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# A Case Study of Toll Implementation in Northern Jæren


*Figure 1: Elasticity map of Northern Jæren*

*"What is the impact of cordon and peak period pricing on car use demand?"*


By:

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**UIS BUSINESS SCHOOL**

# MASTER'S THESIS

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# Acknowledgement

This master thesis has been written as a final part of the two-year master program in Economics and Administration – Economic analysis, at the University of Stavanger. The magnitude of the thesis is 30 credits.

Motivation for writing about the new toll regulation in Northern Jæren is the attention this has received in the media, additionally to our local knowledge. It has been an educational semester, where we have been challenged, and found the dynamics that have led us to the result of this task.

We would like to thank Stian Brosvik Bayer, researcher from NORCE, who has been very helpful in analysing data, and Danielangela Obiacoro for assisting us with illustration of the elasticity map presented as our graphical abstract.

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Inela Elkasevic & Gina Eriksen,

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# Abstract

The purpose for this thesis is to elucidate on the effects of toll pricing schemes. The new toll implementation in Northern Jæren have been investigated to measure the effect cordon and peak-period pricing have on car use demand. This research can be useful for policy makers when deciding a strategy for regulating traffic demand.

Through estimation of toll price elasticities, this study shows how sensitive car users are to toll price change. Count data of number of cars on the road is collected to examine the change in traffic flow. The overall decrease in traffic is found to be 8% in Northern Jæren, ranging from -3% to 11% in the different cordon areas. The elasticity analysis shows overall inelastic results, ranging from -0.0305 to -0.1478. However, there is observed higher elasticities during peak-period, ranging from -0.0275 to -0.1952.

Results from this study suggest that the toll implementation to some extent works according to its purpose. However, other factors are also effecting the change in car use demand. An interesting finding is that there seems to be a shift in traffic flow as a result of the toll pricing scheme.

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# 1.0 Introduction

A new toll regulation was implemented in Northern Jæren October 1st 2018, with 38 new toll stations located around highly congested areas, in addition to extra charges in periods with high traffic demand. Northern Jæren is a region in Rogaland, Western-Norway, with high population growth. Mainly, as a result of high labour immigration and expansive activity in oil and gas industry. The intention of the implementation is to build a more environmentally friendly region and improve traffic accessibility (Samferdselsdepartementet, 2016).

The new toll regulation has been received with outrage reactions from the public. Since before the implementation, there have been daily updates about the new regulation and reactions in newspapers. A google search on *"bompenger"* (toll charge in Norwegian), results in about 103 000 hits. The same search in google trend, illustrate increasing searches the past 12 months. The writers of this thesis originate from the site of interest and have been surrounded of the commotion and even been affected of the new regulation. This combination makes this research current and interesting to investigate.

The intention of this study is to explain variables which affects traffic demand. Is price the decisive variable, or is it other factors? Policy makers might use the following research to understand how effective such implementations are on car traffic. This thesis presents the results with estimations of elasticities. To the readers information, the research only focuses on personal car use for the commute to and from work. It also provides results only for the hours between 05:00 to 19:00.

With the aim to elucidate the effects of a new toll implementation in Northern Jæren, we have chosen the following research question: "***What is the impact of cordon and peak load pricing on car use demand?",*** with focus on personal car use. To answer the main research question, we have developed the following sub-research questions:

1. Are car users price sensitive?
2. How does toll implementation affect car driving behavior?

Our main research question is based on hypothesis derived from previous research and microeconomic theory, which shows that an increase in price would cause a reduction in traffic demand. This phenomenon is called the law of demand (Snyder & Nicholson, 2012). To answer the sub-research questions, we need to investigate variation at different times.

The thesis is structured as follow: Chapter two and three covers the background theory in term of the new toll implementation in Northern Jæren and previous literature with corresponding table over the literature review. Chapter four describes the theoretical framework, while chapter five present the methodological approach. In chapter six the analysis, with corresponding volume results and elasticity. Lastly, the findings will be discussed in chapter seven. Followed by the conclusion in chapter eight.

# 2.0 Background

An overview of our location of research is first presented in this chapter, before introducing environmental problems associated with traffic. The government's plan for reducing these problems in Northern Jæren is then explained. Overall, this chapter provides the necessary information for the reader to understand the motivation of this thesis.

## 2.1 Northern Jæren

Jæren is a part of Rogaland County, which is located in the southwest part of Norway (Figure 2). It is separated into Northern and Southern Jæren, where Northern Jæren is the area of interest for this thesis, consisting of the municipalities of Stavanger, Sandnes, Sola and Randaberg. Cordon areas located in Stavanger, Sandnes and Sola will be examined further in this thesis.


*Figure 2: Map of Northern Jæren (Kart over Jæren [Image], 2019. Edited.)*

Northern Jæren have one of the largest population growths among the regions in Norway (Samferdselsdepartementet, 2016). The population is increasing in the cities and in the rural districts. Overall in Jæren, the population increased by an average of 1.8% annually in the period 2007 to 2017, having a stronger growth than in entire Norway with 1.2% (Thorsnæs, 2018). The main reason is high labor immigration, especially after 2007, when there was high activity due to oil and gas industry in this region. In recent years, there have been some declining growth in all municipalities, due to lower activity in the petroleum industry (Samferdselsdepartementet, 2016).

Travel register from the Norwegian Public Road Administration (NPRA) shows that this situation has led to an increase in travel time during the rush period by 20% - 40%, and particularly more congestion, especially to Forus. The area of Forus is in the municipal boundary between Stavanger, Sandnes and Sola (see Figure 2), which is one of the most important industrial areas in Norway (Forus.no, 2019). The roads to this area is therefore highly congested, especially during peak hours. In addition to accessibility problems on the road network, it is particularly a challenge for public transport, and major delays reflects the form of low public transport share, compared to other large cities in Norway.

Tananger is also an industrial area located in Sola municipality consisting of a large number of petroleum related activities. As can be seen from Figure 2, Sola is parallel located to Forus, providing a road network that gives commuters a loophole around the cordon of Forus. Involving possibilities to avoid toll stations, by driving through Sola, can be interesting to analyze relative to the traffic behavior in this area.

The new toll implementation in Northern Jæren is an interesting regulation to investigate because of its profound form. New tolls affect many people economically, and there has been a great amount of media attention regarding this matter. Furthermore, the researchers of this thesis originate from this area, and therefore provides some local knowledge that can be useful for the analysis.

## 2.2 Environmental focus

Traffic congestion and emissions represent some of the most serious challenges that European cities face today. The climate and weather are changing all over the world. This affects the quality of life for the people living and working in the cities, and represent substantial costs to society (The Norwegian Environment Agency, 2018). Emission increased with 22% during 1990–2017, then stabilized and have declined in recent years (Miljødirektoratet, 2018). According to SSP, changes in air climate emissions have been reduced by 1.6% in 2017 (Statistisk sentralbyrå, 2018).

Road traffic activity and congestion generates negative externalities related to air contaminations, where air contamination is one of the main reasons for local pollution and global warming. Road traffic is responsible for 17% of the total emissions of greenhouse gases in Norway. Passenger cars account for the largest share of emissions and accounted for 53% of the road traffic emissions in 2017. Road traffic was among the largest contributors to the decline of greenhouse gases in 2017 compared to the previous years, with reduction of road traffic by 9.5% (Statistisk sentralbyrå, 2018). Over the years, the number of gasoline cars has reduced, while the number of diesel cars have increased. At the same time, there has been an increase in the proportion of electric cars, which accounted for approximately 40.6% change in purchase of electric cars in 2018 compared to the previous year (Statistisk sentralbyrå, 2019).

Congestion is a large and increasing problem in several cities around the world. People moving from suburban to urban areas causes accumulation of cars, queue, stress, traffic accidents and particularly higher pollution. Some places in Northern Jæren are characterized by queuing and accessibility problems. As a result of increased transport demand over time, the number of car journeys will also increase. In the absence of measures, it is therefore reasonable to expect that the accessibility problems on the roads will continue to increase in the future.

### 2.3 Urban Environmental Agreement for Northern Jæren

The City Growth Agreement "*Byvekstavtalen*" is an agreement between the Norwegian government and municipalities regarding the traffic growth. The government plans for a more environmental friendly city development, with a goal of zero growth in personal car use (Regjeringen, 2019). The municipalities in Northern Jæren is committed to the agreement through the Urban Environmental Agreement for Northern Jæren "*Bymiljøpakken Nord Jæren*".

The Urban Environmental Agreement is a toll package for the municipalities Stavanger, Sandnes, Sola and Randaberg. The agreement states: "Number of people and cars in Northern Jæren is constantly increasing. We have to take actions – and everyone can contribute. Sometimes we can leave the car at home and use the bus, train, bicycles or walk instead. On the other hand, we can pay toll for those times we actually have to drive. This is what the Urban Environmental Agreement for Northern Jæren contributes to." (Our translation) (Bymiljøpakken, 2019a). The intention is to build a more environmentally friendly region by 2033.

The agreement was approved by the Parliament 30. March 2017 and will contribute to improved accessibility and urban environment in Northern Jæren, including among other things, strong focus on urban areas. The plan is to use about 29 billion NOK on the investment (Bypakke Nord-Jæren, 2017). In total, most of the revenues in the investment package, in which tolls contributes main of the funds, should be spent on planning and building roads, bus roads and bike roads. In addition, 3.3 billion NOK have been set to run and improve public transport. Through "Byvekstavtalen" and National plan of Transportation, the government will provide about 11 billion NOK in funds, and approximately 1.5 billion NOK in VAT-refund contributes from Rogaland County. The toll revenues are contributing to finance the following construction plans (Bymiljøpakken, 2019b).

- Bus road – the longest bus road in Europe
- Bike path – a connected bike path between Stavanger and Sandnes by Forus.
- Own road for trucks from Sola to Risavika and Sundekrossen
- Four-line road at E39 from Tasta to Harestad and From Hove to Ålgård.
- In addition, there are several roads and many good measures for everyone who cycles, walks and using the public transportation.

Similar schemes are currently being implemented in the Norwegian cities of Trondheim, Oslo, Bergen, Kristiansand and Tromsø (Bymiljøpakken, 2019b).

### 2.3.1 The Toll Implementation

Congestion charging scheme was in place from October 1st 2018, with time-differentiated charges, mainly consisting of cordons around the inner city of Stavanger, Sandnes and Forus. The cordons are presented in our graphical abstract Figure 1. Vehicles traveling in the inbound direction are required to pay a toll when passing a cordon. This is illustrated by the arrows in the figure. When it comes to Randaberg, car users pay toll in the outbound direction, which means this is not a cordon. Therefore, these toll stations will not be investigated in this study. Cordon areas will be explained further in the theory section.

Bymiljøpakken has decided to locate 38 toll stations in the areas with most traffic, especially in the peak period hours, and where there is or will be good alternatives to cars. The list of the new toll stations is presented in Table 11, appendix 2, showing roads in the second column and what area they are located, in third column.

Vehicles are identified by automatic number plate recognition. There is no opportunity to pay at the toll station. Instead, the payments are made automatically through direct debit, and through bank transfers. Auto pass agreement is available for the drivers. The cost of the electronic toll payment tag is 200 NOK, giving drivers a 20% discount of the normal tax. With this agreement, drivers get maximum one charge crossing within an hour and maximum 75 chargeable crossings per vehicle per month (Ferde, 2019). Heavy vehicles have not the opportunity of discounted prices. An overview of prices is presented in Table 1.

