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Safety first? The effect of studded tyres on traffic accidents and local air pollution☆

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ABSTRACT

This paper offers empirical insights into the trade-off between local air pollution and traffic accidents by exploiting an annual studded tyre ban in Norway. Studded tyres offer superior traction on icy roads, but also contribute to harmful particulate matter pollution. The use of studs is therefore restricted to certain dates which, due to its dependence on Easter, can differ by over a month from one year to another. I exploit this variation in a type of regression discontinuity in time design. The findings suggest that the use of studded tyres does not decrease the number of traffic accidents. Moreover, there is no evidence that studded tyres increase particulate matter pollution. As studded tyres increases road wear and tear and appears to not contribute to road safety, this paper raises the question of whether North-American and European countries where studded tyres are widely used should revisit their traffic safety policies.

1. Introduction

Particulate matter pollution and the negative health effects associated with increased pollution are a major concern worldwide. According to the World Health Organization (2018), particulate matter pollution is believed to have caused as many as 4.2 million deaths globally in 2016. Moreover, air pollution is particularly challenging to curb as it is considered as a standard textbook negative externality that is not priced into individual decisions (Pigou, 1920). Aligning these costs hinges upon proper pricing of the externality, which is achieved by revealing and understanding the real economic costs of pollution (Vickrey, 1963). Recognising this, there have been a range of policies aimed at reducing pollution, including driving restrictions and congestion charges.

At the same time, how to increase winter road safety is a question raised by policymakers in several countries worldwide. According to the U.S. Department of Transportation, over 70 percent of the U.S.'s roads are located in snowy regions and almost 70 percent of the U.S. population lives in these areas. Moreover, 24 percent of weather-related vehicle crashes occur on snowy, slushy, or icy roads. Challenging winter driving conditions have made the use of studded tyres common in many countries. However, studded tyres are frequently debated and considered as a double-edged sword. On the one hand, studded tyres provide superior traction under icy conditions, greatly increasing road safety under demanding driving conditions. On the other hand, the metal studs contribute to pollution by tearing off micro-particles from the road surface and from the studs themselves. Consequently, it also increases road maintenance costs.

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The weight applied to the two different effects of studded tyres is different across the world. In approximately half of the countries in Europe, studs have been banned for over 20 years. In the other half, studded tyres are allowed between certain dates. This division is also true in the province of Ontario in Canada. Whereas studded tyres are forbidden in Southern Ontario, the period when studded tyres is allowed was extended in the Northern Ontario in 2014, following a suggestion by Ontario Provincial Police.

Thus, while studded tyre use is believed to increase social welfare by reducing traffic accidents, the negative externality that includes harmful pollution might offset the traffic safety benefit. The casual effect of studded tyres on particulate matter pollution and traffic safety has not previously been studied outside of a laboratory setting. Moreover, there have been many changes both with respect to overall car safety and road construction and maintenance since studded tyres were developed in the 1960s. This motivates the need for updated evidence of the safety and pollution effects of studded tyres.

This paper explores the effect of studded tyres on both traffic accidents and particulate matter pollution levels in Norway. I exploit that studded tyres are allowed only between certain dates and that the dates vary from year to year in most of the country. More precisely, the yearly reinstatement of the studded tyre ban depends on when Easter falls, a date that can vary by up to a month from one year to another. Most importantly, this date is independent of, for example, prevailing weather conditions. The three northernmost counties, however, have a fixed ban date. This causes the actual ban date to vary both within Norway and across years.

I employ a regression discontinuity design and compare accidents and pollution levels one week before and after the ban within the same year, assuming that unobservable variables such as driver behaviour and driving conditions are unaltered during this two-week period. Specifically, as the date of the ban changes from year to year, this greatly reduces the threat of other variables changing simultaneously with the ban.

This paper aims to offer novel insights into the trade-offs between decreases in local air pollution and enhancements in traffic safety. If studded tyres prevents accidents, the ban date should be postponed and policymakers should consider deregulating the use of studded tyres. If the opposite is true, areas allowing studded tyres should consider restricting the use due to potential pollution and maintenance costs.

The analysis is based on daily data on police-reported traffic accidents and daily pollution levels from the ten largest cities in Norway, between 2008 and 2019. The findings imply that neither the number of traffic accidents nor the particulate matter pollution level changes after the ban has been reinstated. These results are robust to variations in controls, alternative functional forms and placebo tests. Even in the coldest years of the sample, when the superior traction of studded tyres is believed to be greatly utilised, there is no effect on the number of traffic accidents. These findings imply either that studded tyres, given modern cars and roads, in general do not prevent traffic accidents, or that the ban is reinstated too late every year so that the driving conditions around ban start is not icy enough.

Despite that the findings in this paper suggest that studded tyres do not increase pollution levels, studded tyres increase road wear and tear, which in turn increases road maintenance costs. Therefore, policymakers should potentially revisit the use of studded tyres as the use of studded tyres may entail net costs for society.

In what follows, I briefly review the relevant literature. Furthermore, I explain the institutional settings of the studded tyre ban. I then outline the data used in the analysis and follow this with a description of the empirical approach and key results. In addition, I present a series of robustness tests, discuss the findings, and conclude.

2. Related literature

A sizeable literature exists where the adverse effects of air pollution on physical health are explored. A large body of this literature is related to the pollution effects of congestion, and typically, pollution level effects are studied following the introduction of a congestion charging policy (see for example Currie, Neidell, and Schmieder (2009); Wolff (2014); Gibson and Carnovale (2015); Simeonova et al. (2021); Green et al. (2020); Pestel and Wozny (2021)). The results show that reducing pollution has the potential to reduce circulatory and chronic lower respiratory diseases for both adults and children. Moreover, some studies show that congestion charging policies decrease car use and traffic accidents (Gibson and Carnovale, 2015; Green et al., 2014).

