Silencing the Rails: A Study of the Noise-Safety Trade-off in Railway Quiet Zones

By Emtiaz Hossain Hritan *

I examine quiet zones—established to alleviate noise pollution at railroad-highway crossings while ensuring public safety—in this study as a natural experiment to assess their impact on accident frequency in the United States. Utilizing highway-rail crossing accident data from the Federal Railroad Administration between 1994 and 2023 and employing various estimators suitable for difference-in-differences designs with staggered treatment, I find that the establishment of quiet zones is linked to an increased number of accidents. Although no significant effect is observed on the cost of damaged vehicles, the establishment of quiet zones increases fatalities and injuries. This study underscores policy implications, probing the safety standards and cost-effectiveness of quiet zones, and highlights the potential of emerging vehicle safety technology to mitigate grade crossing accidents.

I. Introduction

Train horns must operate within a set volume range, ranging from a minimum of 96 decibels to a maximum of 110 decibels. The US Environmental Protection Agency and the World Health Organization consider noises above 70 decibels to be noise pollution (Moroe and Mabaso, 2022). This environmental concern extends beyond mere inconvenience, as studies indicate that excessive noise can elevate stress, blood pressure (Babisch, 2000), and contribute to hearing impairment (McBride, 2004). Notably, exposure to noise from sources such as airports (Haines, 2002) and trains (Bronzaft and McCarthy, 1975) has been linked to learning difficulties in children (Cushing-Daniels and Murray, 2005). Furthermore, the health impact of railway noise is particularly pronounced in sleep quality Aasvang et al. (2011), with railway noise exhibiting a stronger influence on physiological parameters during sleep compared to road traffic noise (Griefahn, Marks and Robens, 2006; Hofman et al., 1993; Marks, Griefahn and Basner, 2008). The Train Horn Rule, established in response to a surge in collisions at highway-grade crossings in the late 1980s, aimed to address safety concerns, particularly those associated with nighttime whistle bans. Congressional legislation in 1994 led to the Federal Railroad Administration (FRA) regulating train horns at all public highway-railway crossings. Subsequently, in 2005, a final rule emerged, eliminating the mandatory use of train horns and introducing the concept of quiet zones.

I exploit the establishment of quiet zones in the U.S. since 2005 as a quasi-natural experiment to explore their impact on the frequency of accidents at railway grade crossings within the period from 1995 to 2023. A quiet zone refers to a stretch of railway that is at least half a mile long, encompassing one or more consecutive public highway-rail grade crossings where locomotive horns are not routinely sounded. Leveraging highway-rail grade crossing accident data extracted from the Federal Railroad Administration's Office of Railroad Safety spanning from 1975 to 2023, I employ a two-way fixed effect difference-in-differences estimation (TWFE DD) as the baseline estimation. To account for heterogeneous treatment effects, my preferred difference-in-difference model is Wooldridge (2021)'s (2021)

* Hritan: School of Economics, Georgia Institute of Technology, Old C.E. Building 221 Bobby Dodd Way Atlanta, GA 30332, hritan@gatech.edu.

extended two-way Mundlak regression, chosen for its adaptability to count outcome variables. Ensuring robustness and sensitivity checks, I also incorporate estimation methods proposed by Borusyak, Jaravel and Spiess (2021) and Callaway and Sant'Anna (2021) to assess average treatment effects in settings with staggered treatment timing and potentially heterogenous treatment effects. The research design compares accidents before and after the establishment of quiet zones at crossings with those at crossings that had not yet been deemed quiet zones or would never be deemed such. Employing the conventional two-way fixed effect difference-in-differences (TWFE DID) model with Poisson Pseudo Maximum Likelihood estimation method, I find that establishment of quiet zone leads to 1.27 times higher yearly accident rate for railway crossings within quiet zones. Additionally, utilizing estimators developed by Borusyak, Jaravel and Spiess (2021), Callaway and Sant'Anna (2021), and Wooldridge (2021), I observe a consistent pattern across alternative estimates. In essence, the establishment of quiet zones is linked to an increased number of accidents, with alternative estimates exhibiting a similar direction, albeit with smaller magnitudes compared to the baseline estimates.