*Table 1: Toll fees*

| | | Normal tax | Discounted tax |
|---|---|---|---|
| Per vehicle entering | Off-peak | 22 NOK | 17.60 NOK |
| | Peak | 44 NOK | 35.20 NOK |
| Per heavy vehicle entering | Off-peak | 55 NOK | |
| | Peak | 110 NOK | |

The table shows the toll charge for entering a cordon region. Some vehicles are exempt from charges altogether (e.g., busses in routes and emergency vehicles). Electric cars also have free admission through the toll cordons as for now, but it is highly discussed when and how much these cars are going to pay (Ferde, 2019).

Peak period charging is introduced as a part of "Bymiljøpakken", the purpose is to reduce traffic during those periods with most traffic: when people commute to and from work. During the peak period hours between 07:00–09:00 and 15:00–17:00, vehicles are charged double price. Peak charging only applies from Monday to Friday in the peak period, while off peak pricing applies to all times every day, including Saturday and Sunday.

### 2.3.2 Toll Complications

As a result of technologic problems related to incorrect invoices sent to costumers, the NPRA decided to temporarily remove the peak charging until the problem were solved. The decision ended up with a break in the peak period charging between December 10$^{th}$ 2018 to March 25$^{th}$ 2019, were vehicles were only charged the normal tax by every toll passing (Bymiljøpakken, 2018, 2019a).

A successful congestion charging scheme is one that works technically, reduces congestion, are acceptable, and generates net socioeconomic benefits. Acceptability is the overriding concern for policy-makers, as without it, no lasting implementation is possible. Earlier studies point that individuals with more knowledge and information about a new toll system, are generally more positive for new schemes than others (Gu, Liu, Cheng, & Saberi, 2018; Odeck & Bråthen, 2008).

A survey from Norwegian Broadcasting Corporation (NRK) showed that 70% were against the new toll regulation before the implementation (Evensen & Topdahl, 2018). In consideration of the agreement, articles about the new toll regulation have filled newspapers. People already pay for the use of car and roads, and react on the extra payment through toll stations, mainly the peak pricing. As a result of different cordons between individuals home, their workplace and children's preschools, it can infuse extra expenses to households up to 34 000 NOK yearly (Bjerkan, 2018).

Introduction of the new regulation has created a lot of commotion among the population. A search on Facebook results in several groups and pages against toll regulations and the population is strongly opposed to tolls in Norway. In Northern Jæren, a Facebook group named "Bomfritt Jæren – nok er nok" was created, which can be translated to "Toll free Jæren - enough is enough". The Facebook group has approximately 60 000 members fighting against the new regulation.

All the commotion among the people has created divisions internally in The Urban Environmental agreement between the municipalities in Northern Jæren, especially regarding the peak pricing. The Mayor of Sandnes has on several occasions stated that he wants to remove the peak period pricing. Disagreement between political parties about the agreement may cause increased hostility and confusion among the community (Topdahl & Schibevaag, 2019). A combination of the problems above, creates skepticism among the people.

# 3.0 Literature Review

In this chapter, we have selected 29 research papers, with similar topics as in our analysis. A full representation of the literature is provided in Table 10, appendix 1. We want to discuss and compare our results to previous research. Topics of interest are congestion pricing, public acceptance and travel behavior according to route choice. The research papers consist of studies from the past 30 years, with focus on toll implementation and travel behavior.

## 3.1 Describing Literature

The representation of the literature consists of six columns. The first column provides the author, journal and year of the paper; second column indicates location of the study, while the third describes the study's purpose. Further, fourth and fifth column provides the methods and theory used, including information about the type of survey conducted. The last column presents relevant results of each study.

The previous researches, which are used in this study, have been completed in different countries. Many of these studies were carried out in the USA with primary focus on peak-period pricing. The study by Braid (1996) explores the choice of transportation route after implementation of rush hour tax. In Braid (1989), different elasticities are investigated regarding constant and peak-period pricing on bottleneck roads. A summary article by Crew, Fernando, and Kleindorfer (1995), presents a literature overview behind peak-period pricing. Studies in USA is followed by Sweden with a total of six studies. Case studies from Stockholm, Sweden is very similar to our research (Börjesson & Kristoffersson, 2018; Daunfeldt, Rudholm, & Rämme, 2009; Eliasson, Hultkrantz, Nerhagen, & Rosqvist, 2009; Eriksson, Garvill, & Nordlund, 2008; Hårsman & Quigley, 2010). 15 studies were performed in Europe, 9 studies in America, followed by four studies from Asia.

Collection of data are most common through count data. 17 studies use this type of data collection. Count data were often collected by more modern automatic number plate recognition (Hårsman & Quigley, 2010). 11 studies collected data through surveys. These surveys consist of among other telephone-surveys, web-surveys, and two studies with interviews. Some studies used panel data for their research, where data from commercial stores and roads were collected

(Daunfeldt et al., 2009; de Grange, González, Vargas, & Troncoso, 2015; Quddus, Bell, Schmöcker, & Fonzone, 2007).

## 3.2 Results From Literature

Some studies investigated increasing concern about negative consequences related to people's reaction of a new toll implementation. Odeck and Bråthen (2008), stated that negative attitude related to toll implementation is highly correlated with the level of information. Based on survey data (Gu et al., 2018), people with inadequate information about road pricing would be 2.14 times more negative than well informed. Others have shown that congestion charging schemes improves high skepticism in the beginning, turning more positive after it has been active for a while. According to Eliasson et al. (2009), the general opinion of congestion charging was negative prior the trial in Stockholm. Before the event, 55% stated the trial was a bad decision, while 53% stated that the trail was a good decision after the event.

Other studies have focused on strategies for reducing traffic congestion, and the effect on traffic flow. Most common are congestion and cordon/zonal-based charging. Congestion charging scheme was studied in London by Carslaw and Beevers (2005), including implementation of charge during the hours 07:00 to 18:00, Monday-Friday. The results presented a 29% reduction in personal car traffic, while demand for public transportation increased by 20%.

In addition to studies that explore the effect of cordon-based pricing, some studies investigate the effect of congestion combined with peak-period pricing (Börjesson & Kristoffersson, 2018; Eliasson et al., 2009).

Both Carslaw and Beevers (2005) with the study from London, and Braid (1989) from New York, found that congestion charging scheme reduced personal car traffic demand. The special case of temporary charging scheme in Trondheim, Norway studied by Jones and Hervik (1992), presented a reduction in personal car traffic demand. While the effect of removing the charging scheme in Trondheim resulted in an 11.3% increase in traffic (Meland, Tretvik, & Welde, 2010). The effect of cordon toll system were studied in Singapore, on office residential real estate prices (Agarwal, Koo, & Sing, 2015). Similar to the study in Trondheim, the results showed 19% decrease in real estate prices within the cordon area.

Most of the literature deals with the situation of implemented toll or increased toll rates, and some empirical evidence regarding elasticities when tolls are removed. Results from previous studies, such as Meland et al. (2010), indicated that an increase in traffic pricing results in decreasing car traffic demand. Study from London (Carslaw & Beevers, 2005) observed a decrease in car traffic demand by 29%, which led to an increase in public transportation by 20%. In studies with peak charging, traffic tends to decrease in peak hours, while off-peak traffic increase (Jou & Yeh, 2013). Table *2* presents elasticity results from the list of reviewed literature in appendix 1.

Table 2: Elasticity results in previous research

| Author | Toll charge | Elasticities |
|---|---|---|
| (Burris, 2003) | Time-of-day variable toll rate in | -0.76 to -0.15 |
| (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2012) | Congestion charging in Stockholm, Sweden | -1.9 in 2006 and -1.27 in 2009 |
| (Börjesson & Kristoffersson, 2018) | Cordon and peak period pricing in Stockholm, Sweden | Peak: -0.53 to 0.67 and Off-peak: -0.93 to -1.13 |
| (de Grange et al., 2015) | Congestion charging in Chile | -0.05 to 0.47 |
| (Albert & Mahalel, 2006) | Congestion pricing and parking fees in Israel | Congestion tolls -1.8 and parking fees -1.2 |
| (Duranton & Turner, 2011) | How lane km for one type of road affect traffic from other types of road | 0.67 to 0.89 |
| (Jones & Hervik, 1992) | Cordon pricing in Oslo and Toll road schemes in Ålesund, Norway | Oslo: -0.22 & Ålesund: -0.45 |
| (Odeck & Bråthen, 2008) | Congestion charging in Norway | -0.56 |

Elasticities from the table range from –1.8 to 0.89, which explains a reduction in traffic in common studies and decrease in traffic congestion. Burris (2003) studied peak load charging and found that the morning traffic were the most sensitive.

The results from previous research on this topic are unison, stating that congestion and peak-period charging is working according to its purpose. Previous researchers also confirm that people are primarily hostile against road pricing, but are adopting to the changes after implementation and become more positive when they observe the benefits from the tax. The results from our analysis will be discussed according these former conclusions.

From the literature review, a large amount of studies have been carried out on the topic of road pricing. Few studies have been carried out on the combination of cordon and peak-period pricing in Norway, in addition to the daily variations in traffic. Our research can contribute to the literature by investigating these matters.

# 4.0 Theory

This chapter begins by formalizing road pricing and congestion pricing, the latter as a special case of peak-load pricing. Further, we describe transportation mode choices using the discrete choice random utility model. The purpose of toll charges and congestion pricing is to reduce the use of car and increase the use of alternative transportation modes, such as bus, train or bicycle. Finally, we proceed to describe relevant elasticity concepts, which will be the explicit focus of our empirical analysis. At an aggregate transportation volume level, elasticities represent individuals' transportation mode and travel frequency choices. These theories will not be followed up in the analysis, but it is important to have a microeconomic understanding of the individual's choice problem.

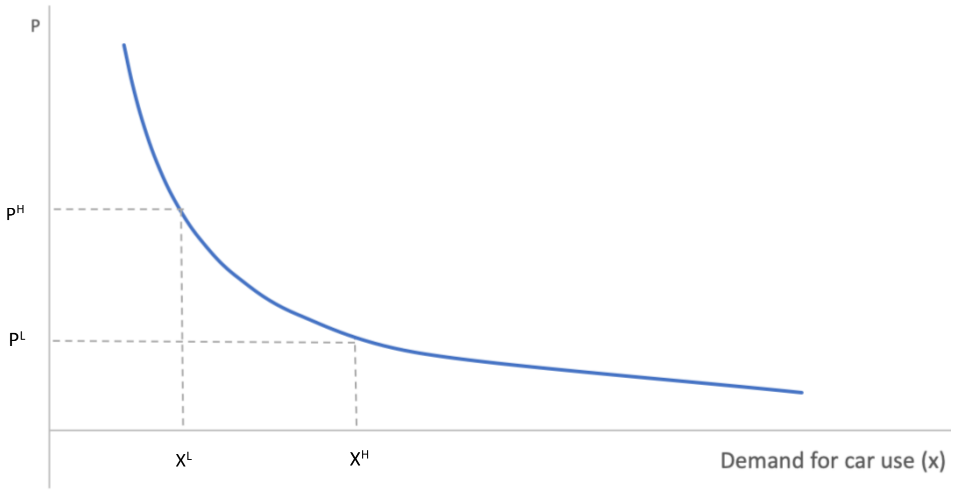
## 4.1 Road Pricing and Congestion Charges

Policies that have the objective to influence travel behavior is a part of travel demand management (TDM) (Saleh & Sammer, 2009). Road pricing has long been advocated as an efficient mean to reduce road congestion and the problems associated with traffic (Siu & Lo, 2009). One strategy to deal with congestion problems, is to use cordon-based pricing in areas with particularly high traffic volume. This is especially evident in city centers (Mahendra et al., 2011). Cordon-based congestion pricing sections off geographical areas with high congestion and charges a toll for entering that area.