Other studies have shown a relationship between particulate matter pollution and cognitive performance, aggression and impatience, which can affect mental health, labour productivity and crime levels (Zhang et al., 2017; Zivin and Neidell, 2012; Lu et al., 2018; Bondy et al., 2020). Sager (2019) exploits this link to investigate whether pollution can affect the number of traffic accidents by impairing safe driving performance. Indeed, the author finds that an increase PM2.5 pollution of 1 $\mu g/m^3$ leads to a 0.4 percent increase in traffic accidents in the United Kingdom. Thus, if studded tyres are found to significantly increase pollution, the safety effect of studded tyres might to some extent be offset by their contribution to particulate matter pollution.

More closely related to this paper is research that is concerned with studded tyres specifically. Although studded tyres are widely used in several European countries, Canada and the northernmost states in the US, few studies considering both the costs and benefits of studded tyres exist. Moreover, the limited existing literature focusing on the road safety effects of studded tyres find mixed results. Malmivuo et al. (2017) study the number of accidents involving cars using studded tyres and determine whether there are differences in accident rates compared to cars without studded tyres. The authors find that the overall risk of fatal road accidents in winter does not differ statistically significantly between vehicles with and without studded tyres. On icy roads however, the authors find a higher accident risk for vehicles without studded tyres. However, a concern with this particular study is the risk of selection in people driving with studded tyres, which may confound the true effect on road safety. Indeed, the authors find that motorists driving with non-studded tyres were more experienced and drove newer cars. If less experienced drivers and older cars are more likely to have studded tyres, then the observed safety effect of studded tyres is likely to be deflated.

Elvik et al. (2013) estimate the use of studded tyres and traffic accidents in five cities in Norway between 1991 and 2009. They find that accidents involving injuries increase by five percent when the use of studded tyres decreases by 25 percentage points. A challenge associated with exploiting general variation in the percentage of cars using studded tyres over several years is that factors such as car safety features, road safety and maintenance and other relevant variables are likely to have also changed over time. In the absence of counterfactuals, it is difficult to disentangle the effect of changes in studded tyre use and the other confounding factors.

This paper differs in several ways from the aforementioned literature, most importantly by exploring the causal effect of studded tyres on both traffic safety and particulate matter pollution. Because the studded tyre ban is cyclical and follows a fixed rule, the date the ban begins varies from year to year, and, more importantly, no other policy is enacted at the same time as the ban on studded tyres. By utilising a regression discontinuity design to compare changes in accidents and pollution only a short period before and after the ban, unobserved characteristics are likely to remain unchanged, strongly reducing the risk of confounding factors. This also means that the characteristics of the people driving and of their cars should be the same before and after the ban, making the selection problem in this study less salient than that of previous studies.

Moreover, it contributes to clarifying the trade-off between traffic safety measures and air pollution effects. Identifying the overall effect of studded tyres is important for policymakers that are considering restricting the use of studs to reduce pollution. Likewise, for areas experiencing a spike in accidents during winter this study offers insights into whether studs should be encouraged or if other safety measures, such as increased road maintenance, are preferable.

3. Background

Car traffic is the main source of PM_{10} pollution in urban areas, deriving mainly from road and tyre wear and tear. According to the Norwegian Institute of Public Health (2013) the use of studded tyres during winter in Norway and similar countries results in these countries having a considerably higher prevalence of ambient air particulate matter pollution than other parts of the world. It is widely known that long-term exposure to particulate matter pollution directly contributes to the development of lung and cardiovascular diseases. In addition, research shows that health risks accrue at lower concentration levels and after shorter exposure than previously thought (World Health Organization, 2006).

At the same time, many countries have a strong tradition of using studded winter tyres, especially in the Nordic countries. The observations utilised in this paper spans over 11 years. Indeed, vehicle performance and safety, as well as road maintenance, is likely to have improved over the sample period. This, in addition to increased public knowledge on the pollution effect of studded tyres, is likely to have affected the use of studded tyres. The road authorities conduct a yearly manual counting of cars with and without studs at a given point in time during the winter.[1] Their counting suggests that the share of cars driving without studded tyres in Norwegian cities have increased from 59 percent in 2008 to 70 percent in 2019, translating to a decrease of 11 percentage-points in studded tyre use over the sample period. Although their counting is to be interpreted with caution, because the counting is performed over a short period during the middle of the day and on selected down-town areas in Norway's biggest cities, it is an indication of a decreasing studded tyre share in Norway. It should be noted, however, that the share of studded tyre use varies significantly between cities and across the country. For example, the share of studded tyres in Tromsø, a relatively large city in the north, is believed to be 73 percent in 2019, whereas it is 9 percent in Oslo, which is in the south.

While studded tyres, compared to winter tyres without studs, are thought to give superior traction under icy driving conditions, they also contribute considerably to pollution by tearing off micro-particles from the road surface. Moreover, the friction between the metallic studs and asphalt arbrades the studs, which is transformed to particulate matter pollution. In an effort to limit pollution, many authorities including the Norwegian road authorities, restrict the use of studded tyres to be within certain dates. Because the climate in Norway varies considerably from the north to the south, the ban varies across counties. In the northernmost counties, which encompass approximately 10 percent of the population and 35 percent of the landmass, studded tyres are permitted from the 16th of October through the 30th of April every year. For the rest of the country, the ban ends every year from the 1st of November and is reinstated the first Monday after Easter Monday. Since Easter falls on the first Sunday after the first full moon following the spring equinox, the actual date of the ban implementation varies greatly from year to year. For example, in 2008, the last date studded tyres use was permitted was March 30th, whereas May 1st was the corresponding date in 2011. An overview of all ban start and end days are presented in Table 1.

