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Are current Norwegian speed limits optimal?

A quasi-experimental analysis of changes in speed limits on Norwegian freeways

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NORWEGIAN SCHOOL OF ECONOMICS

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Preface and acknowledgements

The choice of topic for our master thesis was done based on mutual interest by us as master partners for the topic of transportation. When locating a thesis proposition by Torfinn Harding, we decided to go for it. We were also lucky enough to get Torfinn with us on the writing of this thesis as our supervisor. We would like to thank Torfinn for his inputs, guidance and flexibility helping us work out this case. He was always available to meet us on short notice. We would not have come very far without him.

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Executive summary

The aim of this paper was to examine if Norwegian speed limits on freeways could be more efficient from a social economic standpoint. We examined the relationship between regulations in speed limits and actual speed held by vehicles on Norwegian freeways, as well as looking at how this regulation changes the magnitude of traffic. With these estimations of relationship, we sought to estimate actual benefits and costs of a change in speed limit from 110 km/h to 120 km/h by analyzing the change from 100 km/h to 110 km/h and apply this to a potential change from 110 km/h to 120 km/h. There are few studies on this topic in Norway and seeing, as this is a very hot topic politically in Norway today, we found this study to be of interest. With hourly counting data for two Norwegian freeways, we analyzed the effect of a change in the speed limit from 100 km/h to 110 km/h on actual speed change and change in traffic magnitude. With these results, we wanted to see if it would be economically efficient to increase the speed limit further from 110 km/h to 120/km on Norwegian freeways.

Based on a sharp regression discontinuity design (RDD) analysis of the increased speed limit on freeways E39 Skoger and E6 Kløfta Sør we found that only smaller vehicles benefits from the increase in speed limit, when it comes to time saving. Other vehicles are observed to be given no time savings, as these vehicles are restricted in Norwegian law to drive no faster than 80 km/h.

For smaller vehicles, an increase in the speed limit from 100 km/h to 110 km/h resulted in an increase in observed speed between ***2.59 km/h*** and ***2.93 km/h***. With an increased maximum speed limit from 110 km/h to 120 km/h we get an increase in the average speed held by drivers from 110 km/h to 113 km/h in the left lane and from 101 km/h to 104 km/h in the right lane. We saw no direct effect on the traffic magnitude on the roads of the higher speed limit, but we observe an increasing trend. Utilizing our estimates for actual speed increase and traffic magnitude from the impact of an increase of maximum speed limit to 110 km/h, we try to evaluate the economic impact of a further increase to 120 km/h.

To determine the economic effect of a further increase in the speed limit, we used a cost-benefit analysis and sensitivity analysis on actual speed increase and the effect of using our estimated value of time. We found that per year, people save on average 232 NOK with a speed increase of 3 km/h.

With a cost-benefit analysis of a further increase in the maximum speed limit from 110 km/h to 120 km/h on existing freeways, running sensitivity analysis on actual speed increase, with no change in observed traffic magnitude and change in time value, we estimate that the total social economic effect of this shift varies between ***280 MNOK*** and ***1694 MNOK***.

1. Introduction

In the Norwegian national transport plan for 2002-2011, the Norwegian Government constituted a vision of zero traffic accidents causing death or serious injury (*Vision Zero*) (Det Kongelige Samferdselsdepartement, 2000). *Vision Zero* has been the leading guideline for the Norwegian Public Roads Administration (NPRA) since. Any new measures on how the public roads are to be structured, must take into account whether it works towards safer and more secure traffic for drivers and pedestrians. Several comprehensive measures have been taken to better the quality of the infrastructure and to make Norwegian roads safer. Physical barriers, stricter requirements for road geometry and automatic traffic control systems (ATK) among a few of them. One of the most used measures to reduce accidents are reducing the speed limits.

In 2011, the NPRA reduced the speed limit on *490 kilometers* of road for the purpose of reducing the risk of accidents (Aftenposten, 2011). These reductions in speed were mostly done on roads with speed limit 90 km/h and 80 km/h, which were viewed as the most hazardous roads and accident prone roads. Three years later, however, the speed limit on Norwegian freeways were raised from 100 km/h to 110 km/h on *163.7 kilometers* of road. The purpose was to raise the efficiency on the current roads and save time for drivers (Bjerkan, Ragnøy, & Engebretsen, 2019). We see that there are two different, and perhaps contradicting reasonings behind how speed limits were regulated.

As it is well documented that speed and accidents are strongly positively correlated (Bjerkan, Ragnøy & Engebretsen, 2019), one can argue that regulators emphasized more on road efficiency rather than the increased risk of accidents. It is important to add that speed limits were lowered on roads with speed limits of 80 km/h and 90 km/h, and raised mainly on roads with speed limits of 100 km/h. Still, speed limits were reduced to better safety, while speed limits were raised to better efficiency. This possible dichotomy has been a topic for conversation both administratively and politically for several years, domestic and abroad (van Bentham, 2015). In his paper, van Bentham found that speed limits should not have been raised in America and argued that government officials did not act as benevolent social planners, but responded more to the private desires of their constituents.

Research strongly indicates that reduced speed leads to reduced risks in traffic and occurrence of serious accidents (International Traffic Safety Data and Analysis Group, 2018). However, it`s well known that reduced speed has social costs as people spend more time in traffic.[1] From a social economic standpoint, one needs to take these costs into account and find a trade-off between safety on the one hand, and speed and efficiency on the other. According to the guidelines for NPRA however, speed limits are to be evaluated not just towards what is economically efficient but to take into account vision statements constituted trough the national transport plan (Statens Vegvesen, 2019). Our analysis is solely interested in the economic trade off.

In this paper we will analyze the current speed limits on freeways and evaluate the benefits of time savings and potential increase in traffic with an increase of speed limits. A date-specific implementation of an increase in speed limits makes for a natural intersection in our data set. High quality hourly data with the concrete cut-off point for speed regulations, where drivers cannot sort themselves along the cutoff point, allows us to utilize a regression discontinuity design (RDD) of our analysis (Lee & Lemieux, 2010). We look at our ex-post estimations of the speed limit increase conducted in 2014 and use this as the basis for our continued estimation of a further increase in speed limit to 120 km/h. We estimate the actual speed increase as a result of raised speed limit and the change in the number of registered vehicles on the freeway. We use these estimations to calculate the time savings per vehicle and the total social economic gain that comes with a further increase from 110 km/h to 120 km/h.

We will argue the case from an economic perspective and see if todays speed limits are economically efficient. We will present the current guidelines for speed limit implementation, estimate changes in actual speed and traffic magnitude as a result of the changed speed limit, set up our analysis for a further 10 km/h increase of the speed limit and finally present our analysis and conclusion regarding social economic costs related to an implementation. Our main analytical focus is to see how actual speed has increased as a result of increased speed limits, impact on traffic magnitude and increases in time savings.

[1] Reports showing an effect of lower observed speed, because of a reduction in speed limits, works as evidence for this. Examples of this impact can be found in (Ragnøy, 2007; Folgerø, Harding, & Westby, 2019).

2. Related literature

There are many ways to approach the task of regulating speed limits. Elvik (2017) discusses three principles to determine how to set speed limits in Norway based on different views and criteria. These are to choose between optimal speed limits, Vision Zero speed limits or an understandable speed limit system. They weight the criteria to determine speed limits differently and therefore leads to different views in how one can decide what speed limits should be.

Optimal speed limits are speed limits set to minimize the traffics costs to society (Elvik, 2017). These costs include cost of travel time, vehicle operating cost, accident cost and cost due to noise and air pollution. Optimal speed limits correspond with current speed limits of 80 km/h and 100 km/h. For all other speed limits, optimal speed limits are higher than today's limits, and for no roads lower than 60 km/h, even for roads with current speed limits of 30 km/h (Elvik, 2017). An introduction of optimal speed limits would lead to an expected increase in number of killed and injured on Norwegian roads, which is against Norwegian government goal of reducing the number of killed and seriously injured road users (Elvik, 2017). Despite the increased number of road caused deaths and injuries, Elvik (2017) arguments that the benefits in mobility and time savings outweighs these negative impacts with optimal speed limits.