Charging fees can be flat or flexible. Flexible fees are occasionally higher during peak hours (Marburger, 2015). Peak-period pricing forces car owners to pay for the driving when traffic demand is high. Higher price during peak(s) discourage driving during peak hours, redistributes traffic volume, and reduce congestion. The potential benefits of road pricing is reduced congestion, fewer traffic incidents, decreased pollution and revenues which can be used for public transport and infrastructure (Franklin, Eliasson, & Karlström, 2009).

The base of investing TDM measures in this case is the law of demand, which is one of the most fundamental concepts in economics. Figure 3 illustrates the demand curve, where demand for car use is on the horizontal axis, and toll price is on the vertical axis. The negative slope of the demand curve reflects the assumption that demand decrease when the price increase. This is demonstrated in the figure showing that when price is high ($P^H$) demand ($x^L$) is lower than when price is low ($P^L$, $x^H$). The expected results of road pricing is decreasing demand for car use (Snyder & Nicholson, 2012).

*Figure 3 Demand curve for car use*




The hypothesis for this study is based on the theory mentioned. The expected results are that cordon-based charging systems reduces traffic in congested cities, while peak-period reduces traffic during peak hours.

## 4.2 Discrete Choice – Random Utility Model

An individual must make a choice of transportation mode to work. This economic concept is called discrete choice. Discrete choice models simulate the relationship between user choices and the features of each alternative (De Luca & Cantarella, 2009). A decision maker is modeled as selecting the alternative with the highest utility among those available at the time a choice is made (M. E. Ben-Akiva & Lerman, 1985). The choice set consists of a finite number of alternatives that are mutually exclusive and exhaustive, meaning that all possible alternatives are included. Decision makers can be people, household firms, and the alternatives might represent competing products, courses or other options or items over which choices must be made (Train, 2003).

Discrete choice model can be used to analyze people's travel behavior and the reason why people choose one transportation mode over another. Most important decisions on travel mode depends on location, distance, choice of departure time and choice of route. Framework of the model can be presented by 4 variables: decision maker, alternatives, attributes and decision rule (M. Ben-Akiva & Bierlaire, 1999). It is impossible to specify and estimate a discrete choice model that will always succeed in predicting the chosen alternatives by all individuals. Therefore, we adopt the concept of random utility. The true utilities of the alternatives are considered random variables, so the probability that an alternative is chosen is defined as the probability that it has the greatest utility among the available alternatives (M. E. Ben-Akiva & Lerman, 1985).

Discrete choice models are usually derived under an assumption of utility-maximizing behavior by the decision maker (Train, 2003). Random utility models (RUM) can also be derived from utility maximization. A consumer is always interested in maximizing its utility (Snyder & Nicholson, 2012), and is therefore an important concept to be aware of when modelling traffic demand and travel choice.

From Train (2003), derivation of RUM, we have conceptualized for our research, which gives the following utility maximizing functions:

$$U_{CPP} = \alpha_{CPP} + \beta_P P_{CPP} + \beta_T T_{CPP} + \beta_x X_{CPP} + \varepsilon_{CPP} \quad (1)$$

$$U_{COP} = \alpha_{COP} + \beta_P P_{COP} + \beta_T T_{COP} + \beta_x X_{COP} + \varepsilon_{CPP} \quad (2)$$

Where $U_{CPP}$ is utility for driving during peak-period, and $U_{COP}$ is utility for driving during off-peak. The betas represent its variable effect on utility. $\beta_P$ is the coefficient for toll price $P$ and can be interpreted as toll price elasticity. $T$ is transportation time, and $\beta_T$ is coefficient for time. All other factor that influence the utility are included in the variable $X$, with $\beta_X$ being its coefficient. ε is the error term. In addition to utility for car driving during peak and off-peak period, the user also considers other transportation modes, for instance bus or bicycle.

## 4.3 Toll Price Elasticities

Elasticity is a general concept used in economics to measure the sensitivity of an economic outcome (Y) to a change in an influencing factor (X), all else held constant. Specifically, the elasticity of Y with respect to X is constructed as: the percentage change in Y divided by the percentage change in X. In transportation demand analysis, it is money price, time price, and income elasticities that are most frequent employed. Since the goal of this research is to estimate the effect of the new congestion charge system on personal car use, this paper will focus on own-price elasticities. The remainder of this chapter we will explain this economic concept further.

Price elasticity of demand provides a convenient way to summarize how people respond to price changes for a wide variety of economic goods (Snyder & Nicholson, 2012). We distinguish between two types of price elasticities: Own-price and cross-price elasticities, where own-price elasticity expresses the dependency of demand for how a good respond to the price of the same good (Grøvdal & Hjelle, 1998). This thesis investigates how traffic demand responds to a change in toll price. Since the demand for a good do not only depend on the price of the good itself, but also on the price of other good, we also find it interesting to explain the concept cross-price elasticities. Cross-price elasticity measures the proportionate compensates change in quantity demanded in response to a proportionate change in the price in another good. The compensated own-price and cross-price elasticities of demand are shown in equation 3 and 4 (Snyder & Nicholson, 2012).

$$e_x, p_x = \frac{\frac{\Delta x}{x}}{\frac{\Delta p_x}{p_x}} \quad (3)$$

$$e_x, p_y = \frac{\frac{\Delta x}{x}}{\frac{\Delta p_y}{p_y}} \quad (4)$$

In the equations above, x is presented as traffic demand quantity, and $P_x$ is toll charge and $P_y$ is price of another good, for example bus, bicycle and other transportation modes.

Price elasticity of demand ($\frac{\partial x}{\partial p}$ ) is usually negative because people buy less of a good when it becomes more expensive, except in the unlikely case of Giffen´s paradox. The dividing line between large and small responses in generally set at –1. If,($e_{x,}p_x = -1$) changes in x and p, are of the same proportionate size. Which means, a 1 percent increase in price leads to a decrease of 1 percent in quantity demanded. In this case, demand is said to be unit-elastic. Alternatively, if ($e_{x,}p_x < -1$), then quantity changes are proportionately larger than price changes and we say that demand is elastic. Finally, if ($e_{x,}p_x > -1$), then demand is inelastic, and quantity changes are proportionately smaller than price changes (Snyder & Nicholson, 2012).

# 5.0 Methodological Approach

This chapter provides methodological details of the study. We have chosen a quantitative approach in order to answer the research questions. We start by presenting important variables for the analysis, before collection of data is described. Further, calculation of prices is explained and finally the use of arc elasticity is defined.

## 5.1 Describing Variables

To examine the effect of toll price on traffic demand, two main variables are needed: The amount of traffic on roads and the cost of driving. Other factors can affect the demand of traffic such as weather and availability of public transportation, which is not taken account for in this analysis.

Data is restricted to only include cars smaller than 5.7 meters, to avoid inclusion of commercial vehicles and trucks. However, the available data sets do not exclude smaller commercial cars. Households who have access to company cars for personal use, often have toll charges included in the fringe benefits from the company. Users of company cars bear some of the costs, as they must pay tax for these benefits. Similar research has included company cars in the analysis (Odeck & Bråthen, 2008). On the other hand, users of taxis and electrical cars do not carry any toll charge costs and can neither be excluded from the data sets.

There are many costs to take account for when analyzing traffic demand. Some costs of car driving can be fuel cost, road charges, fees for owning a car and value of time. Because we are measuring short-run effect, it is assumed that other costs than toll prices remain constant (Börjesson et al., 2012). The analysis will only account for changes in toll prices.

## 5.2 Data Collection

Classification of data is not important for this thesis, because the analysis does not include regression analysis. However, the reader may be interested to know that the data used is pooled cross sectional, where samples are collected randomly from different points in time (Wooldridge, 2013). Data is collected from 33 automatic traffic counting points (ATC), registering the number of cars passing each point per hour. An overview of the chosen counting points is listed in Table 12, appendix 2. These counting points are primarily located close to the new toll stations, although some information is retrieved from ATC's further away to develop a broader understanding of how traffic is shifting. For example, ATC's from Sola municipality is included to collect information about users trying to avoid toll charge. A requirement for the chosen ATC's is that they provide us with sufficient information to conduct the analysis. Many counting points have been excluded, because they are missing information for the time period analyzed.

Data is extracted from NPRA's webpage. For this study, data from October and November have been collected from 2017 and 2018. To investigate the effect of the temporarily removal of peak-period charge, we also gathered data from January 2018 and 2019, and April 2019, to be compared to each other.

## 5.3 Calculation of Toll Price

Estimation of correct changes in price is necessary for the elasticity analysis. In the short run, the analysis only accounts for change in toll prices. Each counting point have their own before and after price. Prices are determined whether the car passing a certain point must pay toll charge, before passing the next point. If the car does not pass a toll station before the next counting point, the price is zero. Prices are calculated by using a weighted average estimation to account for different toll charges. Using this method makes sure that the analysis contains the most realistic picture of the fee users pay.

Statistics of the former toll system provided by the NPRA show that 85% of the population in Northern Jæren used tag in their car before the toll regulation. The tag gives the user a 20% discount on toll charges. NPRA implies that the use of tag remains constant over time, and 85% share of users, are assumed for the new toll system. An overview of toll charges is listed in Table 3.

*Table 3: Toll charge overview*

| | Ordinary price | | Discount price | |
|---|---|---|---|---|
| | Peak | Off peak | Peak | Off peak |
| Before regulation | 20 | 20 | 16 | 16 |
| After regulation | 44 | 22 | 35.20 | 17.60 |

Ordinary prices are presented on the left side, and prices with 20 % discount on the right side. Before the new regulation, the same price was charged the entire day, without peak pricing. Discount opportunities existed also in the old toll system, with the alternatives of pre-payment and post-payment. Most of the population used the alternative of pre-payment because of the highest discount (20%). For simplicity, we assume 85% of the population used tag in their car and received 20% discount in the old toll system.

Toll charges used for this analysis are the weighted average of before charges, which were constant over time, and the peak and off-peak charges after the implementation. Weighted average of the total charge is also noteworthy to estimate total elasticity of the region. Weighted average prices are calculated for each counting point. These are used to estimate elasticity for peak and off-peak periods during morning and afternoon traffic for each point. The charges are also used to calculate the weighted average charges for the cordon region, which again can be used to calculate total charges for Northern Jæren. The weighted average ($\bar{p}$) for the cordon region is calculated by multiplying each counting point's share of passing cars ($w_i$) with its toll charge ($p_i$) and summarizing for all counting points in the region.

$$\bar{p} = \Sigma w_i p_i \qquad (5)$$

We developed the formula in equation 5 showing how weighted average price is calculated. This method is used to determine all charges used for this analysis. The weighted average charges for each cordon region are represented in Table 4.