Driving with studded tyres after the ban start is fined with 1,000 NOK (106 USD), which is issued by the authorities. The date when the ban is lifted are merely days when the use of studded tyres is allowed and do not represent a period where use is mandatory. A concern is therefore that the end of the ban is not as binding as the beginning of it. Drivers will not be fined for a lack of studded tyres and can wait until the driving conditions demand studs. In that respect, the use of studded tyres around the ban end date is endogenous to weather conditions, and thus does not serve as a indicator for studded tyre use. With this in mind, I focus my analysis on the days around the Easter dependent start of the ban, and not the end of the ban.

A concern with employing the ban start date as the assignment variable is that, if conditions appear dry, car owners may remove the studded tyres and switch to summer tyres before the ban starts. However, there are several examples of sudden temperature drops and heavy snowfalls in both late April and May are not uncommon anywhere in Norway.[2] Therefore, it is not obvious why a driver would

[1] This data can be found at https://www.vegvesen.no/fag/fokusomrader/klima-miljo-ogomgivelser/luftforurensning/luftkvalitet/piggdekktellinger/.

[2] According to meteorologist Kristian Gislefoss, May is a month that has historically experienced both snow and 30-degree Celsius days, even from one year to the next (Ertesvåg, 2018).

Table 1
Studded tyre ban start and end between 2008 and 2019.

Northern Norway:	**Ban end:**	**Ban start:**
	October 16th	April 30th
Rest of Norway:	**Ban end:**	**Ban start:**[a]
	November 1st	March 30th, April 19th, April 11th, May 1st, April 15th, April 7th, April 21st, April 12th, April 3rd, April 23rd April 8th, April 28th

[a] The dates are in chronological order, where March 30th was the last day studded tyres was allowed in 2008, April 19th corresponds to the last day before ban start date in 2009 and so on.

risk his or her safety by switching earlier than necessary, especially since there are no apparent individual disadvantages to driving with studs. In addition, the use of tyre hotels has become increasingly popular, where auto repair shops both change and store your tyres until the year. This implies reduced flexibility in the timing of tyre switching. Nonetheless, if people were to change tyres before the ban starts, it would simply mean that the estimates found in the analysis represent a lower bound on the true effect of studded tyres on traffic accidents and pollution.

4. Data

The data used in this paper come from several sources. The accidents data is collected from the Norwegian Public Roads Administration and contain information on all accidents reported to the police between 2008 and 2019. This data offers information on the date and time of accident, severity of accident, and accident location. Note that the accident numbers are only accidents reported to the police and may be an under-representation of the actual number of accidents. On the other hand, the accidents reported here are likely to be of a more serious manner. Thus, they represent an important segment of accidents with respect to societal costs and may be of greater policy interest.

I concentrate on ten cities in Norway.[3] The disaggregated city data allow me to study local outcomes, and most importantly, local air pollution, which is only available for the biggest cities. Moreover, it also allows for the control for weather conditions that are likely to impact both traffic accidents and pollution. This, in turn, allows for a number of extended tests of robustness and heterogeneous effects.

According to the Norwegian Institute of Public Health (2013), the size of the particulate matter is of significance for the diffusion of the pollution. Because of its size, PM_{10} spends less time in the air and spreads less than, for example, $PM_{2.5}$ particles. This implies that the measured level of PM_{10} originates from local emissions, which is an important assumption for the identification strategy of this paper. Thus, I collect data from the national service Air Quality in Norway on PM_{10} pollution for ten cities in Norway, measured hourly from fixed-location monitoring stations. I also collect data on nitrogen-dioxide (NO_2), a particular pollutant that is strongly associated with car traffic but not with studded tyre use. Consequently, regressions on NO_2 will serve as an important placebo test, indicating for example whether a behavioural change in car use occurs following the studded tyre ban.

When estimating the accidents and pollution effects in cities, I include weather variables on precipitation, temperature and wind speed drawn from the Norwegian Meteorological Institute. Finally, all regressions include population-level data attained from Statistics Norway. Table 2 displays summary statistics on accidents, population, and pollution levels one week before and after the ban in the years between 2008 and 2019. Temperature, precipitation, and wind speed statistics are also displayed, as these variables are known to influence pollution level metering and the number of accidents. In the sample period from 2008 to 2019 there is a total of 680 accidents over the two-week period on the city level. The average number of daily police-reported accidents is 0.35 in each city before the ban starts, and this number increases after the ban starts. However, the difference in means is not statistically significant. Generally, the only two variables that are significantly different before and after the ban, are the decrease in particulate matter pollution and the increase in temperature.

5. Empirical approach

To estimate the causal effect of studded tyres on traffic accident and pollution, I exploit the date of the studded tyres ban start. The ban date, that can vary up to a month from one year to another due to its dependence on Easter, serves as a cut-off that causes a drop in the studded tyre use the days following the ban. Assuming that the characteristics of drivers and driving patterns, cars and roads are comparable the days around the ban start, I can assess the effect of studded tyres on traffic accidents and pollution levels. The main equation of interest is a flexible model estimated using a type of regression discontinuity in time design (RDiT), represented by the following equation:

$$y_{it} = \delta Ban_{it} + f(DaysSinceBan_{it}) + DOW_t\alpha + \beta_1 H_t + \beta_2 p_{it} + W_{it}\gamma + \lambda_t + u_{it} \tag{1}$$

[3] The cities included are Bergen, Drammen, Fredrikstad, Kristiansand, Lillehammer, Oslo, Stavanger, Tromsø, Trondheim and Ålesund.

Table 2
The mean and standard deviation (in parentheses) of each variable one week before and after the yearly studded tyre ban (2008–2019).