About Vision Zero

Vision Zero is a vision constituted by the Norwegian parliament in 2002 and is a vision to have zero killed or severely injured in accidents caused by traffic (Statens Vegvesen, 2018). In the Norwegian national transport plan for 2018-2029, the goal is to have a maximum of 350 killed or severely injured within 2030. There has been a targeted and long-term effort in Norway since 1970 to better these statistics, long before the constitution of Vision Zero. 560 were killed on Norwegian roads in 1970, and this number has now been reduced to about 100 (Statens Vegvesen, 2018), despite the fact that there now are more cars, higher traffic and more people travelling in the traffic than back in 1970 (Det Kongelige Samferdselsdepartement, 2000).This indicates that road safety has improved over the years. This can be a result of many measures implemented as a result of Vision Zero and all the years of focus on road safety since before year 2000 as well. Examples of such measures can be increased road safety, actions towards speeding, actions towards drinking and driving, campaigns and actions towards speeding (Statens Vegvesen et. al., 2018). There are 13 different areas of priority in the cited report that will contribute towards reaching Vision Zero.

An introduction of Vision Zero speed limits would generally mean an overall lowering of speed limits. Vision Zero speed limits would be determined in a way such that accidents would not happen at higher speeds than the likelihood to survive and avoid serious injuries should be high (Elvik, 2017). An introduction to Vision Zero speed limits would also somewhat surprisingly allow an increase in speed on certain roads. This would be on roads with speed limit 80 km/h and median guard rail, and the speed here could be set to for example 90 km/h (Elvik, 2017), as these roads have a lower chance of severe accidents as cars driving in opposite direction are physically separated from each other. It has been estimated that 20-38 lives could be saved and a reduction of 69-134 seriously injured road users could be achieved by implementing Vision Zero speed limits, which coincides with the Vision Zero goal.

An understandable speed limit system is based on the idea that speed limits, when looked on as a system, makes sense to road users and also that there are good and understandable reasons for different roads to have different speed limits (Elvik, 2017). The concept is introduced in recent driver opinion studies on suitable speed limits for roads (Elvik, 2017). The finding indicates that drivers have very different views on what is appropriate speed limits, and that they therefore do not give too good information on how to set speed limits seen on as understandable. However, Elvik (2017), discusses that in the case of Norway there are indicators that we have an understandable speed limit system, based on surveys response. Nevertheless, he also makes an argument that when studying such surveys, one should be aware of what he calls “conservative” bias. By this, he means people are likely to support what is well known and familiar instead of supporting changes. Since we seem to be close to an understandable speed limit system, it is not likely that an implementation would lead to noticeable changes in road caused deaths and injuries, as they are close to todays speed limits (Elvik, 2017).

The three methods all suggest ways of deciding speed limits that can be justified. However, as mentioned, Norway seems to have something close to an understandable speed limit system (Elvik, 2017). Norway also seem to have a system strongly influenced by Vision Zero, as there is evidence that an optimal speed limit system could be achieved by higher speed limits, but then at a cost of more traffic caused deaths and serious injuries (Elvik, 2017).

For our report, we wanted to look at the socio-economic impact of a change in the speed limit on freeways with a current speed limit of 110 km/h. For that purpose, two main forms of previous research were of interest. We wanted to look at previous studies on the relationship between speed limits and actual speed, as well as on speed limit and traffic magnitude.

When studying the implications of a change in speed limits, there are several alternative viewpoints made towards how to properly formulate the methodology for analysis and which parameters to explore and include. Since the implementation of Vision Zero, there has been a stronger focus when it comes to weighing consequences and reaching verdicts regarding governmental regulations of speed limits. A cost-benefit study is almost always included, to get an economic perspective of an interaction. In 2015, van Bentham published a paper where he conducted a full economic evaluation of roads in the United States, attempting to discover if speed limits should be raised and what the optimal speed limit should be (van Bentham, 2015). His report rested in its entirety on quantifiable calculations, while still arguing that no cost-benefit analysis will ever be complete, thus open to omitted variable bias in his analysis.

The National Public Roads Administration has conducted similar calculations but included more non-quantifiable consequences as well. In their own report investigating the possible consequences of raising the speed limit on Norwegian freeways from 110 km/h to 120 km/h, they presented a cost-benefit analysis together with arguments referring to the implications this regulation would have for the constituted guidelines from the Norwegian national transport plan (Vegvesen, 2019). NPRA themselves argued that their report was only a calculation of costs and benefits associated with a change in the speed limit, and not to be used as a measure for economic profitability.

This paper adds mostly to the previous prediction analysis from NPRA regarding the effect of speed limits to actual speed increase and changes in observed traffic. We have made som refinement to their calculations based on our findings.

3. Data

Our analysis is based on official counting data provided from the Directorate of Public Roads (Vegdirektoratet) from two Norwegian freeway-monitoring stations, *E39 Skoger* and *E6 Kløfta Sør*, for the period 2011 to 2018. Monitoring station for E6 Kløfta Sør is located roadside north of Oslo, while the monitoring station for E18 Skoger is located roadside E18 outside Skoger, just south of Drammen. The data are hourly registrations of average speed, with both cumulative speed registrations for all registered vehicles and sectional averages divided into five different vehicle groups based on length of the vehicles. The registrations are done by lanes, which gives us an accurate picture and measure of road behavior in general.

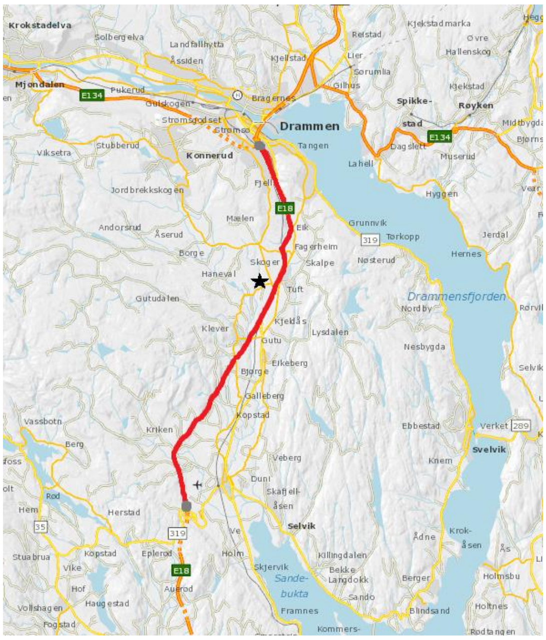

Figure 1 - Map over freeway analyzed E18 Skoger. Star indicates location of the measure point

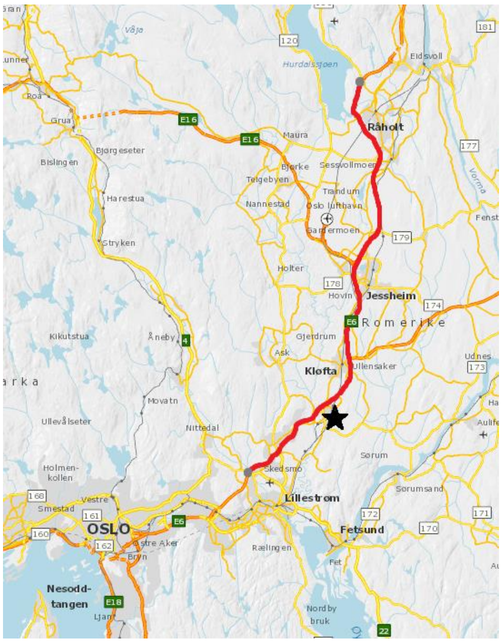

Figure 2 - Map over freeway analyzed E6 Kløfta Sør Star indicates location of the measure point.