*Table 4 Weighted average charges in NOK for each cordon region, before and after the regulation*

| | | Total | Peak | Off peak |
|---|---|---|---|---|
| Forus | Before | 16.60 | 16.60 | 16.60 |
| | After | 27.39 | 36.52 | 18.26 |
| Sandnes | Before | 6.51 | 6.53 | 6.56 |
| | After | 27.39 | 36.52 | 18.26 |
| Sola | Before | 16.60 | 16.60 | 16.60 |
| | After | 0.00 | 0.00 | 0.00 |
| Stavanger | Before | 0.00 | 0.00 | 0.00 |
| | After | 27.39 | 36.52 | 18.26 |
| Tananger | Before | 8.57 | 8.68 | 8.44 |
| | After | 27.39 | 36.52 | 18.26 |

As seen by Table 4, Stavanger is a cordon, without toll prior to the regulation, but has received tolls now, while the case is opposite for Sola.

## 5.4 Arc Elasticity

To evaluate the effect of new toll implementation, an elasticity analysis is conducted to answer the research question. Odeck and Bråthen (2008) discuss in their paper different measurements of elasticities. They use arc elasticity to appropriately measure toll-price elasticity. It is stated in their paper that arc elasticity assumes convex demand function, which is more common in the transportation sector. A problem with compensated price elasticity of demand is that it gives different values depending on different starting and ending points. The arc elasticity measures the midpoint elasticity between two selected points, and is more useful when there is a considerable change in price. Because of these facts, arc elasticity is used in this thesis. The arc elasticity formula was given to us by our supervisor, and is as follows:

$$E = \frac{\%\Delta Q}{\%\Delta P} = \frac{\frac{\Delta Q}{\bar{Q}}}{\frac{\Delta P}{\bar{P}}} \tag{6}$$

In the elasticity analysis, $\bar{Q}$ represents the average of demand, and $\bar{P}$ is the average of prices between two different points. The results of the analysis describe how sensitive car users are to the toll price.

# 6.0 Empirical Analysis

The results of the empirical analysis are presented in this chapter. The aim of the analysis is to answer the research question: What is the impact of cordon and peak load pricing on car use demand? Our hypothesis for this thesis is based on previous research and theory on this topic, expecting decreased traffic and overall inelastic results.

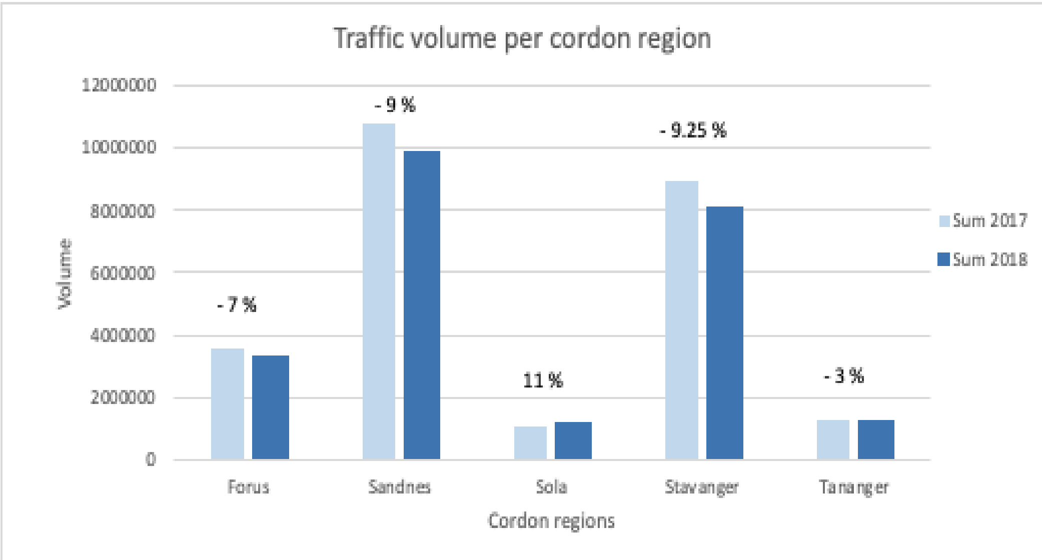
Due to the nature of the case studied and the available data, the following structure of the analysis is chosen. A descriptive overview of traffic volume is first displayed, before a total overview of elasticities is presented. We then investigate the effect at different time periods, according to time of day, and day of week. Primarily data from October and November before and after implementation is analyzed, except in sub-chapter 6.4, were data from January and April are included. The focus of the analysis is to examine commuters travel behavior to work.

The attention of this study is therefore weekdays, and the hours 06:00-10:00 for morning traffic and 14:00-18:00 for afternoon traffic.

## 6.1 Traffic Volume

Table 5 presents the overall traffic volume of the five cordon regions in Northern Jæren, with detailed information of each automatic traffic count before and after the implementation. Total volume of the chosen periods is portrayed in column two and three. Quantity and percentage change in volume is also described in the table. Overall traffic volume has reduced by 8% after implementing new tolls.

*Figure 4: Traffic volume per cordon region*




An overview of traffic volume separated for each cordon area is also provided in Figure 4. Decreasing traffic is recurring in all of the cordon regions except from Sola. This is an interesting aspect, especially since Sola is the area with largest percentage change in traffic volume. Stavanger has the largest reduction of traffic with 9.25%, followed by Sandnes and Forus. Tananger is the least affected region with only 3% reduction in traffic. The results in this part shows that the overall traffic have decreased, implying that the toll implementation is working according to its purpose.

*Table 5: Traffic volume: an overview of Northern Jæren*

| | 2017 | 2018 | | |
|---|---|---|---|---|
| ATC | Total | Total | Difference | % |
| **Forus** | | | | |
| Bærheim | 318452 | 284132 | -34320 | -11 % |
| Eikaberget | 704316 | 741929 | 37613 | 5 % |
| Forus Gamleveien | 312202 | 230494 | -81708 | -26 % |
| Forus v stvg aftenblad | 2203717 | 2034613 | -169104 | -8 % |
| Sum | **3538687** | **3291168** | **-247519** | **-7 %** |
| | | | | |
| **Sandnes** | | | | |
| Asheimveien Bru | 783516 | 748408 | -35108 | -4 % |
| Austrått | 385454 | 243452 | -142002 | -37 % |
| Austråttunelen | 648951 | 686763 | 37812 | 6 % |
| Brueland | 853114 | 858278 | 5164 | 1 % |
| Bråstein | 400351 | 281944 | -118407 | -30 % |
| E39 / Somaveien | 2907336 | 2392842 | -514494 | -18 % |
| Folkvord | 1628362 | 1639049 | 10687 | 1 % |
| Oalsgata | 719686 | 672836 | -46850 | -7 % |
| Smeaheia vest retning sør | 434104 | 351699 | -82405 | -19 % |
| Smeheia vest retning nord | 429707 | 341438 | -88269 | -21 % |
| Soma | 463208 | 414146 | -49062 | -11 % |
| Strandgata nord | 443213 | 344525 | -98688 | -22 % |
| Vatnekrossen | 260850 | 267803 | 6953 | 3 % |
| Åsedalen | 411788 | 600734 | 188946 | 46 % |
| Sum | **10769640** | **9843917** | **-925723** | **-9 %** |
| | | | | |
| **Sola** | | | | |
| Joabakken | 394927 | 453190 | 58263 | 15 % |
| Sola N. ved Arabergv. | 650051 | 706399 | 56348 | 9 % |
| Sum | **1044978** | **1159589** | **114611** | **11 %** |
| | | | | |
| **Stavanger** | | | | |
| Bjergsted | 329042 | 225078 | -103964 | -31.60 % |
| Byhaugtunnelen sør | 1028122 | 1071941 | 43819 | 4.26 % |
| Dusavikveien | 228228 | 196026 | -32202 | -14.11 % |
| E39 / Oscar Wistingsgt. | 2459985 | 2018055 | -441930 | -17.96 % |
| Hillevåg / Skjæring | 667651 | 640521 | -27130 | -4.06 % |
| Hillevågstunnelen | 681721 | 625593 | -56128 | -8.23 % |
| Lassa | 1344149 | 1351182 | 7033 | 0.52 % |
| Madlav. Ved Mosvann | 387493 | 550224 | 162731 | 42.00 % |
| Siddishallen | 940673 | 880336 | -60337 | -6.41 % |
| Tanke Svilandsgate | 361086 | 281046 | -80040 | -22.17 % |
| Ullandhaugveien | 531116 | 290648 | -240468 | -45.28 % |
| Sum | **8959266** | **8130650** | **-828616** | **-9.25 %** |
| | | | | |
| **Tananger** | | | | |
| Risavika | 596218 | 706399 | 110181 | 18 % |
| Sundekrossen | 653731 | 706399 | 52668 | 8 % |
| Sum | **1249949** | **1211042** | **-38907** | **-3 %** |
| | | | | |
| **Northern Jæren** | | | | |
| Sum | **25562520** | **23636366** | **-1926154** | **-8 %** |

## 6.2 Elasticity Results

This part of the analysis provides a table (Table 6) of computed toll price elasticities. Negative elasticities in the table indicate reduced traffic, while positive elasticities in the table suggest increased traffic. The overall total elasticity for Northern Jæren is -0.0633, supporting the results in the previous chapter. However, the result is inelastic, which implies that car users are not sensitive to the price change.

Further in this chapter we want to examine whether commuters continue the same driving pattern. The implementation of peak-period pricing makes it interesting to separate the analysis into peak and off-peak. This way, we can examine if commuters choose to drive at the same times or change driving behavior. To get a broader overview of the traffic pattern, we have collected hourly data in Figure 5 The overall traffic volume is presented on the left side of the graphs, and elasticities on the right side. This way, we obtain a more precise overview of the most influenced hours