To extend the investigation beyond accident frequency, I include additional outcome measures, specifically the expenses related to damaged vehicles, the count of crossing users killed, and the count of crossing users injured. While the study reveals no notable impact on the cost of damaged vehicles, it does indicate a rise in the occurrences of user fatalities and injuries linked to the establishment of quiet zones. Moreover, the comprehensive dataset on collisions at railway grade crossings, covering details such as weather conditions, visibility, time of accidents, reasons for accidents primarily attributed to user actions (predominantly motorists), and whether the accident occurred at a public or private crossing, enables a detailed investigation into the heterogeneity of treatment effects. I observe that the 'quiet zone' status increases the number of accidents at public grade crossings compared to private ones. However, I do not find any significant differences in actions of users between quiet zone and non-quiet zone crossings. There is a significant increase in accidents at crossings designated as 'quiet zone' from 6 am to midnight, while the quiet zone does not contribute to increased accidents from midnight till morning. Interestingly, I identify a higher frequency of accidents during clear and rainy weather, but not in cloudy weather. Additionally, quiet zones lead to a higher frequency of collisions both during dark and daytime.

The study closest to mine is conducted by Ngamdung and daSilva (2020), focusing on the impact of quiet zone implementation on trespass accidents along the national rail network. Trespassing on rail right-of-way (ROW) is a major contributor to rail-related fatalities in the United States, primarily involving pedestrians using railroad tracks as shortcuts. While traditional safety systems concentrate on crossings, they often neglect potential trespass issues nearby. Their research examined 333 quiet zones established between 2012 and 2018, comparing trespass casualties within these zones before and after their implementation. The findings reveal no statistically significant difference in trespass casualties before and after quiet zone establishment. However, trespass incidents at grade crossings increased by 108.7%, rising from 23 before to 48 after the quiet zones were established. In comparison, overall grade crossing incidents increased by 7.4%, from 2,064 in 2011 to 2,217 in 2019.

It is necessary to acknowledge that in this paper, I do not delve into specific driver behaviors, particularly distractions and inattention, which may contribute to the observed effects of quiet zone establishment on accident frequency. Research on the impact of driver distraction and inattention is extensive(Mulvihill et al., 2016; Lenné et al., 2011). In a study conducted by Wundersitz (2019) on 186 fatal and injury crashes in South Australia from 2014 to 2018, the analysis of crash case notes found that 31.3% of the 160 crashes exhibited evidence of driver inattention. Distraction and misprioritized attention accounted for 13.8% and 8.1% of all crashes, respectively. Notably, the majority of distraction-based crashes, constituting 64% and 77% of total accidents, were cognitive and voluntary, rather than technology-based. Surprisingly, only 2.5% of total crashes were identified as being distracted by mobile phones.

This study contributes significantly to the existing literature in several ways. Firstly, it stands out as the first exploration into the impact of quiet zone status on the frequency of accidents at railway grade crossings, moving beyond the scope of internal reports prepared and distributed by the Federal Railroad Administration (FRA). Secondly, unlike the before-and-after descriptive analysis or two-sample t-test commonly employed in FRA decision-making reports, this study utilizes newly developed difference-in-differences estimation methods. These methods, designed to accommodate heterogeneous treatment effects across crossings and over time, contribute to a reduction in bias and enhance the statistical rigor of the findings. Third, the documented increase in crashes at railway grade crossings within quiet zones provides valuable policy insights into the elevated costs associated with increased accidents, mortality, and injuries within quiet zone areas. It also sheds light on the efficacy of safety measures at these crossings, legal implications resulting from collisions, and the role of driver-assist systems in cars.

The structure of the rest of this paper is as follows: the second section provides an overview of the background and history of train horns and quiet zones in the U.S. The third section covers the data source, summary statistics, and descriptive analysis. The fourth section outlines the empirical strategy. Moving forward, the fifth section presents the empirical results, while the sixth section delves into the heterogeneous treatment effects of quiet zones. Following this, the seventh section explores the policy implications arising from the findings of this paper. The concluding remarks are presented in the final section.