All values for average speed lower than 60 km/h were omitted, so to regulate for these abnormal incidences. Constraining speed to be over 60 km/h allows us to look at normal traffic, but still not omit observations to the point where omitting could be seen as biased manipulation.[2]

Unfortunately, the data had several flaws, that needed adjusting and accounting for. Several registrations were missing, which made it difficult to compare all years equally. Some registrations for speed were showing negative speed and were omitted in our analysis. The data does not give any indications about traffic jams or other extraordinary incidents, making it difficult to omit these incidences from our analysis. However, we believe these situations are accounted for with our constraint of 60 km/h for our observations. As the data are hourly registrations, we feared that some registrations might be extremely high as well. At night, people might be speeding because of little traffic. We therefore chose to omit averaged speed registrations above 150 km/h, to account for this.[3]

Our final counting data set consists of more than 2 million observations regarding vehicle classes and speed held on hourly basis for the different segments through the period on two separate freeways. The time of interaction in our data set is the specific time the increased speed limit from 100 km/h to 110 km/h was initiated. The implementation took place on *E6 Kløfta sør* at *22nd of April 2015* and for *E39 Skoger* at *13th of June 2014.*

Descriptive Statistics for Traffic

	Full Sample				
	Obs. (1)	Mean (2)	S.D (3)	Min. (4)	Max. (5)
Panel A: descriptive statistics for traffic, Kløfta Sør					
Speed	1 003 797	95.04517	9.973421	61	159
Vehicles per hour	1 009 978	141.2157	286.0968	1	2 242
Panel B: descriptive statistics for traffic, Skoger					
Speed	1 003 797	95.04517	9.973421	61	159
Vehicles per hour	1 009 978	141.2157	286.0968	1	2 242

Table 1 - Descriptive statistics for speed and traffic magnitude on E6 Kløfta Sør and E18 Skoger 2011-2018. All speeds are in km/h. Traffic is measured in both directions on both roads.

[2] Standard practice to exclude outliers in statistical analysis.

[3] Important to omit extreme outliers on both sides of the analysis, to get representative data sets.

Date of implementation was confirmed directly from NPRA. We have analyzed the roads separately, as speed regulations took place at two different dates, so to keep the clean cutoff periods accurate in our analysis of the data sets.

4. Background for changing speed limits on freeways

In 2014, the Norwegian government raised the speed limit on 163.7 kilometers of freeways from 100 km/h to 110 km/h. In an ex-post analysis by the NPRA, the regulation led to a 2.3 km/h increase in actual speed, an increase of 1.4 accidents per year and a yearly cost increase of NOK 13.5 million (Ragnøy, 2014).

In a letter to the Norwegian Public Roads Administration from the former minister of transportation, Ketil Solvik-Olsen, NPRA were asked to lay out the requirements for freeways with a speed limit of 120 km/h. He also wished that NPRA laid out what needed to be done for current freeways with speed limit 110 km/h to get 120 km/h as maximum speed. This was a process sat in motion to evaluate if the Norwegian road network could be more efficient, arguing that higher speed limits would connect regions, improve value creation, employment and economic growth (Rogne & Henriksen, 2018).

The report from NPRA showed, with a cost-benefit analysis, that it would not be economically beneficial to construct new roads to the requirements for a 120 km/h freeway, with a net present value of negative *NOK 3.4 billion* for society as a whole. The report shows however that it could be beneficial to raise the speed limit from 110 km/h to 120 km/h on a 110 km on existing freeways, with a net present value of positive *NOK 0.4 billion* (Statens Vegvesen, 2019). NPRA themselves were reluctant to state their analysis as a measure on actual profitability, but rather as a measure of upsides and downsides of such an implementation.

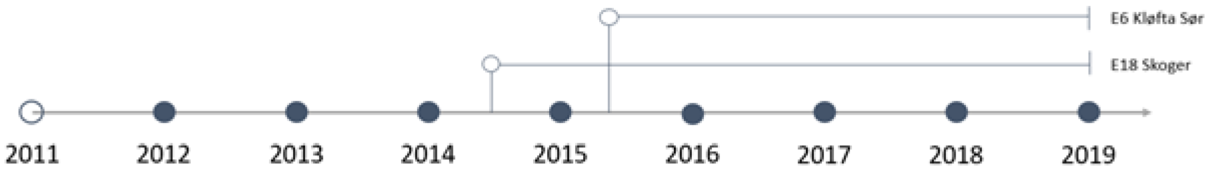

Figure 3 - Timeline for implementation of speed limit 110 km/h on E6 Kløfta sør and E18 Skoger.

5. Empirical methodology

5.1 Analysis of speed and traffic

In our analysis, we look at two freeways who both had a change in their speed limit from 100 km/h to 110 km/h. We therefore analyze these roads using a sharp regression discontinuity design model (RDD), applicable for situations where no control group is available and all observed research objects receives treatment (Jacob, Zhu, Somers, & Bloom, 2012). When analyzing our RDD model, we are interested in the effect of the interaction of the change in speed limit on actual speed and traffic magnitude. To observe the actual impact, we need to make some assumptions about our data.

A key assumption for our analysis is that all characteristics relevant for speed, other than the change in speed limit and change in registered vehicle observations, are continuous over the threshold, i.e. shortly before the cutoff and shortly after. The assumption is that people who drive have no way of sorting themselves in such a way that one can substitute driving in one period with driving in another period. This way, any variation in the treatment are as good as random.

Another assumption for our RDD model is that observations are randomized. Even though the registered roads are constant, and it`s fair to assume that most of the observations are of same people passing each day, we have no way of identifying singular observations, as our data are averaged speed measures of several observations every hour. The roads does not restrict anyone from using them. By definition, we can assume that our hourly counting data is randomized. Our analysis draws inspiration from previous ex ante, post ante estimation with a clear treatment effect (Lee & Lemieux, 2010; Folgerø, Harding, & Westby, 2019).

We estimate the effect of raising the speed limit on actual speed and traffic magnitude by utilizing the following econometric model:[4]

$$\boldsymbol{y_{it}} = \boldsymbol{\gamma_0} + \boldsymbol{\alpha}(\boldsymbol{SL_t}) + \boldsymbol{\gamma_1 f}(\boldsymbol{X_t} - \overline{\boldsymbol{x}}) + \boldsymbol{\gamma_2}(\boldsymbol{SL_t}) * \boldsymbol{f}(\boldsymbol{X_t} - \overline{\boldsymbol{x}}) + \boldsymbol{\gamma_3 Z_{it}} + \boldsymbol{u_{it}} \qquad (1)$$

Where $\boldsymbol{y}$ is a placeholder for actual speed and the logged value of the number of passing vehicles on an hourly basis.[5] $\boldsymbol{SL_t}$ is our indicator variable for treatment, which equals 1 in the period after the raised speed limit is implemented and 0 otherwise. $\boldsymbol{\alpha}$ expresses the estimated effect of the increased speed limit. For actual speed, $\boldsymbol{\alpha}$ is the km/h change while for traffic it is the $100 * \alpha$ percentage change in observations as a result of the increased speed limit. $\boldsymbol{f}(.)$ is a polynomial in time, and the interaction with $\boldsymbol{SL_t}$ allows this polynomial to differ on both sides of the cutoff period. $\boldsymbol{Z_{it}}$ is an accumulated variable for all control variables in our regression (vehicle class and day of the week). **t** is our running time variable and **i** is a identifier of what vehicle class and lane we are looking at.[6]

We treat our data set as continuous panel data with calendar date and registered hour as a grouped running time variable. In our analysis, it could have been interesting to evaluate differences in speed behavior in different hours as well. We argue that with as many registrations in our data set, we can make out the general trend for speed across the period, where the interesting change in behavior happens at the cutoff of the implemented change in speed limit. Our key identifier in each period is a compounding variable identifying the specific

[4] We follow similar estimation techniques laid out in (Lee & Lemieux, 2010) and (Folgerø, Harding, & Westby, 2019)

[5] Using a level-level model for our regression on speed, our effect variable will give us the effect on speed in km/h. Using a log-level model for our regression on traffic magnitude, our treatment variable will give us the effect on traffic observations as a (100*α) percentage change.