*Table 6: Elasticity overview of Northern Jæren*

| | | Morning traffic | | Afternoon traffic | |
|---|---|---|---|---|---|
| ATC | Total | Off-peak | Peak | Off-peak | Peak |
| **Forus** | | | | | |
| Bærheim | -0.2322 | 2.4593 | -0.4449 | -0.6722 | -0.2683 |
| Eikaberget | 0.1060 | 1.1405 | 0.0848 | 0.4931 | 0.1072 |
| Forus Gamleveien | -0.6138 | -0.6811 | -0.6329 | -2.0345 | -0.5623 |
| Forus v stvg aftenblad | -0.1627 | 0.3561 | -0.2055 | -0.3861 | -0.1855 |
| Overall elasticity Forus | **-0.1478** | **0.6095** | **-0.1952** | **-0.3504** | **-0.1707** |
| **Sandnes** | | | | | |
| Asheimveien Bru | -0.0229 | 0.0040 | -0.0332 | -0.0177 | -0.0413 |
| Austrått | -0.2258 | -0.1442 | -0.2931 | -0.2024 | -0.2624 |
| Austråttunelen | 0.0283 | 0.0426 | 0.0343 | 0.0400 | 0.0120 |
| Brueland | 0.0123 | 0.5905 | -0.0270 | 0.2325 | -0.0034 |
| Bråstein | -0.1735 | -0.0983 | -0.2393 | -0.1493 | -0.2101 |
| E39 / Somaveien | -0.3958 | -0.7017 | -0.2608 | -1.8439 | -0.3531 |
| Folkvord | 0.0033 | 0.0494 | 0.0091 | 0.0076 | -0.0161 |
| Oalsgata | -0.0336 | 0.0239 | -0.0676 | -0.0210 | -0.0461 |
| Smeaheia vest retning sør | -0.1049 | -0.0867 | -0.1040 | -0.0952 | -0.1120 |
| Smeheia vest retning nord | -0.1145 | -0.0719 | -0.1107 | -0.1030 | -0.1783 |
| Soma | -0.2280 | -0.5244 | -0.2818 | -0.7035 | -0.2037 |
| Strandgata nord | -0.1253 | -0.0140 | -0.1797 | -0.1041 | -0.1655 |
| Vatnekrossen | 0.0132 | 0.0377 | 0.0330 | 0.0158 | 0.0104 |
| Åsedalen | 0.1866 | 0.2294 | 0.2213 | 0.1855 | 0.1665 |
| Overall elasticity Sandnes | **-0.0729** | **0.0106** | **-0.0761** | **-0.0755** | **-0.0962** |
| **Sola** | | | | | |
| Joabakken | -0.0687 | -0.1316 | -0.0695 | -0.0756 | -0.0423 |
| Sola N. ved Arabergv. | -0.0415 | -0.0717 | -0.0413 | -0.0599 | -0.0173 |
| Overall elasticity Sola | **-0.0520** | **-0.0899** | **-0.0523** | **-0.0660** | **-0.0278** |
| **Stavanger** | | | | | |
| Bjergsted | -0.1876 | -0.0415 | -0.2393 | -0.1609 | -0.2484 |
| Byhaugtunnelen sør | 0.0209 | 0.0360 | 0.0347 | 0.0255 | 0.0040 |
| Dusavikveien | -0.0759 | 0.0619 | -0.1585 | -0.0235 | -0.1257 |
| E39 / Oscar Wistingsgt. | -0.0987 | -0.0284 | -0.1230 | -0.0811 | -0.1592 |
| Hillevåg / Skjæring | -0.0207 | -0.0205 | -0.0796 | -0.0215 | 0.0413 |
| Hillevågstunnelen | -0.0429 | 0.0079 | -0.0684 | -0.0360 | -0.0310 |
| Lassa | 0.0026 | 0.0212 | 0.0103 | 0.0076 | -0.0087 |
| Madlav. Ved Mosvann | 0.1735 | 0.1998 | 0.1048 | 0.1988 | 0.2032 |
| Siddishallen | -0.0331 | -0.0030 | -0.0390 | -0.0315 | -0.0561 |
| Tanke Svilandsgate | -0.1246 | -0.0507 | -0.1716 | -0.1169 | -0.1375 |
| Ullandhaugveien | -0.2926 | -0.2729 | -0.3222 | -0.2693 | -0.3054 |
| Overall elasticity Stavanger | **-0.0485** | **-0.0030** | **-0.0765** | **-0.0360** | **-0.0719** |
| **Tananger** | | | | | |
| Risavika | -0.0154 | 0.0483 | -0.0511 | 0.0149 | -0.0443 |
| Sundekrossen | -0.0660 | 1.5507 | -0.1577 | 0.1476 | -0.1198 |
| Overall elasticity Tananger | **-0.0305** | **0.1690** | **-0.0884** | **0.0297** | **-0.0715** |
| **Northern Jæren** | **-0.0633** | **0.0267** | **-0.0855** | **-0.0573** | **-0.0899** |

### 6.2.1 Peak Traffic

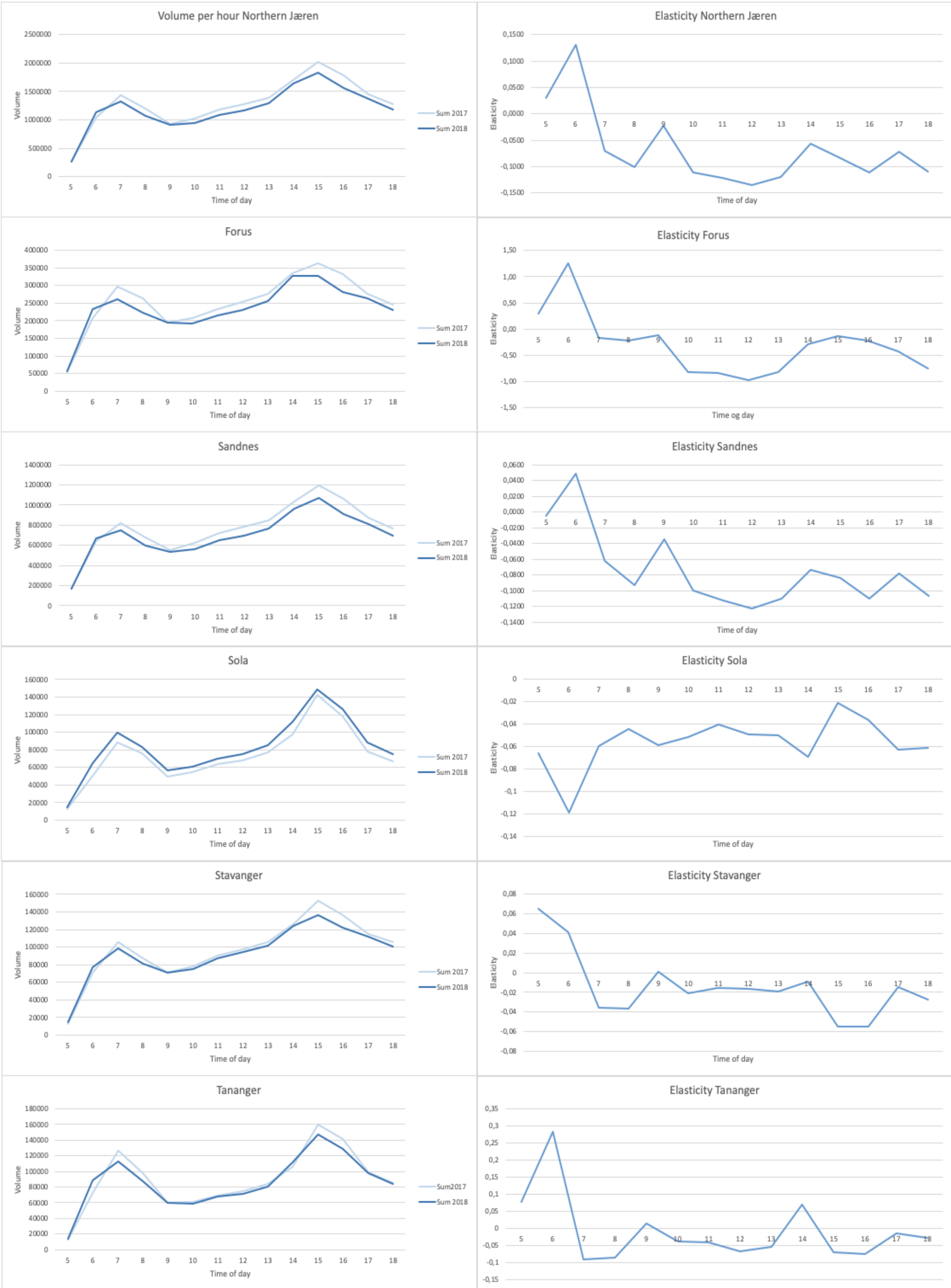
Peak traffic is divided into morning and afternoon peak. For morning peak, we analyze the results between the hours 07:00-09:00. Elasticity results for the morning peak in overall Northern Jæren is -0.0855. As evident in Table 6, the price elasticities of each cordon region are below 1, and inelastic. The elasticities are estimated to be in the interval [-0.1952 to -0.0523] during the peak hours. This confirms inelasticity and indicates that the consumer will not, to a certain extent, change behavior as a result of the increased price. Negative elasticities are recurring in all the cordon regions, with the largest effect in Forus. While Sola cordon is the region with the lowest elasticity.

As evident by Figure 5, the overall change in traffic pattern in Northern Jæren, decreased during the morning peak. When analyzing this period, it can be seen from the right-hand side of the figure that consumers tend to be most sensitive to price at 08:00. The result indicates greatest change in demand during this period, which is confirmed by the decreasing traffic volume, illustrated on the left-hand side of the graphs. Compared to overall results of Northern Jæren, we observe recurring traffic pattern in all the cordon regions, except from Sola. Oppose to decreasing traffic, Sola has more traffic during morning peak. This result is expected due to removal of toll stations, and it correlates with the elasticity for the region.

For the afternoon peak, we analyze the results between 15:00-17:00. Elasticity result (Table 6) for the afternoon peak traffic is -0.0899 overall in Northern Jæren, which is similar to the morning peak result. This implies that car drivers have made the same changes for morning and afternoon peak. Similar to morning peak, negative elasticities are recurring for all cordons, ranging from [-0.1707 to -0.0278] during the afternoon peak hours. Furthermore, analyzing changes per hour in Figure 5, we observe most sensitive consumers at 16:00 on the right-hand side of the figure. This is confirmed by the largest change in volume during the same time.

When comparing morning and afternoon peak, it can be seen from the left-hand side of Figure 5, that volume changes are largest during afternoon peak in Northern Jæren, while there are marginal differences in the elasticities in Table 6 between morning and afternoon peak.

*Figure 5: Volume and elasticity overview*



### 6.2.2 Off-Peak Traffic

When analyzing the off-peak period, we focus on the hour right before and after the peak periods for morning and afternoon traffic. The results from off-peak period is presented in the third and fifth column in Table 6. The overall region elasticity for morning off-peak is estimated to be 0.0267 and the afternoon off-peak -0.0573. These results are lower than the estimates for peak-period, suggesting that commuters are less sensitive to price change in the off-peak period.

Contrary to previous results, a positive elasticity is observed during morning traffic. The positive estimate during morning traffic indicates that more people are driving to work during off-peak hours. Elasticities for off-peak period varies among regions and are estimated to be between [-0.0899 to 0.6095] during morning traffic, and [-0.3504 to 0.0297] during afternoon traffic. The outcome is still inelastic, implying that commuters driving habits remain unchanged.

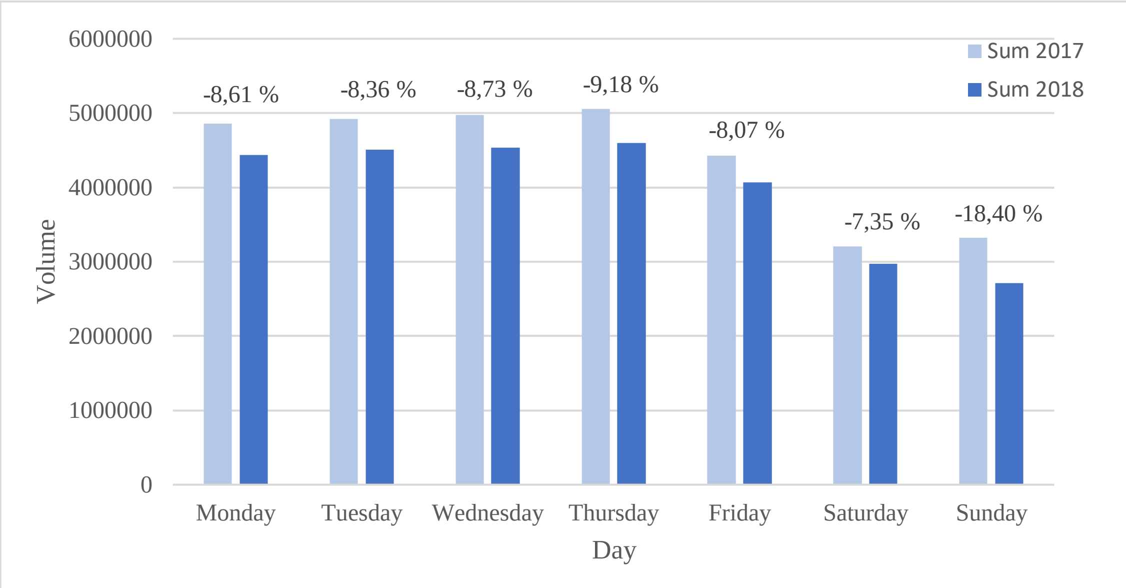
For all cordon regions, elasticity is peaking between the hours of 06:00-07:00. By examining Figure 5, we observe more traffic at this time for all regions. An interesting phenomenon is that the same behavior is not observed during the afternoon traffic, where traffic is lower for all regions, except Sola. Sandnes is however the only region with higher elasticities in the afternoon traffic. A greater change in traffic volume is also perceived at this time. There are interesting outcomes represented in this paragraph that should be discussed further.