II. Background

A. Train Horn Rule: History and Timeline

Since 1970s, the utilization of whistles or locomotive horns has been established in the united states as a safety precaution, employed when approaching railway crossings or in emergency scenarios. The guidelines outlined in the Federal Railroad Administration's Train Horn Rule (49 CFR 222) detail specific instructions regarding when, where, and for how long the train horn should be sounded. These instructions cover various situations, such as sounding the horn while traversing a tunnel, emitting it a maximum of one-fourth of a mile from a crossing when the train speed exceeds 60 miles per hour, and maintaining a sound level between 96 to 110 decibels—equivalent to the noise produced by a lawnmower (CSX, 2017). According to federal regulations, the locomotive train horn must last a minimum of 15 seconds and a maximum of 20 seconds, and it must be sounded when approaching any public grade crossing. Exceptions to this rule include instances where the train speed exceeds 45 miles per hour and is not within one-quarter mile of the crossing, when the train stops in close proximity to the crossing and resumes movement after the stop, or when locomotive engineers are unable to accurately estimate the train's arrival time. In practice, train horns typically follow a standardized pattern: two long horns followed by one short and another long one, continuing for the duration that the train occupies the grade crossing (FRA Office of Public Affairs, 2013).

In the last century, while various states in the U.S. had enacted laws regarding railway whistles, certain local communities were able to enforce a "whistle ban," resulting in trains operating silently during specific hours. An exemplification of this occurred in the late 1980s when the Federal Railroad Administration (FRA) observed a notable surge in nighttime vehicle-train collisions at railway crossings along the Florida East Coast Railway

(FEC). During this period, a nighttime whistle ban from 10 p.m. to 6 a.m. was implemented, accompanied by the installation of flashing lights and gates (Federal Railroad Administration, 2005). The Florida Whistle Ban Study Federal Railroad Administration (1990), conducted to assess the impact of this measure, revealed a substantial 195% increase in vehicle-train collisions during the designated ban hours. While acknowledging the limitations of the analysis, which focused solely on Florida crossings and may not meet contemporary standards for similar studies, the FRA identified the whistle ban as the primary factor contributing to the increased collisions. Consequently, Emergency Order 15 was issued in 1991, overturning the whistle ban. Zador (2003), a consequential nationwide study demonstrated a 66.8% rise in the risk of vehicle-train collisions at railway grade crossings equipped solely with flashing lights and gates but without the sounding of a whistle. In response to these findings, Congress mandated the FRA to establish federal regulations necessitating trains to sound whistles when approaching any public highway crossings. This directive also granted the FRA the authority to determine exceptions to this rule, allowing local communities to establish quiet zones without compromising safety measures.

The "Final Rule on the Use of Locomotive Horns at Highway-Rail Grade Crossings,"

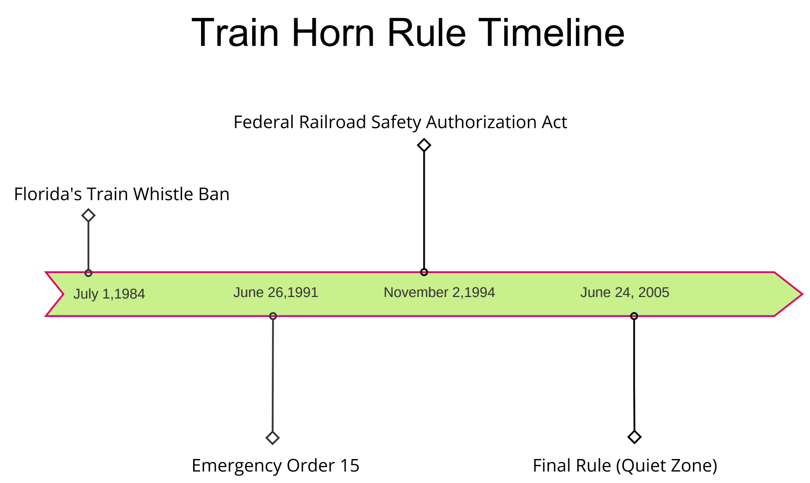

Figure 1. Accidents at Railway Crossings From 1990 to 2019

which took effect on June 24, 2005, delineated comprehensive federal regulations governing the specific circumstances and procedures for sounding train horns as trains approach public highway-rail grade crossings. Notably, this regulatory framework introduced a shift from distance-based criteria to time-based criteria for sounding the horn, concurrently imposing restrictions on the volume levels of train horns. Furthermore, the ruling established a structured process through which public agencies could designate and implement quiet zones (Federal Railroad Administration, 2005; Federal Railroad Administraon, 2013).

