher the

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meaning that the marginal effect of F on WT diminishes. The same is true for hidden waiting time (*HT).* The above implies that the marginal benefits for the users of increasing frequency decline.

uncertainty in departure times, see Jørgensen and Sæterdal (1983) for a thorough discussion of these problems. Both these factors can vary significantly between ferry connections and, hence affect waiting times.

Some of these effects are, however, captured in the headway variable because lower headway increases users' threshold probabilities of not reaching the planned ferry departures which subsequently decrease waiting times. This strengthen the argument of headway being the most important explanatory variable for waiting time. Moreover, the Si (i = 1, 2, ..., 15) variables indicating the service in question do, broadly speaking capture the overall impact of punctuality and other omitted variables such as use of the prebooking arrangement, regularity and the variations in traffic over the day.

Although the model used is a result of thorough statistical examination of different model alternatives with special emphasis on the characteristics of the residuals, its formulation is also open to debate. The most prominent weakness is perhaps that all cross derivatives in (3.1) are zero, that is, the marginal effect of each explanatory variable is independent of the values of the other explanatory variables. For many of the variables, this situation is not very serious, but for others, it may be. The implications are, for example, that a marginal change in headway when it is equal to start with has the same effect on the waiting time in all 16 connections. Like all econometric analyses, our chosen model is, however, a weighing between an easy interpretable model, its statistical properties, and to what extent it corresponds with reasonable a priori assumptions. Also notable is that our data are from 2013. Since then, the ferry companies' digital information has improved, making it easier for passengers to obtain current information on timetables and delays. This innovation may have subsequently reduced waiting time and perhaps the magnitudes of the influences of its explanatory variables.

Despite the limitations, this paper provides an extensive analysis of factors that influence waiting times and inconvenience costs for users of ferry services. The results may also be useful in analysing quality aspects in the provision of other non-frequent public transport services.

APPENDIX – THE QUESTIONNAIRE

Only questions applied in this study are included. The complete questionnaire can be observed in (Denstadli et al., 2013).

Questions used in this study

1. What is your home address?

   Zip code: __________

   Place:__________

   Country (if other than Norway):_____________

2. Where did your trip start?

   Place (city / district):______________

   Municipality:_______________

   Country (if other than Norway):_____________

3. Where are you going?

   Place (city / district):______________

   Municipality:_______________

   Country (if other than Norway):_____________

4. What is the main purpose of your trip?

   ☐ Trip to / from work

   ☐ Travel in work

   ☐ Freight transport

   ☐ Travel to / from school / campus

   ☐ Visit family / friends

   ☐ Holiday / leisure

   ☐ Private trip (shopping, visit doctor, etc.)

   ☐ Other

5. How did you get to the ferry? I was…
   - ☐ The driver of a car
   - ☐ The driver of a van
   - ☐ The driver of a truck
   - ☐ The driver of a trailer
   - ☐ The driver of a motorcycle / moped
   - ☐ A passenger in a car / van / truck / motorcycle
   - ☐ A passenger in a scheduled bus / coach
   - ☐ A pedestrian / cyclist
   - ☐ Other (please specify):___________________

6. How long did you wait for the ferry?

   ___________ minutes

7. Do you often travel on this ferry stretch? (Specify the number of single trips)
   - ☐ 8 or more times per week
   - ☐ 4–7 times per week
   - ☐ 1–3 times per week
   - ☐ 1–3 times per month
   - ☐ 5–10 times per year
   - ☐ 1–4 times per year
   - ☐ Rarer

8. What is your gender?
   - ☐ Male
   - ☐ Female

9. What is your gross income before tax?
   - ☐ Less than 200 000 NOK
   - ☐ 200 000 – 349 999 NOK
   - ☐ 350 000 – 499 999 NOK
   - ☐ 500 000 – 649 999 NOK
   - ☐ 500 000 – 649 999 NOK
   - ☐ More than 650 000 NOK

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