Daily city data (N = 10*)		
Variable	Before	After
Accidents	0.35 (0.78)	0.40 (0.81)
Population (/1000)	165.9 (168.8)	165.9 (168.9)
PM_{10}	31.46 (21.28)	28.3 (21.1)
NO_2	32.39 (16.96)	31.62 (15.67)
Temperature (°C)	5.74 (4.18)	6.12 (3.31)
Precipitation (mm)	1.85 (3.96)	1.69 (3.93)
Wind speed (m/s)	3.63 (2.03)	3.7 (1.91)

Note: Cities include Bergen, Drammen, Fredrikstad, Kristiansand, Lillehammer, Oslo, Stavanger, Tromsø, Trondheim and Ålesund. PM_{10}, NO_2, temperature and wind are 24-h averages. Precipitation is the 24-h total. *: NO_2 levels are not available for Ålesund.

where y_{it} is the logarithm of the number of accidents or the pollution level in local authority i on day t, Ban is a treatment indicator equal to 1 on the days the ban is in effect in county i in year t, and zero otherwise, and $f\,(DaysSinceBan)$ is a flexible function that includes the running variable indicating the number of days since the ban was reinstated. For example, the variable $f\,(DaysSinceBan)$ takes the values of -5 and 5; five days before and after the ban is reinstated, respectively. To examine the robustness of the main result, this variable will be estimated both as a linear and nonlinear function.[4] Furthermore, DOW_t is a vector of dummies indicating the day of the week, and H_t is a dummy indicating public holidays. The inclusion of these controls is crucial as traffic flows vary greatly between workdays and non-workdays. The variable p_{it} is the natural logarithm of the population in location i in year t. W_{it} is a vector of weather dummies, made of weather quartiles for precipitation, temperature and wind speed, respectively. For example, if a city one day experiences little or no rain corresponding to the first quartile, a dummy variable R_{1it} is equal to one.[5] All models also include year dummies, represented by the coefficient λ_t.

The regression discontinuity in time is frequently used in environmental economics and differs somewhat from the traditional regression discontinuity design. The most prominent difference is that in the RDiT context, time is the running variable and treatment begins at a particular threshold in time. Hausman and Rapson (2018) discuss two main challenges related to the RDiT design which is important to address in this paper. First, as the threshold is one event in time, observations that are farther away from the threshold are typically included to increase power. Consequently, this translates to including observations that are less comparable in the analysis. A second challenge is related to the issue of serial correlation. For example, weather conditions or local air pollution from previous days may influence local air pollution on a given day. This dynamic effect can potentially create biased estimates if it is not accounted for.

This study differs from a standard regression discontinuity in time because the policy utilised is a recurring event, as opposed to a one-time policy change. It is therefore more precisely described as a stacked or multiple RDiT analysis. This is a crucial difference that leads to an alternative analysis set up, which also relaxes some of the usual challenges related to RDiTs. Compared to other studies examining the effect of pollution-restricting policies using a RDiT design, such as Davis (2008) and Viard and Fu (2015), the estimation window in this paper (one week before and after the ban) is quite narrow. There are two main reasons for this narrow estimation window. First, the multiple events set up in this analysis increases the number of observations close to the cut-off. This in turn reduces the need to extend the estimation window to increase power. Moreover, although the studded tyre rule forces the ban *date* to vary from year to year, the ban date always happens one week after Easter, a period comprised of several public holidays. Expanding the analysis to encompass the two or three weeks before the ban would not constitute a valid comparison group for the two or three weeks after the ban.

Although a potential consequence of exclusively using one week before and after the ban is lower precision, it is also likely to reduce the risk of bias due to confounding factors (Lee and Lemieux, 2010). It also reduces the dependence of observations that are potentially less comparable. This is especially important as for example weather and daylight conditions can change greatly across weeks.

Another advantage of the irregular recurrence of the studded tyre ban is that it allows for a panel structure of the data. While time dependency might exist from one day to another within a city in a year, it is not likely that there is serial correlation between cities, or from one year to another within a city. In the analysis, I control for year fixed effects, which greatly reduces the challenge related to serial correlation raised by Hausman and Rapson (2018).

The parameter of interest is δ, which captures the average difference in accidents and pollution when studded tyres are allowed and when studded tyres are banned. The identifying assumption is that observing the number of accidents and the pollution levels just before the ban provides a valid measurement of the average number of accidents and the average pollution levels that would have been if the ban had not been reinstated. More specifically, this requires that no other observable or unobservable factors that influence

[4] The spesific form of $f(DaysSinceBan)$ depends on the polynomial order with which I model the regression. For example, when modelling a linear model, the function can be written as $\alpha_0 + \beta DaysSinceBan$, whereas when including a second-order polynomial, the function becomes $\alpha_0 + \beta_1 DaysSinceBan + \beta_2 DaysSinceBan^2$. See Angrist and Pischke (2009) for a more detailed explanation.

[5] All regressions have also been estimated where weather variables enter into the model as continuous variables of the first and second degree polynomial, with no change in results in the variable of interest.

accidents or pollution jump at the cut-off point. In addition, as the accident data do not include information on whether the involved cars were using studded tyres or not, it is crucial for identification that the only change around the cut-off is drivers switching from studded to summer tyres. In discussing the results, I recognise this and other potential threats to identification and seek to address these. Checks for robustness in the analysis include varying the control variables and the polynomials, changing the bandwidth, analysing the covariates and performing placebo tests, in line with Angrist and Pischke (2009), Cattaneo et al. (2020) and Lee and Lemieux (2010).

An alternative estimation method that could have been applied in this setting is the event study. The event study method has many similarities with the regression discontinuity in time, the goal being to assess the impact of a certain event on a given outcome over time. The method is mostly used within finance, and one reason for that is that there is a richness of data and multiple observations over time over for example one firm's stock returns. Using this data, the researcher is supposed to calculate the normal returns in an estimation window using multiple observations prior to the event, and then deduct these normal returns from actual returns to find abnormal returns that can be attributed to the event. Using a sufficient number of observations in the estimation window is crucial to have a good understanding of what the normal returns are.