B. Quiet Zone

Quietzones exempt crossings from the FRA whistle mandate and require adoption of additional safety precautions. The creation of quiet zones by the FRA aims to enhance the quality of life by minimizing noise pollution and decreasing accidents at highway-rail grade crossings. For a quiet zone to be established, it must span a minimum distance of half a mile, encompass at least one public highway-rail grade crossing, and is exclusively authorized by local governments or public agencies. Furthermore, each grade crossing within a quiet zone is mandated to feature warning devices and safety measures, such as flashing lights, gates, continuous warning train detection systems, and power-outage indicators. Additional safety measures, known as Supplemental Safety Measures (SSMs), may also be required in certain quiet zones, including four-quadrant gates, roadway channelization, median barriers, one-way roadways with gate(s), and potentially the permanent closure of nearby public crossings. Locomotive engineers are not legally obligated to sound the whistle in quiet zones, except in emergency situations such as the detection of vehicles, maintenance workers, contractors, or any individuals on the railway tracks. Additionally, it is important to highlight that the implementation of quiet zone regulations does not eliminate locomotive bells, leading to the more accurate characterization of quiet zones as "reduced train horn areas" (CSX, 2017; Federal Railroad Administraon, 2013; FRA Office of Public Affairs, 2013).

Establishing a quiet zone for a community begins with reaching out to the local or regional FRA Crossing manager. While community residents interested in a quiet zone may engage with local or regional FRA officials, the formal request, initiation of the establishment process, and ultimate approval from the FRA rest solely with the local public agency. This designated agency takes charge of determining the crossings to be encompassed in the quiet zone, identifying any private highway-rail grade crossings within the proposed zone, and verifying access permissions from private entities. Collaboratively, the local public agency, FRA, and private railroad operators like CSX undertake a diagnostic review of the identified crossings. The diagnostic team typically comprises representatives from the public authority, railroad, the State agency responsible for crossing safety, and FRA grade crossing managers. The public agency then evaluates the risk associated with each grade crossing within the proposed quiet zone, quantified by the Quiet Zone Risk Index (QZRI). Determining if a crossing meets FRA requirements for a quiet zone relies on the QZRI being either less than or equal to the Risk Index with Horns (RIWH), representing the average risk for all public highway-rail crossings in the proposed quiet zone with routinely sounded whistles, or less than the National Significant Risk Threshold (NSRT), representing the average risk of a crossing with safety gates and train horns. Upon reaching this determination, a Notice of Intent (NOI) is sent to all relevant parties, including the state's Department of Transportation (DOT). Subsequently, the public agency enters into a Preliminary Engineering Agreement with the railroad operators and oversees the installation of Supplemental Safety Measures (SSMs), while the road authority takes charge of placing required signs. The process concludes with the dispatch of a Notice of Establishment (NOE) to all parties involved, formalizing the establishment of the quiet zone (CSX, 2017; Federal Railroad Administraon, 2013).

Due to the perception of quiet zones primarily as a quality-of-life concern rather than a safety enhancement, federal funding for these initiatives is constrained. Consequently, public authorities aiming to implement quiet zones typically bear the financial responsibility for installing Supplemental Safety Measures (SSMs) and Additional Safety Measures (ASMs). Funding sources for public authorities encompass a range of options, including but not limited to federal allocations, state or railroad funds, grade crossing incentive funds, and financial support from private investors (United States Government Accountability Office, 2017).