The findings indicate a more even traffic pattern in 2018 compared with 2017. The traffic has decreased during the peak hours, while an increasing traffic is observed in the hours outside the peak period. It seems like the change in traffic pattern is a combination of people choosing another mode of transport as well as driving outside the peak period, to avoid the high peak charging.

## 6.3 Daily Variations

Traffic volume per day for Northern Jæren, is summarized in Figure 6, with percentage change in volume. Greatest effect can be observed on Sunday, while Thursday has the largest decrease of the weekdays. Traffic volume decrease range from 8.07% to 9.18% during weekdays, which is similar to the total decrease in Northern Jæren presented in Table 5. Figure 7 displays overall elasticities for Northern Jæren per day and is a good representation of the trend for the different cordon areas investigated in this paper.

*Figure 6: Volume per day in Northern Jæren*



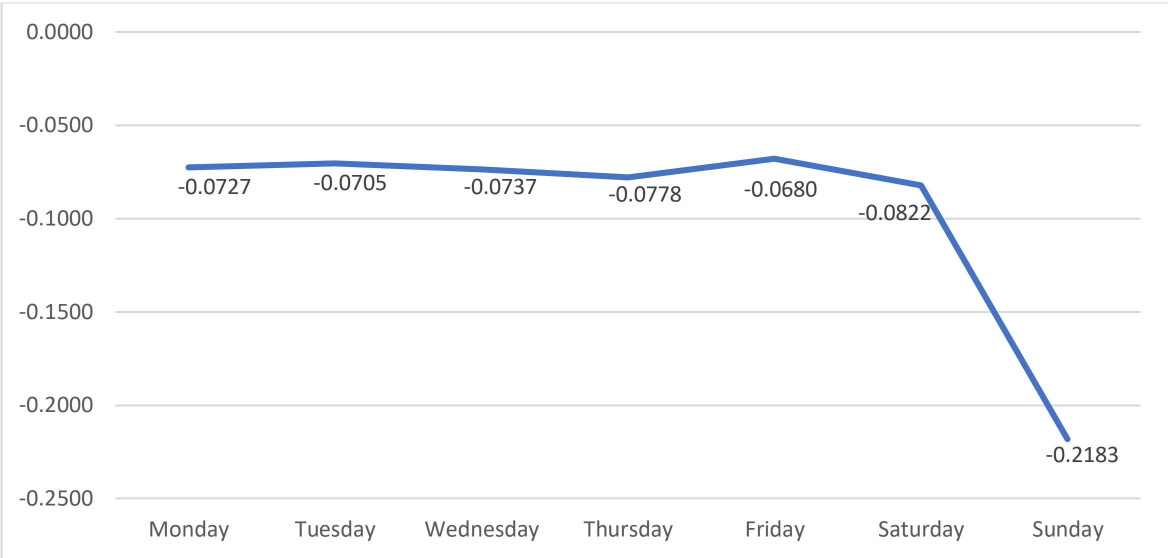

Elasticities represented in Figure 7 are computed by using weighted average toll charges for Northern Jæren. Elasticities range from [-0.0680 to -0.0778] during weekdays, while higher on Saturday and Sunday with elasticities of -0.0822 and 0.2183. Consistent with the change in traffic volume, demand is most sensitive on Thursday during weekdays, and on Sundays when weekends are accounted for. The graph for elasticities is flat, exhibiting minor variance in car driving behavior during weekdays.

*Table 7: Regional percentage change in volume per day*

| | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|---|---|---|---|---|---|---|---|
| Forus | -7,84 % | -7,70 % | -8,75 % | -8,49 % | 4,22 % | -3,71 % | -18,86 % |
| Sandnes | -9,37 % | -8,75 % | -9,19 % | -10,63 % | 1,17 % | -1,06 % | -19,82 % |
| Sola | 10,12 % | 9,06 % | 11,33 % | 10,06 % | 9,61 % | 11,00 % | -1,71 % |
| Stavanger | -10,78 % | -10,75 % | -11,11 % | -10,79 % | -10,32 % | -7,37 % | -18,55 % |
| Tananger | -4,35 % | -4,06 % | -4,36 % | -3,56 % | -4,51 % | -3,30 % | -15,65 % |

It can be seen from Table 7 that Sola stands out, being the only region where traffic is increasing. Increase in traffic range from 9.06% to 11.33% in weekdays, with Wednesday having the largest boost. Saturday has 11% increase in traffic, while Sunday is the only day where traffic is decreasing, with 1.71%. Removal of old toll stations can be influential to these results. Another interesting observation is increasing traffic in Forus and Sandnes on Friday, with 4.22% and 1.17% respectively. These results are somewhat counterintuitive, given the law of demand (Snyder & Nicholson, 2012).

*Figure 7: Elasticities per day Northern Jæren*




## 6.4 Examining Removal of Peak-Period Charge

For the period when peak charge was temporary eliminated, a quasi-natural experiment arises. It opens for an opportunity to analyze the effect of peak-load pricing within the period after implementation. In December 2018 it became publicly known that the new toll stations had technical errors. Peak-period charge was removed, and the toll charge was adjusted to flat tax of 22 NOK (before discount). Because December is a month with holidays and interference, we chose for the analysis to use January 2019 compared to October 2018 and April 2019 to measure how sensitive commuters are to peak-period charge. January 2019 are also compared to January 2018, to evaluate the difference from removed peak load charging, and before the implementation.

*Table 8: Elasticities for the period with removed peak-period charge*

| Period | Total | Morning peak | Afternoon peak |
|---|---:|---:|---:|
| Oct & Jan | 0.2377 | -0.004 | 0.0238 |
| Jan & Apr | -0.1806 | -2.5718 | -2.4301 |
| Jan.18 & Jan.19 | -2.2576 | -2.4326 | -2.1514 |

*Table 9: Percentage change in traffic during period with removed peak-period charge*

| Period | Total | Morning peak | Afternoon peak |
|---|---:|---:|---:|
| Oct & Jan | -9.08 % | 0.27% | -1.58% |
| Jan & Apr | -6.97 % | -17.89% | -11.91% |
| Jan.18 & Jan.19 | -19.41 % | -20.76% | -18.59% |

Elasticities for the mentioned periods are presented in Table 8, while percentage change in volume are represented in Table 9. It can be seen from the latter table that total change is largest when peak price is removed, while its higher during peak when peak is reimplemented. The comparison between January and April is seen to be most sensitive during the peak period, while October and January are the most sensitive in total, shown in Table 8. Personal car use demand during the peak period is shown to be elastic in the price change from high to low (flat) tax, with the elasticities ranging from -0.0040 to 0.0238 for morning and afternoon rush. Morning rush view marginally increasing in volume, while it is decreasing during the afternoon rush. Elasticities and volume change correlates intuitively to each other.

In contrast, when peak-load pricing revived, demand for personal car use tend to be more sensitive to price change. Tables above shows elasticities of -2.5718 and -2.4301, with decreasing traffic volume of 17.89% and 11.91% in the morning and afternoon rush respectively. The results show that total traffic demand is most sensitive when the peak-period price is removed. On the other hand, during peak-period demand is most sensitive when the peak-period charge retrieves.

Comparing January 2018 to January 2019 (after implementation), demand for personal car use tend to be elastic, with an elasticity of -2.2576. Higher elasticities results are shown during morning rush with an elasticity of -2.4326, despite the temporary removal of peak-load price. Percentage change is also largest between these periods.

Summarizing this chapter, the number of cars on the roads have decreased by 8%. Overall elasticities are consistent with previous research on toll charging, ranging from -0.0305 to -0.1478. These inelastic results show that car users are not price sensitive to toll charge. The overall elasticity for Northern Jæren is -0.0633, which is somewhat higher than previous studies. The elasticities are higher when we focus on peak and off-peak period, where peak elasticity is highest. Forus have the highest elasticity of -0.1952 and 0.6095 during peak and off-peak. However, when analyzing the temporary removal of peak-period pricing, we can see that car users are price sensitive during peak-period when the peak charge is implemented.

# 7.0 Discussion

Table 5 display overall increasing traffic volume Northern Jæren. This indicates that the new toll implementation is working according to the government's plan. This supports the hypothesis of a downward sloping demand curve when price is increasing.

In this thesis, the particular field of interest was to determine whether a toll and peak implementation had any effect on traffic demand. The results confirmed a decrease in traffic demand after a new toll implementation, which was expected in our hypothesis, as a result of higher cost associated to car use. The results support the finding of Börjesson and Kristoffersson (2018); Carslaw and Beevers (2005); Jones and Hervik (1992); Meland et al. (2010); Odeck and Bråthen (2008). On the other hand, we have not found decreasing effect over time, which could be because our short run analysis, in contrast to the long run study of Eliasson et al. (2009).

The elasticity findings present positive sensitivity in the morning off-peak (0.0267), especially sensitive between 06:00-07:00. This result is supported by the study of Burris (2003). We find increasing volume in the morning before activation of peak charging, which indicates that people are driving more during off-peak than before. Some companies offer flexible work hours 09:00-15:00, were employees have to be at work within these hours. Results indicate that some people choose to start at work earlier to avoid peak charging, if they have the opportunity.

It is interesting to observe why this tendency is not appearing in the afternoon traffic. Figure 5 presents findings suggesting that the overall traffic has moved one hour ahead, with more significant results in the morning traffic. This can also be explained by the core period, because the activation of afternoon peak charging starts before people are able to leave work.

The result for the large decrease in traffic in the cordon of Stavanger and Sandnes indicates that less people are driving in to city centers. There can be a combination of factors that influence this trend. Development of public transportation makes it more accessible to use, especially in direction of city centers. Parking has also become more expensive in city centers. A combination of new cordon tolls improved public transportation, and increased parking fees may explain the results in the reduced traffic in to city centers. Elasticities are low, inelastic and consistent throughout the weekdays. This implies that people have their standard routines and do not change behavior between weekdays.

In addition to overall reduced traffic, the results shows increasing traffic in Forus and Sandnes on Fridays. Due to scarce literature on daily variations, we use local knowledge to discuss this phenomenon. One thought may be that people choose other transport modes during the weekdays, but chooses the car on Fridays to get home as early as possible to prepare for the weekend activities. It is common for people living in Northern Jæren to have cabins south of the region, especially in Sirdal municipality and southern parts of Norway. People most likely depend on car to travel to their cabins. It is difficult to explain why there is more traffic on Fridays now compared to before toll implementation, without more information and statistics. One theory can be that people travel more to their cabins than before. Another theory is that people are driving more often in that direction, or people are engaging in more weekend activities.