The equivalent in this setting is to find the normal number of accidents and pollution level before the ban is reinstated. The challenge is, however, that there is only one week before the ban start that is normal, as Easter is two weeks before ban start and does not represent a normal week. An alternative is to use the accident and pollution levels before Easter start in the estimation window. However, this translates to using observations between one and two months before the ban start date, which means including observations that are less comparable with the observations right before and after the ban date. Since driving, weather and light conditions changes a lot during the spring, there is a large chance that the observations in the estimation window would not be a good basis of normality for the outcomes in a counterfactual case where there was no studded tyre ban. Thus, the regression discontinuity in time analysis is better suited for this analysis.

6. Main results and robustness

6.1. Traffic accidents

In this section, I present the results for the relationship between the studded tyre ban and traffic accidents estimated according to Equation (1). I start the analysis with a graphical illustration. Fig. 1 shows the average number of accidents in one-day bins, where the solid line represents a fitted value from a quadratic polynomial. I control for the day of the week and holiday and allow for an intercept shift at the cut-off point that represents the ban start. Visual inspection shows that there is a small jump at the ban start, but in general, the graphical analysis suggests no evidence of a clear increase in accidents following the ban. In what follows I examine the data numerically in a more structured manner by multiple controls and examine the robustness of the results by applying different bandwidths.

In Table 3, and in all estimations henceforth, I control for population levels, holidays, day of the week and year. I start off by presenting the results from a fixed-effects regression as a benchmark for assessing potential biases. The result is presented in column (1), where the effect of the ban is expressed as a dummy equal to one if the accident happened when the ban was in force. The estimated coefficient suggests that accidents increase by 21 percent the week following the ban. Nevertheless, the coefficient is not statistically significant.

I move on to estimate the relationship using the regression discontinuity method. Column (2) reports the results when the model is estimated with a linear polynomial. The point estimate increases to 77 percent, suggesting a negative bias in the fixed-effects results. Although 77 percent may appear to be a large effect, the average daily number of accidents reported to the police is 0.37 accidents, meaning that the observed effect translates to an increase of 0.29 accidents per day per city. Nevertheless, the estimate is not statistically significant.[6]

A concern using the regression discontinuity design may be that $f(DaysSinceBan_{it})$ is incorrectly specified, for example with respect to the degree of the polynomial. Although the use of high-order polynomials in the regression discontinuity setup is common in the literature, I prefer a linear or quadratic polynomial of the running variable, following Gelman and Imbens (2019) and Cattaneo et al. (2020). Therefore, I include a second order polynomial to test whether the estimate is sensitive to different specifications of the control function. The result is shown in column (3). The effect of the ban changes neither in direction nor in size. However, the coefficient is now statistically significant at the ten percent level, which suggest that a second order polynomial is a better fit.

As explained in Section 4, one test for whether the regression discontinuity setup is valid entails adding controls to ensure that the estimate does not change considerably, and that only the precision increases. To test this, I add weather controls to the model. The inclusion of weather controls in column (4) increases precision, so that the estimate is now statistically significant at the five percent level. At the same time, the coefficient size changes negligibly, which is a reassuring sign of the robustness of the setup.

The choice of bandwidth is a crucial step related to the setup of a regressing discontinuity design. The standard procedure for choosing a bandwidth is to follow the mean squared error criterion (Cattaneo et al., 2020), which in this analysis suggests an optimal bandwidth of three days. A common test of result sensitivity is to vary the bandwidth. In general, decreasing the bandwidth tends to decrease the possibility of specification error and decrease precision, whereas increasing the bandwidth has the opposite effect. In this

[6] All regressions have also been estimated as level models with no change in results compared to estimating on logarithm form. I prefer the logarithmic presentation to simplify the interpretation of the coefficients.

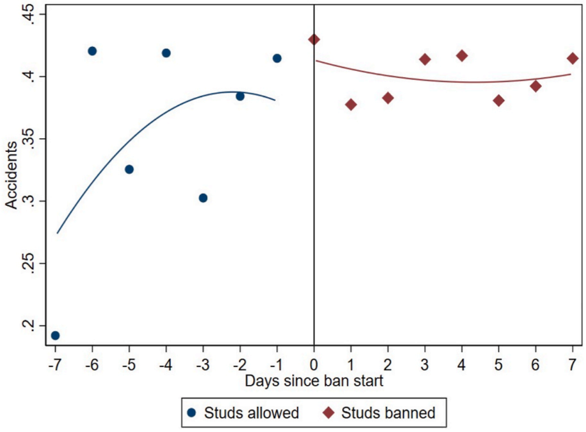

Fig. 1. Regression discontinuity plot of daily traffic accidents in one-day bins.

Table 3
The effect of the studded tyre ban on traffic accidents in Norwegian cities.

Dep.var.:	FE	RD			
ln (accidents)	(1)	(2)	(3)	(4)	(5)
Ban effect	0.213	0.774	0.766*	0.806**	0.64
	(0.134)	(0.552)	(0.392)	(0.392)	(0.486)
Polynomial		First	Second	Second	Second
Weather controls	No	No	No	Yes	Yes
Bandwidth		3	3	3	7
Observations	1,800	840	840	840	1761
Cities	10	10	10	10	10

Note: The dependent variable is the logarithm of the number of daily traffic accidents. All regressions are estimated controlling for population, day of the week, and holidays and include year fixed effects. Heteroscedasticity-robust standard errors in parentheses. ***, **, * indicate statistical significance at 1%, 5% and 10%, respectively.

setting, there is an additional reason for deviating from the optimal bandwidth. Three days before and after the ban in this paper means that we are comparing the last three days before the ban, which is always Friday through Sunday, with the first three days of the week, which is Monday through Wednesday. It is probable that the periods before and after the ban, even after including day of week dummies, are not comparable periods, mainly due to differences in driving patterns and traffic levels between weekdays and weekends. Extending the bandwidth to seven days before and after the ban increases the homogeneity in the sample. Thus, regressions with seven days bandwidths are the preferred models.