[6] Our time variable is based on what hour and what date it is. $t \in [1, T]$, where T is the number of hours observed in total. Our identifier variable is based on what vehicle class and what lane are observed. We have 5 vehicle classes and 4 lanes, so $i \in [1,20]$.

lane and vehicle class registered. This allows us to control for heterogeneity in the different lanes and different types of vehicles passing. We argue that observed speed could be significantly different between two lanes going in the same direction. The social norm in traffic is that the left lane of a freeway shall be used for bypassing slower traffic.

5.2 Scaling implementation and cost-benefit analysis

As we are interested in looking at the potential costs and benefits of an increase from 110 km/h to 120 km/h, we need to scale our numbers from our analysis on the increase from 100 km/h to 110 km/h. As NPRA conducts reports of necessary improvements needed on roads to be fit for different speed limits, and have themselves tried to estimate costs for necessary improvements on freeways of good standard, we lean on their cost estimations (Statens Vegvesen, 2019). We choose to do the same with all other costs presented by NPRA.

NPRA themselves predicts that an increase from 110 km/h to 120 km/h would increase actual speed by 5 km/h (Statens Vegvesen, 2019). We choose to assume that the speed increase to 120 km/h would give at a minimum, the same increase as observed in our analysis of the increase to 110 km/h. As heavier vehicles are not allowed to hold a speed higher than 80 km/h on Norwegian freeways, we would expect to see that an increase in the speed limit would lead to a higher difference between smaller vehicles and larger vehicles. As this happens, we assume that more vehicles would utilize the left lane of a freeway, as this is used to bypass slower traffic. Bypassing in the right lane is forbidden by §12 in the Norwegian bylaws for drivers and pedestrians (The Royal Ministry of Transport, 2018). By this reasoning, it`s fair to assume that if our analysis shows an increase in speed lower than 5 km/h at an increase to 110 km/h, our estimate would be a conservative approach.[7]

[7] The report from NPRA regarding impacts of an increase in the speed limit to 120 km/h does not show its work, so it was difficult for us to replicate or challenge their analysis. We therefore utilize a sensitivity analysis to look at what speed and traffic must increase with for freeways to become economically efficient.

NPRA reported their cost-benefit analysis with a fixed number of traffic observations on existing roads. In our analysis, we will conduct a sensitivity analysis on this measure based on our findings as the most conservative estimate for traffic magnitude.

When looking at the time saved, we are actually looking to find how much time one person would save, as the person is the one valuing the saved time. We assumed an average of 1.5 people per vehicle, based on practice in paper by Harding et.al. (2019). To calculate time saved for one person and per vehicle, we use these frameworks:[8]

$$Per\ person\ (s/km) = \frac{3600}{Actual\ speed\ before\ (km/h)} - \frac{3600}{Actual\ speed\ after\ (km/h)} \tag{2}$$

$$Per\ vehicle = \left(\frac{3600}{Actual\ speed\ before\ \left(\frac{km}{h}\right)} - \frac{3600}{Actual\ speed\ after\ \left(\frac{km}{h}\right)}\right) * people\ per\ vehicle \tag{3}$$

Quantifying the value of the saved time is done by multiplying the saved time on the average hourly wage in 2019 Norwegian kroner (NOK) after tax. Using data from Statistics Norway for monthly wage our estimated average hourly wage comes out to about 218 NOK (Statistics Norway, 2019).[9]

To simplify our comparison to the previous report by NPRA, we will use the same discounting rate of 4.0% and 40 years of discounting period for our analysis.

[8] The calculations gives us the time one vehicle uses to drive 10 kilometers. As a vehicle with lower speed would use more time to drive 10 km, we present our model the way we do to get a positive difference in time.

[9] Hourly wage, ex. tax = (45 610 *monthly salary* x 1,02 *inflation* x *0,75 tax*)/(40 *hours per week* x 4 *weeks*) = 218

5.3 Sensitivity analysis

Several assumptions are made in our analysis to estimate the economic profitability of raising the speed limit. To evaluate the sensitivity to deviation from our estimates, we run a sensitivity analysis on critical components. This is to see if variations from our estimations and assumptions could alter the conclusion of our analysis.

For our sensitivity analysis we will utilize three different parameters for speed based on our estimated speed increase and the reported increase made by NPRA. This is to look at plausible increases in actual speed held by drivers to get a viewpoint on social economic profitability of these increases. As increase is based on prediction models made out by estimating changes in lower speed limits, we find it important to view several plausible outcomes of actual speed increase due to uncertainty. This uncertainty is due to that this change in maximal speed limit have never occurred in Norway.

6. Results

6.1 The effects on observed speed

The purpose of the increase in maximum speed limit on freeways was to improve road effiency. For this to materialize, we needed to observe an increase in the actual registered speeds held by drivers on these freeways. Figure 4 and Figure 5 below present the observed effect of the increased maximum speed limit from 100 km/h to 110 km/h on actual speed at E6 Kløfta Sør and E18 Skoger. In the figures, we can see clear jumps in trend for vehicle class 1 (smaller vehicles) on all lanes.[10] We also see a jump for vehicle class 2 at E6 Kløfta Sør, but not a clear jump for vehicle class 2 on E18 Skoger.

[10] The graphs are illustrated by a 5 x 4 matrix, where each column is the different vehicle classes and each row represents what lane registrations are made in, i.e. top left corner graph represents vehicle class 1 (smaller vehicles) in lane 1 (left lane in first direction), and bottom right graph represents vehicle class 5 (largest vehicles) in lane 4 (right lane in second direction).

For vehicle class 3, 4 and 5, we see different outcomes. We observe some small positive jumps, some small negative jumps and no jumps at all at the cutoff point. These vehicle classes are restricted by Norwegian law *(§13, section 4 of bylaws for drivers and pedestrians*) to drive faster than 80 km/h on any Norwegian road (The Royal Ministry of Transport, 2018).[11]

[11] All vehicles in vehicle class 3, 4 and 5 are registered as vehicles heavier than 3.5 tons. Buses without trailer are excepted from the law of maximum speed of 80 km/h. Some vehicles in vehicle class 2 are lighter than 3.5 tons, and will therefore be able to drive faster than 80 km/h.