Certain local communities have a historical practice of implementing a "whistle ban," either formalized through agreements with local or state authorities or informally recognized by the railroad. At these "grandfathered" crossings where whistle bans were in effect prior to 1994, no specific safety measures were implemented to address the absence of whistle warnings. Post-2005, these communities have the option to transition their whistle bans into "pre-rule quiet zones" through documentation, granting them a grace period of 5 to 8 years to adhere to quiet zone requirements. Pre-Rule Quiet Zones, established in accordance with this regulation, may exclusively include crossings previously under Whistle

Bans in effect from October 9, 1996, to December 18, 2003 (FRA Office of Public Affairs, 2013).

An alternative available to communities aiming to mitigate train horn or whistle noise is the deployment of wayside horns. These fixed horns are strategically installed at railroad crossings to alert motorists about approaching trains. They prove more effective in noise reduction compared to train-mounted horns, emitting a focused sound pattern directed toward oncoming vehicular traffic and thereby minimizing the overall exposure area. Notably, the volume of these wayside horns is determined by the city rather than the railway authority. Additionally, the duration of these horns is automated, eliminating the possibility of excessive noise. The implementation of wayside horns involves fewer steps, incurs lower costs, and requires less time compared to the establishment of quiet zones. While wayside horns offer a notable reduction in noise, they do not entirely eliminate noise pollution (Fehr & Peers, 2022).

III. Data

My study utilizes three distinct datasets: quiet zone data, offering information on the quiet zone indicator and establishment dates; railroad grade crossing data, providing the geographical coordinates for each crossing; and railroad crossing accident data, supplying details on the date and location of accidents. For a comprehensive understanding of the data cleaning process, please refer to the appendix section. The sample covers all railway crossing-level accidents from 1994 to 2023. While the initial data is on a daily basis, I aggregate it at the yearly level. The primary outcome of interest is the annual count of accidents.

Highway-rail grade crossing accident data are extracted from the Office of Railroad Safety of the Federal Railroad Administration. Important variables from the accident data: Estimated Vehicle Speed, Highway user position, Temperature, Weather Condition, Train Speed, User Age, User Gender, Highway User Action (stopped on crossing, did not stop, went through the gate etc.), Crossing Users Killed, Crossing Users Injured.

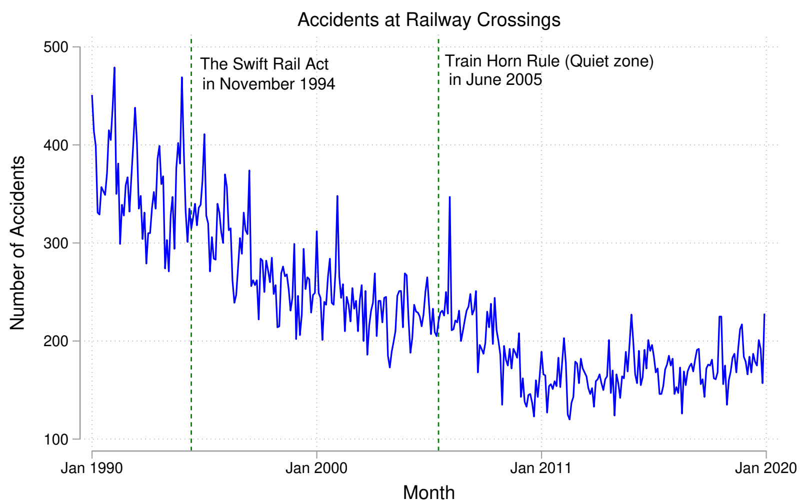

Figure 2. Accidents at Railway Crossings From 1990 to 2019

The dataset related to quiet zones is sourced from the Federal Railroad Administration (FRA) subsequent to the submission of a Freedom of Information Act (FOIA) request

(FOIA-23-00084).This comprehensive dataset consists of distinctive variables, including railroad crossing identifiers, quiet zone designations, establishment dates of whistle bans, geographical coordinates (expressed in terms of latitude and longitude) indicating the precise locations of these quiet zones, as well as indicators detailing the operational status of each crossing, i.e., whether it is open or closed, among other pertinent attributes.