In column (5), I estimate the model increasing the bandwidth from three to seven. Increasing the bandwidth changes the result by reducing the effect size. Moreover, the point estimate is no longer statistically significant. Thus, the findings are somewhat sensitive to alterations in the bandwidth, both in terms of magnitude and precision.

To summarise, I have estimated the effect of the studded tyre ban on traffic accidents in ten Norwegian cities.[7] While some of the results suggest that there is a statistically significant safety effect of studded tyres in cities, these results are sensitive to the standard tests of robustness. This raises uncertainty regarding whether there is a safety effect of studded tyres, or whether the analysis is able to capture the safety effect of studded tyres. It can also imply that the studded tyres ban is on average reinstated too late, when the road conditions are not icy enough for the studs to be properly utilised.

A final reason for the null result on accidents is related to the data. One feature of the data is that it exclusively contains police-reported accidents. It may be that the level of reported accidents is simply too low and thus, there is not sufficient variation in the data. Another possibility is that the type of accident that is most affected by the ban is of a less serious manner, and these are prone to being under-reported in police-reported data. To explore whether this might be the case, I re-estimated the main model using different data, namely accidents reported to insurance companies. The results (not included in the paper) again showed an effect of the studded

[7] In unreported results, I also estimate the effect of studded tyres on traffic accidents using an aggregated data on all 18 Norwegian counties. The coefficients from the county and the city sample are similar both in terms of magnitude and precision. In summary, there seems to be no statistically significant effect on traffic accidents following the studded tyre ban on the county level. I have also performed a jackknife re-sampling analysis, where I exclude 1 year at a time from the regression. This is performed to examine whether some years with large or small accident numbers are driving the main results. This approach showed no signs of outliers influencing the main results.

tyre ban that did not pass the standard tests of robustness. Therefore, studded tyres do not seem to have a heterogeneous and larger safety effect on less serious accidents compared to more serious police-reported accidents.

6.2. Particulate matter pollution

In this subsection, I present the results from estimating the relationship between the studded tyre ban and particulate matter pollution. As in the previous section, I start by illustrating the regression discontinuity for the pollution data around ban start, controlling for holidays and day of week, illustrated in Fig. 2. Compared to the accident levels graph, pollution levels appear to be more volatile than the number of accidents, with a peak of 40 μg/m^3 five days before ban start and a low of 20 μg/m^3 the second day of the ban. On average, there is a weak sign that pollution levels are lower following the ban. Nevertheless, there is no clear effect and no large drop in pollution following the ban.

I go on to analyse the relationship between the ban and pollution level statistically, starting with a fixed-effects model. The result is presented in column (1) in Table 4. The coefficient for the ban is negative and suggests a decrease of 13 percent in PM_{10} pollution following the ban. Moving on to estimating the effect using regression discontinuity analysis, the coefficient increases in absolute value to 42 percent. In columns (3) and (4), I estimate the relationship including a second-order polynomial and weather controls, respectively. The model in column (4) suggests that pollution decreases by 18 percent as a consequence of the ban, an effect that is statistically significant at the five percent level.

Once again, I test the robustness of the results by estimating the model with seven-day bandwidths. The estimates, which are now based on more comparable periods before and after the ban, are no longer statistically significantly different from zero. Moreover, the sign of the point estimate changes from negative to positive, which is an additional a sign that the results are not robust. Consequently, while the regressions using the mathematically optimal bandwidth indicate a reduction in pollution levels following the ban, the results from the preferred models refute this conclusion. In summary, there seems to be no effect on neither the number of accidents nor the particulate matter pollution levels following the ban.

6.3. Robustness

There are some threats related to the underlying identification strategy. For example, Easter may confound the estimates of both air pollution and the number of accidents. In the setup of the main analysis, the first day in the estimation window is the first. Monday after Easter, which is always a public holiday. As many Norwegians spend the Easter holiday with their families or in their cabins, it is likely that the traffic volumes are different the last day of Easter compared to a normal week. For example, traffic volumes, and thus accident and pollution levels, are potentially larger on Easter Monday compared to any other Monday. If this is the case, then the period before the ban may not be sufficiently comparable to the period after the ban even after controlling for holidays, and the main condition for a discontinuity analysis is violated. The consequence for the main result is that the potential change in traffic levels due to the holiday masks the true effect of the ban on accidents or pollution level.

To test whether this is the case, I set a placebo ban start date that mimics the conditions around the actual ban date. More precisely, I set a ban date that is one week after New Year's Day, which is a national holiday that is likely to have similar traffic volumes as Easter Monday. If there is a statistically significant effect of the ban date, it implies that one day of abnormal traffic levels, without a change in the types of tyres used, influences the main results sufficiently and potentially bias the true effect of the ban in the main estimates.

The result of the first placebo test is presented in columns (1) and (2) in Table 5. For this and the rest of the regressions in this table, I include a full set of controls and a second order polynomial. The effect of this placebo ban date is negative on both traffic accidents and pollution, albeit the coefficients are close to zero and not statistically significant. This relaxes the concern that the effect of the ban is masked by different traffic volumes on Easter Monday, and implies that holiday effects are sufficiently controlled for by including holiday dummies.

A second concern is more generally related to potential confounders or changes in driving behaviour related to the ban date. Even though the ban date can vary by up to a month from one year to another, it always occurs during springtime. In this period, the preferred mode of transport might shift from cars to public transport, biking or walking. This will reduce traffic flows and reduce both the probability of accidents and pollution levels.

I approach this concern by performing an additional placebo test, where I replace the dependent variable with nitrogen-dioxide from the same monitoring stations that collect the particulate matter data. This pollutant is formed from car emissions, and its levels are thus independent of the asphalt wear and tear from and produced by using studded tyres. If we do observe a change in this pollutant, it suggests that there are some other omitted variables changing concurrently with the ban, such as the choice of transportation mode, which would threaten the validity of the results from the main model.