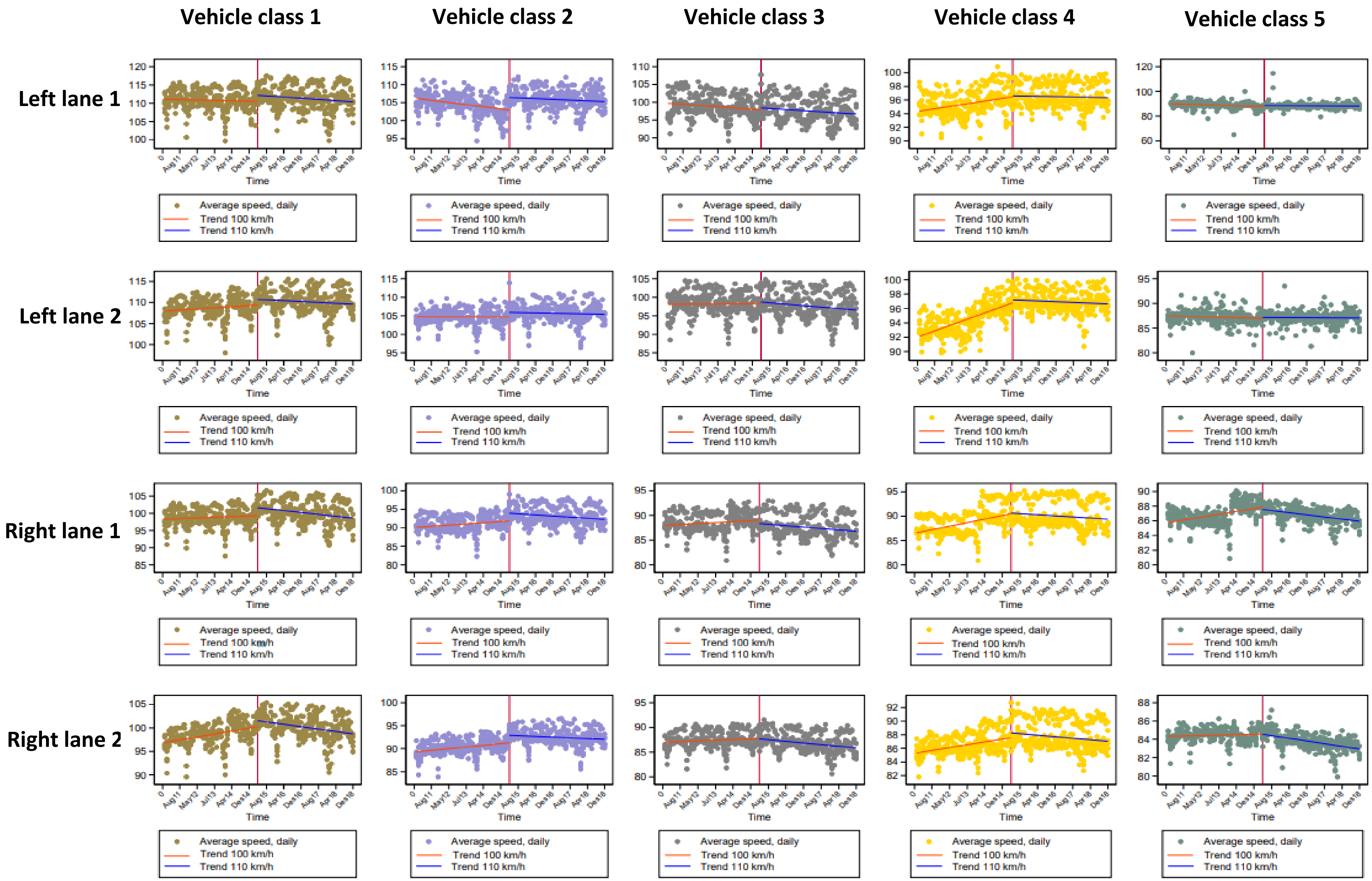

Figure 4 - Average daily speed observed on E6 Kløfta Sør, with trend lines before and after the speed limit increase. Each column corresponds to the same vehicle class where the two first rows are left lanes and the two last ones are right lanes. All vehicles in column 1 are light vehicles that can follow speed limit on sight. Vehicles in column 2 are a mix of light vehicles and heavier vehicles where the heavier vehicles are limited to 80 km/h. All vehicles in vehicle column 3, 4 and 5 are registered as vehicles heavier than 3.5 tons and also limited to 80 km/h. Buses without trailer are excepted from the law of maximum speed of 80 km/h. Some vehicles in vehicle class 2 are lighter than 3.5 tons, and will therefore be able to drive faster than 80 km/h.

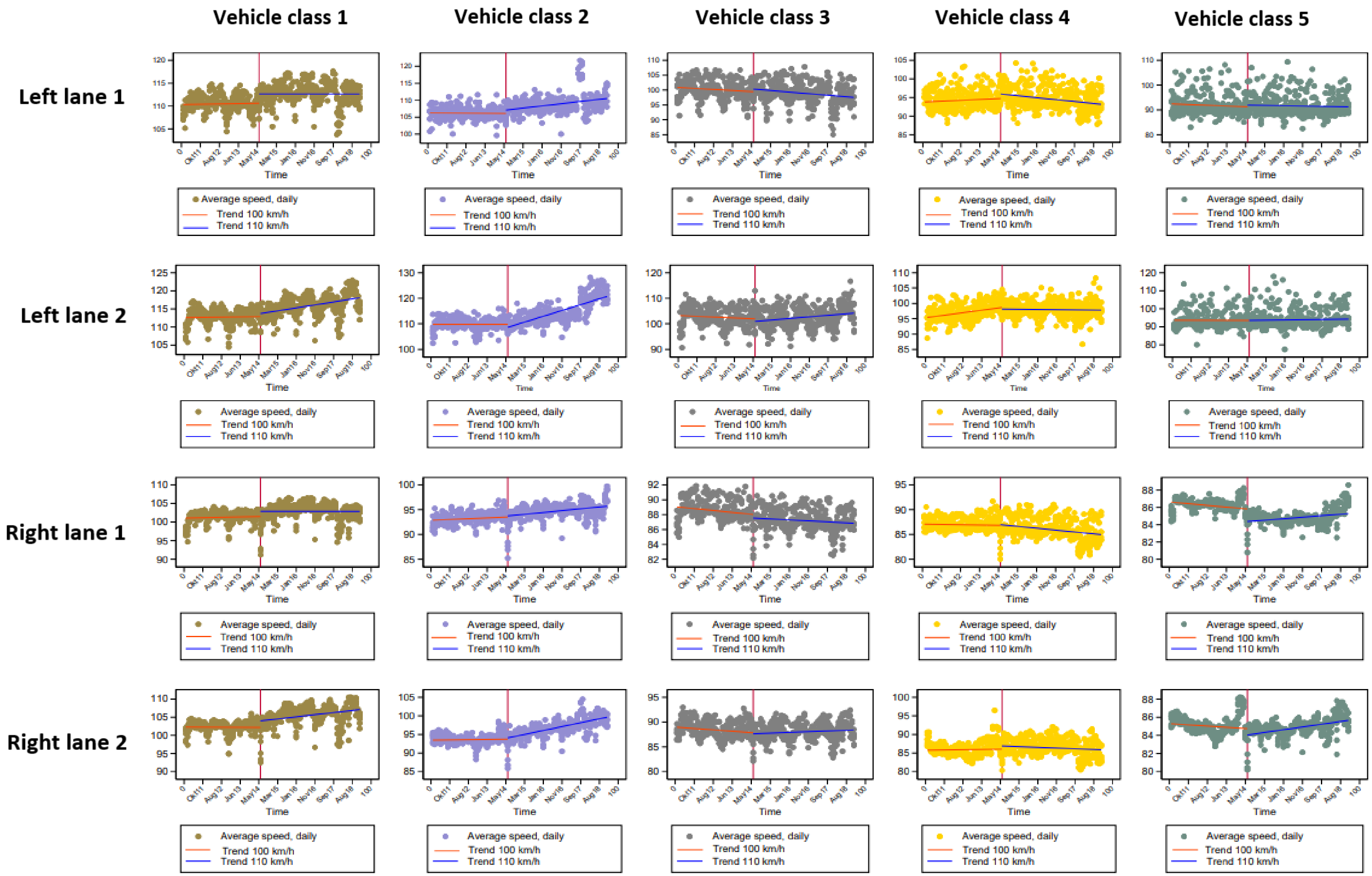

Figure 5 - Average daily speed observed on E18 Skoger, with trend lines before and after the speed limit increase. Each column corresponds to the same vehicle class where the two first rows are left lanes and the two last ones are right lanes. All vehicles in column 1 are light vehicles that can follow speed limit on sight. Vehicles in column 2 are a mix of light vehicles and heavier vehicles where the heavier vehicles are limited to 80 km/h. All vehicles in vehicle column 3, 4 and 5 are registered as vehicles heavier than 3.5 tons and also limited to 80 km/h. Buses without trailer are excepted from the law of maximum speed of 80 km/h. Some vehicles in vehicle class 2 are lighter than 3.5 tons, and will therefore be able to drive faster than 80 km/h.