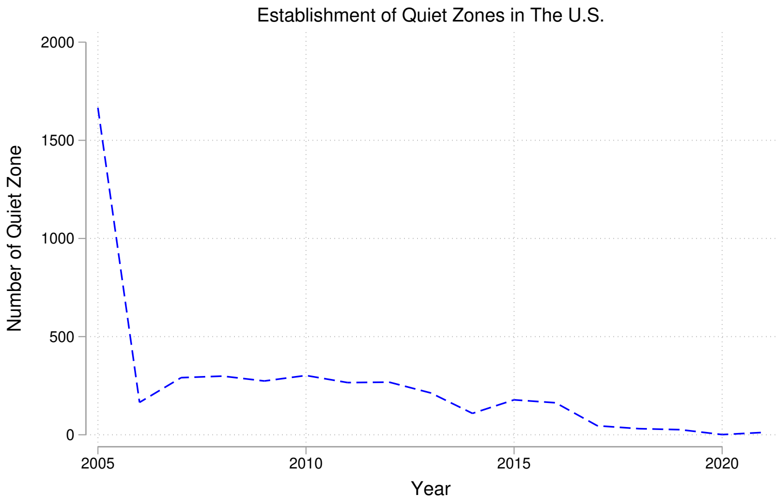

FIGURE 3. ESTABLISHMENT OF QUIET ZONES IN THE U.S.

I derive the dataset concerning railroad grade crossings from the Crossing Inventory Data, which is sourced from the Federal Railroad Administration's Office of Railroad Safety. This dataset provides comprehensive details regarding the geographical coordinates of grade crossings, unique identifiers assigned to each crossing (crossing id), classification of crossing types, metrics such as the volume of passenger train traffic on a daily basis, as well as the frequency of movements per day, among other pertinent attributes.

The core idea behind my identification strategy is that crossings outside quiet zones exhibit similar pre-treatment characteristics to those within quiet zones, making them plausible counterfactuals for the latter. To validate this assumption, I assess whether crossing and accident characteristics differ for "Not Yet Quiet Zone" crossings compared to "Quiet Zone" crossings before 2005. The summary statistics for the final samples are presented in table 1, detailing the mean, standard deviation, differences, and p-values from a two-sample t-test. While there are some observed differences between the two groups, the magnitudes are not substantial, and the p-values are relatively higher. It is important to note that these disparities do not necessarily pose a threat to identification, given the robustness and sensitivity offered by various estimation methods and the heterogeneity analysis applied to each distinct characteristic. Additionally, summary statistics for the "Never Treated" control group are outlined in table A2, and those for the total sample spanning 1995 to 2023 are presented in table A1.

	Not Yet Established Quiet Zone		Established Quiet Zone			
	(1)	(2)	(3)	(4)	(5)	(6)
	mean	sd	mean	sd	Difference	p-value
Accidents Per Month	0.004	0.067	0.004	0.062	0.001***	(0.001)
Highway Public or Private	0.968	0.176	0.978	0.146	-0.010	(0.068)
Crossing Warning Both Sides	0.952	0.213	0.929	0.257	0.023*	(0.015)
Crossing Illuminated	0.525	0.500	0.604	0.489	-0.080***	(0.000)
Time (AM)	0.442	0.497	0.412	0.492	0.030	(0.092)
Visibility (Dark)	0.395	0.489	0.373	0.484	0.022	(0.205)
Weather (Clear)	0.647	0.478	0.668	0.471	-0.021	(0.213)
View Obstruction	0.045	0.207	0.049	0.217	-0.005	(0.547)
Estimated Vehicle Speed	8.430	11.954	6.872	10.930	1.558***	(0.001)
Temperature	55.024	22.946	57.779	23.374	-2.755***	(0.001)
Train Speed	27.224	17.556	28.455	17.033	-1.231	(0.099)
Crossing Users Killed	0.154	0.412	0.160	0.397	-0.006	(0.703)
Crossing Users Injured	0.315	0.704	0.320	0.858	-0.005	(0.863)
Vehicle Damage Cost	4493.204	10652.980	5461.795	9454.080	-968.592**	(0.007)
Employees Killed	0.000	0.000	0.001	0.026	-0.001	(0.318)
Employees Injured	0.014	0.179	0.014	0.147	0.001	(0.921)
Passengers Injured	0.018	0.443	0.024	0.419	-0.006	(0.722)
Observations	1852		1479		3331	