When we get to peak traffic results a marginal increase in peak traffic is presented. Chapter 5.4 proves that many people have prepared and settled with the new situation with cordon tolls and peak-period pricing. Because of the low increase, it can be argued that people who decided to abstain from car use, have settled with their decision. People are also now indifferent to what time to drive to work when accounting for toll charge, suggesting that some people choose to drive in peak-period instead of off-peak. Comparing January to April, a more significant change in traffic is observed. The elastic results show that people are more sensitive to the reestablished peak-period charge. When October-November 2018 is compared to the same months before implementation, we see that traffic have reduced with 8% in Northern Jæren. However, comparing January before and after implementation shows greater decrease in traffic. People may throughout the period after the toll implementation experienced the impact it has on their economy, and therefore changed behavior as time goes. This indicates that people are changing behavior after implementation, instead of before.

Lastly, one of the studies look at the effect of removed toll stations (Meland et al., 2010). Table 5 provided increasing traffic in Sola municipality, contrary to the other cordons. The old toll stations are removed in Sola, and the results support the study of Meland et al. (2010). Increasing traffic may indicate that some driver's choses this route if there is a possibility to avoid the toll charge, even if it takes a longer time. Another idea is that people living in Sola municipality might chooses to drive more after the removal of toll stations.

## 7.1 Limitations

As for most empirical analysis, there are limitations to the methods used in this thesis. One of the main problems we encountered was absence of sufficient data for many of the ATC's we wanted to extract data from, and we had to remove counting points from our data sets. Therefore, the estimations can be an inappropriate representation of real effect of congestion pricing. The results from Forus should especially be interpreted with care, as many of the data sets were insufficient, and this is an area with a large amount of work commute.

Another reason to interpret the results with care, is the inability to exclude vehicles that do not pay toll charge from the data sets. Drivers of these vehicles do not bear the cost of toll and can even be better off because of reduced travel time. Going back to the RUM model, we can make intuitive assumptions that utility for car use for these users increase, and therefore demand also increase. The results are affected by underestimated elasticity estimates.

Other factors that affect choice of travel mode, when and where to drive, are not accounted for in this analysis. Factors that affect the results of this thesis can be household income, weather, availability and price of alternative transportation mode and value of travel time. These are not accounted for in the analysis, hence overestimating elasticities.

## 7.2 Future Work

The result from this thesis offers a starting point for a case that can be investigated further. The short period of available data limits this thesis to be a short-run analysis of the effects of congestion charging and peak-period pricing. Long-run effects of the toll implementation in Northern Jæren can be useful and interesting to investigate for future research.

Estimation of cross-price elasticities can also be interesting to study. The elasticities for peak-price on off-peak demand can be estimated, to acquire information on how sensitive users are to the peak price, and if they shift what time to travel. Cross-price elasticities for other transportation mode can also be useful to estimate, providing information on how for example price of using bus or train affect personal car use.

Moreover, results from a discrete choice analysis of travel mode choice can be fascinating. Through questionnaire researchers can find the probability of choosing a specific mode of transportation and the factors influencing this choice. Logit models can be used to estimate these probabilities (Train, 2003).

Because this study only focus on commute to work, it can be interesting to discuss the other time changes, such as weekend traffic. It can also be appropriate to examine the social economic benefits of this implementation.

# 8.0 Conclusion

The aim of this thesis was to examine the effect of the new toll implementation in Northern Jæren, focusing on personal car use. The following research question was designed: *What is the impact of cordon and peak-period pricing on (car) traffic demand?* This thesis investigates how price sensitive car users are, if the toll implementation has altered traffic flow, and if the implementation worked according to policy makers desired effect. Several analysis have been carried out on this theme, including for a similar case in Stockholm (Börjesson et al., 2012; Börjesson & Kristoffersson, 2018). Estimation of elasticities was carried out to answer the research question. Data was collected from ATC's registering number of cars passing through its point and was used to calculate elasticities affected by the toll charge. Change in traffic volume was also evaluated in the analysis and compared to elasticity estimations.

Results from the analysis revealed that the number of cars on the road have decreased by 8%. Figure 1 illustrates the overall elasticities for each cordon. Car users are most sensitive in peak-period, although the overall elasticity analysis showed that car users are not sensitive to toll charge. One of the most fascinating findings is that traffic have increased during morning off-peak period, from 06:00 to 07:00 in all cordon regions, along with the peak in elasticity during this time. Furthermore, Sola is the only municipality where traffic have increased.

Generally, the basic findings are consistent with previous research showing that car users are not sensitive to toll charge. The combination of cordon and peak-period pricing have somewhat shifted traffic, where more people drive earlier to work and try to avoid toll charge if possible. We can conclude that the toll implementation to some extend has had the desired effect on traffic demand. The inelastic results suggest that there are other factors affecting traffic demand that are not considered in the analysis. Despite its simplified nature, this study can aid policy makers to understand how effective such implementations are. Due to its limitations, this thesis can be a starting point for future research on the new toll implementation in Northern Jæren.

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# Appendix 1: Literature Review

*Table 10 List of literature reviewed*

| Article | Location | Research | Theory | Methodology and data | Result |
|---|---|---|---|---|---|
| Agarwal et al. (2015) | Singapore | Using the congestion rate hike, the research tests the effects of the Electronic Road Pricing (ERP) rate hike on retail, office and residential real estate prices. | Congestion and cordon charging and peak / off peak | Electronic road pricing<br><br>Time series<br><br>Panel data | S$1 increase in toll rates, causes retail real estate prices within the cordon area to decline by nearly 19 % compared to retail prices outside the cordon area. |
| Albert, David (Transport Policy 2006) | Israel | The paper presents a study aimed at evaluating the differences in attitudes towards congestion tolls and parking fees and forecasting the impact for each of the policies on demand for trips and on travel demand. | Congestion charging scheme<br><br>Travel demand elasticities<br><br>Discrete choice model | Multinomial logit models<br><br>Stated preference survey and interview | "High levels of demand elasticity (−1.8 for congestion tolls and −1.2 for parking fees) were found. The readiness to pay parking fees is greater; thus, the effectiveness of congestion tolls in reducing demand is higher during the times the tolls apply." (p. 1) |
| Beevers, Carslaw (Atmospheric environment, 2005) | London | The paper presents the impact of congestion charging on vehicle emissions in London | Congestion charging scheme | Speed survey and count data.<br><br>Electronic road pricing | Reduction in traffic flows in central London where found. There is a reduction in emissions of $CO_2$ (−19.5%). An increase in number of buses (20%) and a reduction in car volume (-29%). |
| Maria Børjesson, Jonas Eliasson, Mariel B. Hugosson, Karin, Brundell – Freij (2012) | Stockholm | The aim of this paper is to explore how the effect traffic reduction according to congestion charging change over time. | Elasticity analysis<br><br>Congestion and cordon charging | Travel survey<br><br>Count data | With the assumption, that only private trips are affected by the congestion charging, elasticity is estimated to be –1.27 in 2006 and increase to –1.9 in 2009. This explains decreasing traffic |

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| | | | | | according to congestion pricing, and the affect increase over time. |
| Börjesson & Kristoffersson (Transportation Research Part A, 2018) | Stockholm, Sweden. | Explores the effects of Swedish congestion charges 10 years on. | Congestion and cordon charging and peak / off peak<br><br>Price elasticity | Count data | Elasticities in the peak period is estimated to be between -0.53 to -0.67, and the off-peak elasticities between -0.93 to -1.13 |
| Braid, Ralph M. (Journal of Urban Economics, 1996) | Michigan, Detroit (USA) | Explores which transport route is selected by implementing rush hour tax on two different routes. | Elasticity analysis<br><br>Congestion charging and peak / off peak | Bottleneck-and-que model of congestion<br><br>MPC (Marginal physical cost) | Inelastic demand |
| Braid, Ralph M. (Journal of Urban Economics, 1989) | New York, USA | Investigates constant or peak-period tax on bottleneck roads with elastic demand | Congestion charging and peak / off peak<br><br>Value of time | Bottleneck analysis | Optimal peak period pricing will eliminate queues without changing total traffic. Constant fee does not reduce queue but reduces total traffic. |
| Burris, MArk W. (2003) | USA | "This paper examines how different price elasticities of travel demand would impact traffic on a toll road with a time-of-day variable toll rate."<br>(p. 354) | Congestion and peak / off peak) | Survey<br><br>Count data | Negative price elasticities are found between 0-076 to –015. With higher elasticities in the morning traffic. |
| Crew, M. A., Fernando, C. S., Kleindorfer, P. R. (Journal of Regulatory Economics, 1995) | USA | Summary article of literature about peak-load pricing within a uniform framework | Peak / off peak<br><br>Meta-analysis<br><br>Elasticity analysis | Multinomial logit model<br><br>Previous articles<br><br>Market research data | Theory and the use of peak load pricing has been used for a long time, and there are many opportunities for further investigation of this theory. |

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| De Palma & Lindsey (Transportation Research Part C, 2011) | France and Canada | Review of methods and technologies for congestion pricing of roads. Describes four road-pricing technologies: ANPR, DSRC, Satellite and Cellular. | Congestion and cordon charging and peak / off peak<br><br>Facility, zonal and distance-based schemes<br><br>Price elasticity | Count data<br><br>Survey of traffic congestion | Facility based schemes dominates in North America. Europe has a few area-based schemes, and a few distance-based schemes, but more designed for revenue generation and internalization of environmental cost than to control congestion. |
| Daunfeldt, Rudholm, Ramme (Transportation Research Part A, 2009) | Stockholm | Studies the impact of the Stockholm road pricing trial, and if the road pricing trial affected retail revenues negatively for shopping malls and stores located within the toll area. | Congestion charging | Panel data<br><br>Revenue data from a sample of retail stores located along the main shopping streets in Stockholm. | Stockholm road pricing trial did not negatively affect total retail revenue, neither in shopping malls nor in the sample of retail stores, only during the hours when the fee was charged.<br><br>Using more public transport, and more shopping in the weekends. |
| Duranton & Turner (American Economic Review, 2011) | USA | Investigating the effect of lane km of roads on vehicle-kilometers traveled (VKT) for different types of roads. | Congestion charging by (VKT)<br><br>Elasticity analysis | Count data on Average annual daily traffic<br><br>National Household Travel Survey (NHTS)<br><br>Time-series | "Increasing lane kilometers for one type of road diverts little traffic from other types of road. We find no evidence that the provision of public transportation affects VKT." (p. 2616)<br><br>Roadway elasticity of VKT between 0.67 and 0.89 |
| Eliasson, Hultkrantz, Nerhagen, Rosqvist (Transportation Research Part A, 2009) | Stockholm | Examines the effect of charging trial, with the purpose to test whether the efficiency of the traffic system could be enhanced by congestion charges. | Congestion and cordon charging and peak / off peak<br><br>Elasticity analysis | Cost-benefit analysis<br><br>Time series<br><br>Two travel surveys, one before the trial period and another during the trial period. | Before the trial of congestion charge, the public attitudes showed that 55% wss against the toll, after the implementation 53% stated that the trail was a very rather good decision. |