The result is presented in column (2) in Table 5. The effect of the ban on nitrogen dioxide is small in magnitude and not statistically significantly different from zero. Overall, the results of these two placebo tests increase the confidence of the regression discontinuity design applied in the main estimates.

An additional assumption for a valid regression discontinuity analysis is that no covariate should jump around the cut-off of the assignment variable (Lee and Lemieux, 2010). To test whether the setup in the main estimates complies with this particular assumption, I replace the main dependent variable PM_{10} with the covariates, iteratively treating each control variable as an outcome. The results of this exercise are presented in columns (3) through (5) of Table 5. Reassuringly, there is no evidence of a sharp discontinuity in precipitation, temperature, or wind at the cut-off date. The exogenous nature of the ban rule and the potentially large variation in the ban date relieve concerns that any of the control variables seriously bias the estimates in the main results.

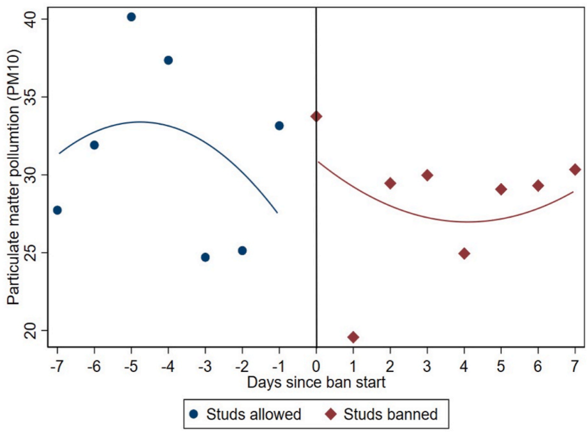

Fig. 2. Regression discontinuity plot of daily particulate matter pollution levels (PM_{10}) in one-day bins.

Table 4
The effect of the studded tyre ban on PM_{10} levels in Norwegian cities.

Dep.var.:	FE	RD			
ln (PM_{10})	(1)	(2)	(3)	(4)	(5)
Ban effect	−0.128***	−0.422***	−0.354***	−0.182**	0.0722
	(0.031)	(0.069)	(0.083)	(0.073)	(0.082)
Polynomial		First	Second	Second	Second
Weather controls	No	No	No	Yes	Yes
		3	3	3	7
Bandwidth					
Observations	1,749	818	818	818	1710
Cities	10	10	10	10	10

Note: The dependent variable is the logarithm of daily 24-h average PM_{10} pollution. All regressions are estimated controlling for population, day of the week, and holidays and include year fixed effects. Heteroscedasticity-robust standard errors in parentheses. ***, **, * indicate statistical significance at 1%, 5% and 10%, respectively.

Table 5
Robustness tests: Different ban date, NO_2 and covariate analysis.

	Placebo date		Alt. dep.	RD on covariates		
	(1)	(2)	(3)	(4)	(5)	(6)
	Acc.	PM_{10}	NO_2	Prec.	Temp.	Wind
Ban effect	−0.072	−0.025	0.012	−0.406	0.014	0.040
	(0.082)	(0.481)	(0.076)	(0.628)	(0.171)	(0.089)
Observations	1,710	1,573	1,321	1,785	1,723	1,776
Cities	10	10	9	10	10	10

Note: All the dependent variables are expressed as natural logarithms and with a second order polynomial and a bandwidth of seven. The different number of observations across the columns is due to occasional pollution metering stations being out of service. Heteroscedasticity-robust standard errors in parentheses. ***, **, * indicate statistical significance at 1%, 5% and 10%, respectively.

There is one standing concern related to the validity of the main results, which is challenging to take into account in the analysis. While the placebo tests to some extent supports the identification strategy and relaxes the concern that for example changes of transportation modes coincides with the ban date, there is a possibility that driver behaviour changes according to with which tyres the car is equipped with. Given somewhat icy roads, drivers might feel more confident and drive less carefully before the ban date while driving with studs, compared with after the ban date when they have switched to summer tyres. This aspect will reduce the potential safety effect of studded tyres.

Another threat is that the composition of drivers might change around the cut off. This effect might bias the estimates in both directions. Some drivers might ask other family members to drive their car if conditions are challenging after the ban start. Alternatively, some drivers might shy from driving in the period that studded tyres are allowed due to potential challenging driving conditions.

While these possible confounders should not affect the pollution outcomes, it does challenge the results related to traffic accidents. It is not possible to control or test for either changes in driver behaviour or composition. Thus, the results of studded tyres on traffic accidents should in general be interpreted with caution. In summary, the ban on studded tyres appears to have no effect on neither accident nor pollution levels.

7. Heterogeneous effects

There are several potential explanations for why the results on traffic accidents are weak. It mainly implies that studded tyres have a weak safety effect. However, although day-to-day weather conditions are controlled for, it might be that the overall weather conditions before ban start affects the timing of drivers switching back to summer tyres. For example, if the average driving condition in the period before the ban is such that studded tyres are no longer advantageous, for example too high temperatures and bare roads, drivers might switch back to summer tyres before the ban starts. Conversely, if the temperature is low and roads are icy, it might lead to drivers waiting as long as possible before replacing their studded tyres. The latter example will leads to the ban date being more binding, and the safety effect of studded tyres are potentially exploited to a larger degree.

Indeed, there are no exact data on when drivers change tyres. One point that reduces the probability of the studded tyre share decreasing steadily two or three weeks before the ban date is that the Easter holidays are always one week before the ban. Traditionally, Easter is a period where many Norwegians drive across the country to visit relatives or go to their cabins through mountain passages.[8] If driving conditions are somewhat challenging in this period, drivers will be fined if caught using summer tyres. Thus, is it likely that people wait at least until the last week before ban start before switching their tyres. It is possible that people might switch to summer tyres the week following Easter, but before the ban date, if the driving conditions allows it. The consequence of this is that the estimates found in the main results are lower bound, as the drop in studded tyre share on the ban date is potentially lower than what it could have been.