	(1) Actual Speed	(2) Actual Speed	(3) Actual Speed	(4) Actual Speed	(5) Actual Speed	(6) Actual Speed	(7) Actual Speed
Speed Limit	0.4820624***	1.911501***	2.585764***	2.924111***	2.924111***	2.926726***	2.926726***
	(0.0576)	(0.1160)	(0.2321)	(0.1836)	(0.1836)	(0.1819)	(0.1819)
trend		-0.0321364***	-0.024396***	-0.0139604***	-0.0139604***	-0.0142965***	-0.0142965***
		(0.0023)	(0.0032)	(0.0026)	(0.0026)	(0.0025)	(0.0025)
trend*Speed Limit			-0.0151911***	-.0162626***	-.0162626***	-0.0166537***	-0.0166537***
			(0.0045)	(0.0036)	(0.0036)	(0.0035)	(0.0035)
Vehicle obs.				-0.0100171***	-0.0100171***	-0.0095159***	-0.0095159***
				(0.0001)	(0.0001)	(0.0001)	(0.0001)
i.Vehicle Class	No	No	No	No	**Yes**	No	**Yes**
i.Day of week_dummy	No	No	No	No	No	**Yes**	**Yes**
F-stat	69.94	135.70	94.23	9032.37	9032.37	3792.00	3792.00
R2	0.0012	0.0045	0.0047	0.3779	0.3779	0.3893	0.3893
N	59 492	59 492	59 492	59 492	59 492	59 492	59 492

Table 2 - Regression output from RDD model on actual speed on E6 Kløfta Sør

	(1) Actual Speed	(2) Actual Speed	(3) Actual Speed	(4) Actual Speed	(5) Actual Speed	(6) Actual Speed	(7) Actual Speed
Speed Limit	2.175944***	2.219272***	2.860352***	2.8541***	2.8541***	2.86001***	2.86001***
	(0.0490)	(0.0965)	(0.1607)	(0.1556)	(0.1556)	(0.1542)	(0.1542)
trend		-0.000909	0.0131543***	0.0181371***	0.0181371***	0.0181356***	0.0181356***
		(0.0017)	(0.0033)	(0.0032)	(0.0032)	(0.0032)	(0.0032)
trend*Speed Limit			-0.0194433***	-0.0177791***	-0.0177791***	-0.0182089***	-0.0182089***
			(0.0039)	(0.0038)	(0.0038)	(0.0037)	(0.0037)
Vehicle obs.				-0.0067793***	-0.0067793***	-0.0063989***	-0.0063989***
				(0.0001)	(0.0001)	(0.0001)	(0.0001)
i.Vehicle Class	No	No	No	No	**Yes**	No	**Yes**
i.Day of week_dummy	No	No	No	No	No	**Yes**	**Yes**
F-stat	1966.67	983.46	664.19	1580.63	1580.63	753.20	753.20
R2	0.0303	0.0303	0.0306	0.0912	0.0912	0.1068	0.1068
N	62 983	62 983	62 983	62 972	62 972	62 972	62 972

Table 3 - Regression output from RDD model on actual speed on E18 Skoger

From Table 3 and Table 4, we get our regression output on vehicle class 1 on E6 Kløfta Sør and E18 Skoger. We see that the effect of speed limit increase (*Speed Limit*) on Kløfta Sør show an increase in actual speed between 2.59 km/h and 2.93 km/h, when adjusting for time trend and interaction component between increased speed limit and time trend. For Skoger, we see an effect of 2.86 km/h with little variation. Variation happens, as more control variables are included in our model. In our model, we control for variations due to what day of the week a registration took place. Controlling for vehicle class gave no effect on estimates, as this effect is already accounted for in our identification variable.[12] Our finding is a little lower than the finding made by van Bentham (2015).[13]

6.2 The effects on traffic magnitude

Figure 6 and Figure 7 below shows the impact the change in speed limit has on the traffic magnitude on both E6 Kløfta Sør and E18 Skoger. We observe that for vehicle class 1 on E6 Kløfta Sør, there is a slight positive jump in the trend line in lanes 1 and 2 (Left lane observations). For lanes 3 and 4 (right lane observations), we observe a negative jump in the trend line. We therefore see two different patterns for the effect of an increased maximum speed limit on the traffic magnitude. On E18 Skoger we observe no shifts in trend line for vehicle class 1. We turn to our regressions to see if we can find a significant effect of the change in the speed limit on traffic magnitude.

[12] Identification variable i is used in our regression. When running our regression, we look at a specific vehicle class on a specific lane. Controlling for vehicle class therefore has no effect, as we analyze every vehicle class separately.
[13] In the rapport from Van Bentham in 2015, he found that for every 1 km/h increase in the speed limit, the actual speed compliance would be between 0.3-0.4 km/h.

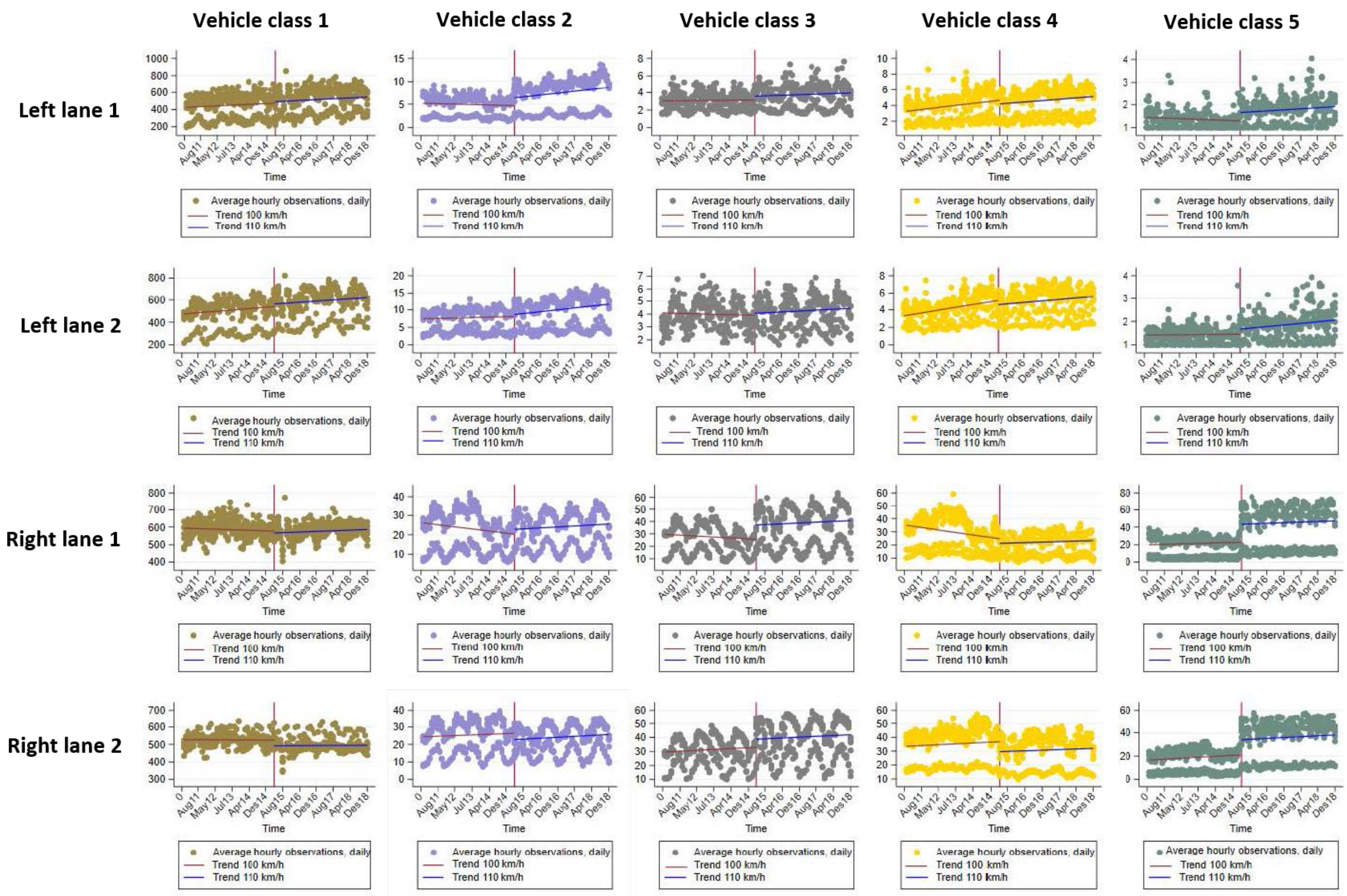

Figure 6 - Average hourly observations by day, with trend lines before and after speed limit increase for E6 Kløfta Sør. Each column corresponds to the same vehicle class where the two first rows are left lanes and the two last ones are right lanes. All vehicles in column 1 are light vehicles. Some vehicles in column 2 are also light vehicles, while others are registered as vehicles heavier than 3.5 tons. All vehicles in vehicle column 3, 4 and 5 are registered as vehicles heavier than 3.5 tons.