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| Eriksson, Nordlund, Garvill (Transport research part F, 2008) | Sweden | Examines the difference between expected reduction in driving at increased fuel prices, improved public transport and the combination of these. | Cordon charging | Pre-questionnaire | The combined measure led to a larger expected reduction in car use compared to the targets that were assessed individually. |
| Geroliminis & Levinson (Transportation and Traffic Theory, 2009) | Minnesota, USA | Aims to lay out a model of traffic congestion that can be applied to cordon pricing. | Congestion and cordon charging and peak / off peak<br><br>RUM | Sensor data (detectors and GPS in vehicles)<br><br>Time series<br><br>Logit models | When applying an optimal toll, delays disappear, and rush hour shortens. Savings on travel delay are much higher than toll paid. Total schedule delays costs are of the same order of magnitude as travel delay cost. |
| Gomez et al. (Transportation, 2015) | Spain | Intends to determine the variable that better explain the evolution of light vehicles demand in toll roads throughout the year, with focus on interurban toll roads. | Congestion charging<br><br>Demand elasticities | Panel data<br><br>qualitative data | Have developed a panel data methodology to analyze light vehicle traffic evolution in toll roads.<br>GDP is not the most suitable socioeconomic explanatory variable.<br>Coastal roads more sensitive to socioeconomic changes.<br>Interior roads more sensitive to toll rates. |
| Grange, Gonzales, Troncoso (Applied Economics, 2015) | Santiago, Chile | Presents econometric estimates of toll pricing and fuel price elasticity in demand of driving in Santiago, Chile. | Congestion charging and peak / off peak<br><br>Price elasticity<br><br>RUM | log-linear regression models<br><br>Hourly count data for cars on the freeway. | The fuel elasticity is higher than the elasticity of toll, this indicates that drivers are more sensitive to the change in fuel price than the change in toll pricing.<br><br>Elasticity –0.05 to 0.47 |
| Gu, Liu, Cheng, Saberi (Case Studies on Transport Policy, 2018) | China, Australia | With the objective of improving public acceptance of congestion pricing, this paper provides a comprehensive overview of the area-based congestion pricing practices. | Congestion charging<br><br>Facility-, Cordon-, zonal- and distance-based scheme | Qualitative case study approach and interview<br><br>Electronic road pricing (ERP) | Based on the survey data, showed that people with inadequate information about road pricing would be 2.14 times more negative than those who were well-informed. |

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| Harrington, W., Krupnick, A. J., Alberini, A. (Transportation Research Part A: Policy and Practice, 2001) | USA | Investigate if driving prices can be made more attractive to car drivers through details of political design. | Sensitivity analysis | Bivariate probit model and<br><br>telephone - survey | "Congestion fees resulted in a 7%-point increase in support for congestion prices policies, and the restriction of censtion pricing to a single lane on a freeway attracts from 9% to 17%-points of additional support." (p. 1) |
| Hårsman & Quigley (Journal of Policy Analysis and Management, 2010) | Stockholm, Sweden. | Examine the political and public acceptability of congestion tolls, using an experiment were road pricing was decided by citizens. | Congestion and cordon charging and peak / off peak<br><br>Empirical analysis<br><br>Transport residence integrated model (T/RIM) GIS | OLS, LPM, GLS<br><br>Experiment: Observed choices and RP | Time saving and incremental cost have a powerful influence on voting behavior.<br>10% decrease in time increased favor to toll by 2%<br>10% increase in cost, decreased favor in toll by 4% |
| Jones & Hervik (Transportation Research Part A: Policy and Practice, 1992) | Oxford, England and Molde, Norway | Investigating the role of cordon charging in Oslo and road pricing in Ålesund. | Congestion and cordon charging and peak / off peak<br><br>Elasticity analysis<br><br>Substitution and income effect | Count data | "Total price elasticity of –0.22 is shown in Oslo and –0.45 in Ålesund. This suggest that, in the Norwegian case, in the absence of significant improvements in public transport, road-pricing charges would only be effective at relatively high-price levels through an income rather than a substitutions effect." (p.143) |

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|---|---|---|---|---|---|
| Jou, Yeh (Transport Policy 2013) | Taiwan | This study uses freeway passenger car drivers as survey targets and utilizes a scenario design approach to explore freeway passenger car drivers' choice behavior for travel route and travel time after the freeway distance-based toll system is being implemented. | Willingness to pay<br><br>Elasticity analysis | Mixed logit model<br><br>Questionnaire | Ratios of short-distance trip drivers, that choose peak, off-peak and local road travel: 25,4%, 54% and 20,6%. Medium-distance trips: 24,6%, 66,1% and 9,3%. Long-distance trips: 19.7%, 73,1% and 7,1%. |
| Meland, Tretvik, Welde (Transport Policy, 2010) | Trondheim | Presents the effect of removing the toll cordon in Trondheim. After 15 years of operation. | Congestion and cordon charging and peak / off peak<br><br>Elasticity analysis | Count data | After removing the toll cordon the peak traffic increased in the period between 06:00 – 18:99 with 11.3%. In the hours between 14:00 – 18:00, the increase of 15.5% were found. |
| Odeck & Bråthen (Transportation Research Part A, 2008) | Trondheim, Norway. | "The objective of this paper is to provide new evidence on the magnitude of travel demand elasticities in<br>tolled roads with particular reference to Norway where road tolling has a long tradition." (p. 78) | Congestion and cordon charging<br><br>Discrete choice<br><br>Elasticity analysis | Count data<br><br>Survey data<br><br>Time series | Negative attitude is highly correlated with the level of information. The average elasticity with respect to the toll is shown to be –0.56. |
| Ozbay, Yanmaz-Tuzel (Transportation Research Part A, 2008) | USA | This paper derives analytical VOTT functions and investigates how commuters value their travel time savings and make their travel choices for different trip purposes mainly as a result of time-of-day pricing. | Congestion charging and peak / off peak<br><br>Discrete choice | survey data.<br><br>New Jersey Turnpike (NJTPK) time-of-day pricing program | The relative magnitude of VOTT values indicate that in the presence of time-of-day pricing, commuters making work related trips are willing to pay higher amount of money to save on travel time. |

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| Proost, Dender (Transportation Research Part A, 2008) | Brussels and London | "This paper studies the effects of introducing optimal urban transport prices in Brussels and in London, focusing on the contribution of externalities, economies of density and non-transport related inefficiencies to the optimal price structure and its effects." (p. 2) | Congestion charging and peak / off peak<br><br>Elasticity analysis | Value of time<br><br>Count data | Peak period congestion costs are higher in Brussels than in London, while the opposite is shown in off-peak hours. Calculations of optimal urban transport prices for Brussels and London show that taking account of economies of density in public transport and of tax revenue premiums increases the welfare gains. |
| Schaller (Transport Policy, 2010) | New York, USA | This paper analyzes how Mayor Michael Bloomberg's´s 2007 congestion pricing proposal gaines widespread public support but was ultimately blocked in the State Legislature. | Congestion and cordon charging and peak / off peak<br><br>Mileage-based pricing | Count data | Gaining broad public acceptance and approval of congestion pricing or mileage-based fees will require changing how motorists see pricing as affecting their own best interests. |
| Zheng, Waraich, Axhausen & Geroliminis (Transportation Research Part A: Policy and Practice 2012) | Switzerland | "In this paper we combine a macroscopic model of traffic congestion in urban networks with an agent-based simulator to study congestion pricing schemes." (p.1) | Congestion and cordon charging and peak / off peak<br><br>Elasticity analysis<br><br>Random utility theory | Case study<br><br>Time series<br><br>logit models | By applying dynamic cordon-based pricing: savings on travel time outweigh the cost of tolling, congestion inside the cordon area is eased and tolling has a stronger impact on leisure-related activities, than on work-related activities. |
| Quddus, Bell, Schmocker, Fonzone (Transport Policy, 2007) | London | Detailed study on the impact of the congestion charge on the John Lewis Oxford Street store. | Congestion and cordon charging<br><br>Cross sectional time Series | Panel data and pooled model<br><br>Retail sales data<br><br>Survey | Actual sales match predicted sales. But actual sales fall consistently below predicted sales thereafter. |

# Appendix 2: Tables

*Table 11 Toll stations overview*

| Number | Toll stations | Area |
|---|---|---|
| 1 | E39 Håkull | Forus |
| 2 | E39 Jåttå | Forus |
| 3 | Fv314 Gamleveien | Forus |
| 4 | Fv433 Forusbeen | Forus |
| 5 | Fv44 Forussletta | Forus |
| 6 | Fv44 Gausel | Forus |
| 7 | Kv. Moseidsletta | Forus |
| 8 | Kv. Norstonekrysset | Forus |
| 9 | Kv. Stokkaveien | Forus |
| 10 | Kv. Åsenveien | Forus |
| 11 | Fv241 Heigreveien | Sandnes |
| 12 | Fv323 Austråttveien | Sandnes |
| 13 | Fv325 Jærveien | Sandnes |
| 14 | Fv330 Hoveveien | Sandnes |
| 15 | Fv332 Hanaveien | Sandnes |
| 16 | Fv334 Ålgårdsveien | Sandnes |
| 17 | Fv44 Strandgata | Sandnes |
| 18 | Fv509 Oalsgata | Sandnes |
| 19 | Kv. Dyre Vaas vei | Sandnes |
| 20 | Kv. Vågen | Sandnes |
| 21 | Rv509 Flyplassen | Sola airport |
| 22 | Rv374 Nordsjøveien | Sola airport |
| 23 | E39 Mosvatnet | Stavanger |
| 24 | Fv404 SUS | Stavanger |
| 25 | Fv411 Tastagata | Stavanger |
| 26 | Fv415 Nedre Stokkavei | Stavanger |
| 27 | Fv416 Øvre Stokkavei | Stavanger |
| 28 | Fv428 Hillevåg | Stavanger |
| 29 | Fv435 Bybrua | Stavanger |
| 30 | Fv44 Lagårdsveien | Stavanger |
| 31 | Fv466 Randabergveien | Stavanger |
| 32 | Kv Chr. Bjellandsgate | Stavanger |
| 33 | Rv509 Madlaveien | Stavanger |
| 34 | E39 Randabergveien | Randaberg |
| 35 | Fv409 Kvernevikveien | Randaberg |
| 36 | Fv413 Finnestadgeilen | Randaberg |
| 37 | Rv509 Jåsund | Tananger |
| 38 | Rv509 Tjora | Tananger |

*Table 12: Selected Automatic Traffic Counts (ATC)*

| Nr. | Counting points | Zone |
|---|---|---|
| 1 | Bærheim | Forus |
| 2 | Eikaberget | Forus |
| 3 | Forus Gamleveien | Forus |
| 4 | Forus v stvg aftenblad | Forus |
| 5 | Asheimveien Bru | Sandnes |
| 6 | Austrått | Sandnes |
| 7 | Austråttunelen | Sandnes |
| 8 | Brueland | Sandnes |
| 9 | Bråstein | Sandnes |
| 10 | E39 / Somaveien | Sandnes |
| 11 | Folkvord | Sandnes |
| 12 | Oalsgata | Sandnes |
| 13 | Smeaheia vest retning sør | Sandnes |
| 14 | Smeheia vest retning nord | Sandnes |
| 15 | Soma | Sandnes |
| 16 | Strandgata nord | Sandnes |
| 17 | Vatnekrossen | Sandnes |
| 18 | Åsedalen | Sandnes |
| 19 | Joabakken | Sola |
| 20 | Sola N. ved Arabergv. | Sola |
| 21 | Bjergsted | Stavanger |
| 22 | Byhaugtunnelen sør | Stavanger |
| 23 | Dusavikveien | Stavanger |
| 24 | E39 / Oscar Wistingsgt. | Stavanger |
| 25 | Hillevåg / Skjæring | Stavanger |
| 26 | Hillevågstunnelen | Stavanger |
| 27 | Lassa | Stavanger |
| 28 | Madlav. Ved Mosvann | Stavanger |
| 29 | Siddishallen | Stavanger |
| 30 | Tanke Svilandsgate | Stavanger |
| 31 | Ullandhaugveien | Stavanger |
| 32 | Risavika | Tananger |
| 33 | Sundekrossen | Tananger |