In an effort to examine whether the ban start date is more binding when driving conditions are more challenging, and consequently, whether the safety effect of studded tyres are stronger, I run theregressions on a sub-sample consisting of the coldest half of the years in the sample. The average temperatures around the ban period range from 2.45 to 9.41 °C, and the coldest years are 2008, 2010, 2012, 2013, 2017 and 2018. Although low temperatures do not necessarily mean icy roads, they are an adequate proxy for the purpose of this test. An alternative approach is to run the regression on early Easter years because the likelihood of challenging driving conditions are expected to be lower earlier in the year. However, there are several examples of cold and relatively late Easters. An example of this is the year 2017, which is the fourth latest ban start and the third coldest winter. Thus, the timing of Easter is a poor proxy for cold winters.

Panel A in Table 6 displays the results from the regression discontinuity analysis on the cold winters.[9] The first column shows the results when estimating the regression with a linear polynomial. With an average of 0.4 accidents, the coefficient implies an increase of 0.64 accidents per day per city, which is the same size effect as in the main estimates. Moreover, the coefficient is statistically significant at the ten percent level. I move on to estimate the relationship including a second-order polynomial. The effect is now reduced to one-third of the first column and is no longer statistically significant. In summary, although there is some weak evidence of a heterogeneous effect where accidents increase following ban start during cold winters, the effect does not pass the standard tests of robustness.

This result has two possible interpretations. Once again, the evidence may point to that there is no safety effect of studded tyres. This is true even in the colder years where we assume that the ban date is more binding, so that the drop in the studded tyre share is larger at the ban date start compared to warmer years. Alternatively, it might be that driving conditions on average are too bare around the ban start date, so that the advantage of studded tyres is never fully exploited. Both interpretations are likely to have an effect on pollution levels during cold years.

If roads on average are icier during cold years, then, all else equal, the ban effect on pollution should be decreased compared to the main results. This is because there is less direct contact between the studs and the asphalt, which is the main contributing factor of particulate matter pollution. On the other hand, if the ban date is more binding during colder years, pollution is expected to be at a higher level before the ban because studded tyres themselves contribute to increased PM10 levels, and consequently, the drop in pollution levels should be larger following the ban compared to the main results. A third effect, which may complicate the interpretation of the pollution results further, is that during cold winter days when the air is dry, there is little air change. This in turn leads to an increased concentration of particulate matter pollution.

To examine whether there is a heterogeneous effect of the ban on particulate matter pollution, I run the analysis for the same subsample of cold years as for the accident data. The results are presented in Panel B in Table 6, where the pollution level is regressed with a first- and second-degree polynomial. The estimate in column (1) again suggests that there is no change in pollution levels following the studded tyre ban during cold years. The estimate in column (2) is negative and suggest a nine percent decrease in pollution, an effect stronger than the effect observed in the main results. Nevertheless, this effect is once again not statistically significantly different from zero.

In summary, neither accident levels nor pollution levels exhibits any evidence of heterogeneous effects of the studded tyre ban during colder years. The result is especially surprising for studded tyres, as studded tyres come into its own in icy conditions.

[8] A fun fact is that this phenomenon has its own name, “påskeutfart”, which is loosely translated to the mass exit of Easter.

[9] Studded tyres are prone to have a larger breaking distance in warmer temperatures. In unreported results, I estimate the number of accidents in warmer years to see if there is a symmetric effect of weather. The estimates are however close to zero and not statistically significant.

Table 6
The effect of the studded tyre ban during cold winters in Norwegian cities.

Panel A:	Traffic accidents	
	(1)	(2)
Ban effect	0.644*	0.235
	(0.355)	(0.587)
Polynomial	First	Second
Bandwidth	7	7
Observations	872	872
Cities	10	10
Panel B:	PM_{10}	
	(1)	(2)
Ban effect	0.022	−0.093
	(0.077)	(0.125)
Polynomial	First	Second
Bandwidth	7	7
Observations	823	823
Cities	10	10

Note: The dependent variable is the logarithm of accidents or pollution. All regressions are estimated controlling for population, day of the week, and holidays and include year fixed effects. Heteroskedasticity robust standard errors in parentheses. ***, **, * indicate statistical significance at 1%, 5% and 10%, respectively.

8. Conclusion

This paper provides empirical evidence on the traffic safety and pollution effects of a specific pollution-restricting policy, namely the periodic studded tyre ban in Norway. The ban date, which due to its dependence on Easter, can vary up to a month from one year to another. This serves as a cut-off that causes a drop in the studded tyre use the days following the ban. I utilise a type of regression discontinuity in time design to identify the extent to which studded tyres decrease traffic accidents and increase particulate matter pollution levels. Over a period of 11 years, I find no safety effect nor an increase in pollution of studded tyres. This result holds through multiple tests of robustness and after exploring possible heterogeneous effects of studded tyres during cold winter.

Failing to find a safety effect of studded tyres have at least three possible explanations. First, driver behaviour and composition may change according to which types of tyres are in use, which is not observed or controlled for in the analysis. If this is the case, the results on traffic accident can be biased in a way that produces zero-effect results. Second, the driving conditions around the ban date is on average too bare and not icy, so that the advantages of studded tyres are not fully exploited around ban start.Third, improvements in car safety technology and increases in general road safety and management has potentially made the safety effect of studded tyres disappear. If the latter is true, it raises a question of the net societal costs of studded tyres.

The result in this paper implies that studded tyres do not contribute to increased particulate matter pollution. However, studded tyres have other costs such as increased wear and tear on roads which increases road maintenance costs. If there is indeed no safety effect of studded tyres given modern cars and general road safety, this implies that studded tyres have a net costs for society. This raises the question of whether policymakers should consider restricting the use of studded tyres entirely or increase the yearly ban period, in favour of applying other measures to increase traffic safety during winter.

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