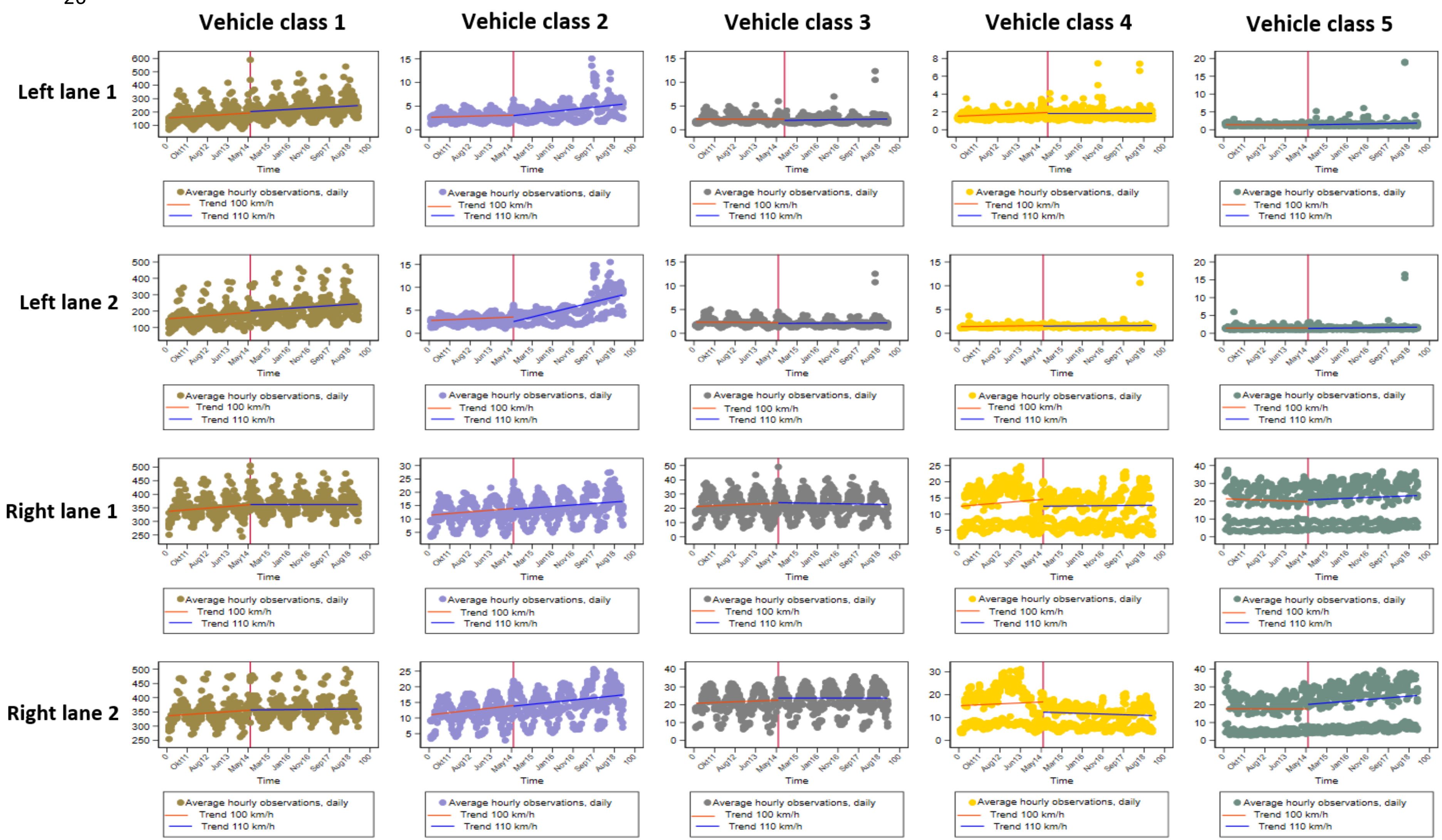

Figure 7 - Average hourly observations by day, with trend lines before and after speed limit increase for E18 Skoge. Each column corresponds to the same vehicle class where the two first rows are left lanes and the two last ones are right lanes. All vehicles in column 1 are light vehicles. Some vehicles in column 2 are also light vehicles, while others are registered as vehicles heavier than 3.5 tons. All vehicles in vehicle column 3, 4 and 5 are registered as vehicles heavier than 3.5 tons.

	(1) ln(Traffic magnitude)	(2) ln(Traffic magnitude)	(3) ln(Traffic magnitude)	(4) ln(Traffic magnitude)	(5) ln(Traffic magnitude)	(6) ln(Traffic magnitude)	(7) ln(Traffic magnitude)
Speed Limit	0.1896871***	0 .0884053**	0.0102209	0.0102209	0.005961	0.005961	
	(0.0128)	(0.0259)	(0.0518)	(0.0518)	(0.0515)	(0.0515)	
trend		0.0022762***	0.0013788	0.0013788	0.0013393	0.0013393	
		(0.0005)	(0.0007)	(0.0007)	(0.0007)	(.0007)	
trend*Dummy_Grense			0.0017614	0.0017614	0.0018586	0.0018586	
			(0.0010)	(0.0010)	(0.0010)	(0.0010)	
i.Vehicle Class	No	No	No	No	**Yes**	No	**Yes**
i.Day of week_dummy	No	No	No	No	No	**Yes**	**Yes**
F-stat	217.99	119.16	80.45	80.45	121.84	121.84	
R2	0.0036	0.004	0.004	0.004	0.018	0.018	
N	59696	59696	59696	59696	59696	59696	

Table 4 - Regression output from RDD model on logged average hourly observations on E6 Kløfta Sør

	(1) ln(Traffic magnitude)	(2) ln(Traffic magnitude)	(3) ln(Traffic magnitude)	(4) ln(Traffic magnitude)	(5) ln(Traffic magnitude)	(6) ln(Traffic magnitude)	(7) ln(Traffic magnitude)
Speed Limit	0.2442865***	0.0269723	-0.0142642	-0.0142642	-0.0150258	-0.0150258	
	(0.0151)	0.0297	(0.0494)	(0.0494)	(0.0491)	(0.0491)	
trend		0.0045564***	0.0036481***	0.0036481***	0.00354***	0.00354***	
		(0.0005)	(0.0010)	(0.0010)	(0.0010)	(0.0010)	
trend*Dummy_Grense			0.0012532	0.0012532	0.0013496	0.0013496	
			(0.0012)	(0.0012)	(0.0012)	(0.0012)	
i.Vehicle Class	No	No	No	**Yes**	No	**Yes**	
i.Day of week_dummy	No	No	No	No	**Yes**	**Yes**	
F-stat	261.14	166.84	111.59	111.59	137.47	137.47	
R2	0.0041	0.0052	0.0053	0.0053	0.0192	0.0192	
N	63273	63273	63273	63273	63273	63273	

Table 5 - Regression output from RDD model on logged average hourly observations on E18 Skoger

From our regression output, we can´t find a statistical significant correlation between the increase in maximum speed limit and observed traffic magnitude, at a 95% confidence interval. Only controlling for the speed increase, we find statistical significance, but when trend is included as a control variable, we see that this variable takes over almost all the explanatory power.

6.3 Cost-benefit analysis

Estimations by NPRA	
Road users and transport users	
Vehicle costs	-949 mill. NOK
Time savings	+ 2570 mill. NOK
The Public	
Investments	- 276 mill NOK
Tax and fee revenue	+ 302 mill. NOK
Society in general	
Accidents	- 353 mill. NOK
Air pollution (global and regional)	- 896 mill. NOK
Tax costs	+ 5 mill. NOK
Accumulated change in NPV by a change in speed limit from 110 km/h to 120 km/h	+ 403 mill. NOK

Table 6 - Cost-benefit analysis reported by NPRA (2019) on speed change from 110 km/h to 115 km/h.

Table 7 presents the simple cost-benefit estimation made by NPRA in their report to the ministry of Transportation (Vegvesen, 2019). In their analysis, they have operated with the following values across the whole period of analysis:

Yearly day traffic (ÅDT)	Years	People per vehicle	Hourly wage (NOK)	Discounting factor	Average speed before	Average speed after
31000	40	1,5	182,53	4.0%	110	115

Table 7 - Key variable values for NPRA estimation of social economic profitability

NPRA apply a fixed measure of 31 000 passing vehicles per day over their whole period of 40 years. To value the travel time, NPRA utilizes a measure of about 185 NOK per hour. This value is based on estimate of people's willingness to pay for extra time.[14] To get the net present value (NPV) of their estimations, they apply a discounting factor of 4.0%. Their estimation starts in 2020.

In our analysis we use a base of the following values:

Yearly day traffic (ÅDT)	Years	People per vehicle	Hourly wage (NOK)	Discounting factor	Average speed before	Average speed after
31000	*40*	*1,5*	*218,07*	*4.0%*	*110*	*113*

Table 8 - Key variable base values for our estimation of social economic profitability

Our estimated time value is, as mentioned earlier, based on the average hourly wage in Norway, in 2019 currency. We keep yearly day observation fixed to start with, and adjust this slightly to look at effects on the estimated value of saved time. In our sensitivity analysis, we look at the effect we get on economic profitability by making some slight differences in our input variables. The following changes were looked at:

Speed increase (km/h)	2,59	3,5 km/h	5 km/h
Change in Time value	182,53		

Table 9 - Parameters we change in our sensitivity analysis on social economic profitability

These changes were all made individually, to make sure we see the clear effects of these changes on the economic profitability estimations. We chose to use our lowest estimated change as the low end of our analysis, and the increase of 5 km/h made by NPRA as our highest estimate for speed change.

The last application to our analysis was that we saw in the analysis made by NPRA that some of the estimated costs most likely are highly correlated with the speed assessed in their analysis. The costs we find plausible to have an effect based on the actual speed increase are vehicle

[14] In handbook V712 Consequence analysis, NPRA values time by vehicle rides less than 70 kilometers to 172 NOK in 2016 value (Statens Vegvesen, 2019). By adjusting for three years of inflation, with a rate of 2.0% inflation, we were able to find their estimated value for time in 2019 value. Checking their calculation values, we found the same timesaving as they present in their rapport.

costs, accidents and air pollution. As we don´t have the exact relationship of these costs to the actual speed, we adjust these costs linearly with our input speed increase.[15]

Implementing our estimated values for increased speed and traffic magnitude, as well as running our sensitivity analysis´s, we receive the following cost-benefit estimations:

	(1) 3 km/h increase	(2) 2,59 km/h increase	(3) 3,5 km/h increase	(4) Time valued 182.53 NOK, 3 km/h increase	(5) 5 km/h increase with time value 208 NOK
Road users and transport users					
Vehicle costs	-569 mill. NOK	-492 mill. NOK	-664 mill. NOK	-569 mill. NOK	-949 mill. NOK
Time savings	+1874 mill. NOK	+1624 mill. NOK	+2176 mill. NOK	+1568 mill. NOK	+ 3069 mill. NOK
The Public					
Investments	- 276 mill NOK	- 276 mill NOK	- 276 mill NOK	- 276 mill NOK	- 276 mill NOK
Tax and fee revenue	+ 302 mill. NOK	+ 302 mill. NOK	+ 302 mill. NOK	+ 302 mill. NOK	+ 302 mill. NOK
Society in general					
Accidents	-212 mill. NOK	-183 mill. NOK	-247 mill. NOK	-212 mill. NOK	- 353 mill. NOK
Air pollution (global and regional)	-538 mill. NOK	-464 mill. NOK	-627 mill. NOK	-538 mill. NOK	- 896 mill. NOK
Tax costs	+ 5 mill. NOK	+ 5 mill. NOK	+ 5 mill. NOK	+ 5 mill. NOK	+ 5 mill. NOK
Accumulated change in NPV by a change in speed limit from 110 km/h to 120 km/h	**+ 586 mill. NOK**	**+ 516 mill. NOK**	**+ 668 mill. NOK**	**+ 280 mill. NOK**	**+ 902 mill. NOK**

Table 10 - Social economic analysis with sensitivity analysis on economic profitability of increased speed limit to 120 km/h. The different columns indicates profitability for different scenarios shown in the top row. Column 1, 2 and 3 uses time value = 218 NOK per hour, while column 4 uses time value = 182.53 NOK per hour and column 5 uses NPRA-estimates with time value = 208 NOK per hour. All columns shows profitability with ÅDT=31000. Scaling of costs has happened in (1), (2), (3) and (4) on vehicle costs, accidents and air pollution.

We see that for all our estimates, we get a positive net present value of an increase in the speed limit from 110 km/h to 120 km/h on existing freeways with 110 km/h. Estimating with 218 NOK as value for time, even with our lowest estimated speed increase the cost-benefit analysis gives us a higher positive estimate than reported by NPRA.

Estimated value of time saved	
Time saved per kilometer per person (seconds)	0,8689
Average kilometers driven (per day)	22,5
Days of the year	365
Average hourly wage (NOK)	218,-
Actual speed increase	3 km/h
Yearly savings	**432,24**

Table 11 - Estimated yealy savings per person with a 3 km/h increase in actual driving speed

[15] If we for example put in a speed increase of 3 km/h, this is a 40% lower estimate than the NPRA reported increase of 5 km/h. We would than scale the costs, so that these are 40% lower than reported by NPRA.

Per person, the yearly savings in time cost is estimated to be between 708 NOK, with the highest estimated change in speed and 375 NOK with the lowest estimated speed increase. From our base estimation of 3 km/h increase and no increasing traffic, we found that people on average save 432 NOK per year from an increase in the speed limit to 120 km/h.

7. Conclusion

For over two decades, since the implementation of Vision zero in the national transport plan, reduced speed limits has been a tool for authorities to reduce the risk of severe accidents on Norwegian roads. The trade-off for more safety has been loss of personal time for drivers, as lower speed limits lead to lower speed and more time spent in traffic. Even if the personal time cost is very low per person, the accumulated time loss leads to a significant accumulated time loss for society.

In this thesis, we sought to find the social economic effect of an increased maximum speed limit from 110 km/h to 120 km/h on 110 kilometers of Norwegian freeway, based on potential social economic benefits that can occur by increasing the speed limit on these roads. We evaluated the potential increase in time saved for drivers, by an increase in the maximum speed limit from 110 km/h to 120 km/h on 110 kilometers of existing freeways. Through our analysis of two freeways in Norway we found that an increase in the maximum speed limit from 100 km/h to 110 km/h led to an increase in actual speed of between 2.59 and 2.93 km/h. With the increase in the maximum speed limit from 100 km/h to 110 km/h, we found no effect on the amount of traffic observed on the freeways.

Utilizing cost estimations made out by the Norwegian Public Roads Administration, we implemented our estimations for speed increase to calculate the social economic impact of an increase in the speed limit to 120 km/h. We ran sensitivity analysis on actual speed increases between 2.59 km/h to 5 km/h made out by NPRA. Cost estimations we believe to be highly correlated with the actual speed increase were scaled in our analysis to give fair cost-benefit estimations. These sensitivity analysis´ gave us a variation in economic profitability of a changed speed limit to 120 km/h of +280 million NOK, up to +1694 million NOK. Even with our lowest estimated value of speed increase from our regression model, we observe that from an economic standpoint, it could be beneficial to increase the speed limit on 110 kilometers of freeway in Norway.

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