Table 1—Summary Statistics for Quiet Zones

Note: This table presents summary statistics based on the sample used in the main specifications, comprising all the railway crossings in the U.S. from 1995 to 2005. The second and third columns of the table reports mean and standard deviation of the variables for the non-quiet zones used in the analysis, respectively. Columns four and five present the mean and standard deviation of the variables for the quiet zones, respectively. Additionally, column six display the difference of each variable for non-quite and quiet zone crossings for each variable used in the estimation. The last column shows the p-value for the difference-in-means test. If present, statistical differences would be denoted by *** denotes $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

IV. Empirical strategy

To assess the effects of quiet zone status on accident frequency, I employ a two-way fixed effects difference-in-differences (TWFE DiD) methodology, leveraging the staggered establishment of quiet zones across the United States. I estimate the following regression model via Poisson pseudo-maximum likelihood (PPML) to identify the effect of quiet zone on accidents at railroad crossings:

$$Accidents_{c,t} = \alpha + \beta Quiet_{c,t} + \gamma_c + \phi_t + \epsilon_{c,t} \tag{1}$$

Here,

- $Accidents_{c,t}$: the number of yearly (t) accidents per crossings c
- $Quiet_{c,t}$: is a dummy variable indicating whether quiet zone is established for a certain crossing-year combination
- γ_c : railway grade crossing fixed effects
- ϕ_t : time fixed effect
- $\epsilon_{c,t}$: standard errors are clustered at the crossing level

Here β_1 is the coefficient of interest which shows the marginal effect of quiet zone status on the frequency of accident at railway crossings. Given the staggered or roll out establishment of quiet zones, this overall effect can be interpreted as a weighted average of all possible two-groups-two-periods DiD estimates. Moreover, with only the assumption that the effect of quiet zones is homogeneous for each crossing and each year can give a causal interpretation. If treatment effects vary across years and crossings, the traditional TWFE settings may assign a negative weight to the β_1. This is attributed to the "forbidden comparison," wherein earlier "quiet zone" crossings may be compared with subsequently established quiet zone crossings (Roth et al., 2023). To assess the robustness of the results from this baseline specification, I also explore the staggered adoption models with heterogeneous treatment effect. I use extended two-way Mundlak (ETWM) regression or Wooldridge (2021) estimator as my preferred approach, but I show that the results are similar using either the Borusyak, Jaravel and Spiess (2021) estimator or the traditional TWFE approach. The main reason for my preference for the Wooldridge (2021) estimator is that this regression method extends to count outcome as my main outcome variable is the "number of accidents"- a count variable. First, I employ the extended two-way Mundlak (ETWM) estimator as follows: [1]

$$Accidents_{c,t} = \gamma_c + \phi_t + \sum_{g=g_0}^{G} \sum_{t=g}^{T} \beta_{g,t} X[\mathbb{1}(g,t)] + \epsilon_{c,t} \tag{2}$$

$$Accidents_{c,t} = \gamma_c + \phi_t + \sum_{g=g_0}^{G} \sum_{t \geq g}^{T} \beta_{g,t} X[\mathbb{1}(g,t)] + \epsilon_{c,t} \tag{3}$$

Here,

- $Accidents_{c,t}$: the number of yearly (t) accidents per crossings c
- T : the total number of periods indexed by $t = 1 \ldots T$

[1] These two equations are based on (Rios-Avila, 2023).

- G: g is the earliest year at which crossing c has received the "quiet zone" status. As a result, G represents sum of all the group cohorts.
- γ_c : railway grade crossing fixed effects
- ϕ_t : time fixed effect I_A
- $\epsilon_{c,t}$: standard errors are clustered at the crossing level

When estimating without covariates, Wooldridge (2021) recommends refining estimation models by not only including individual (or cohort) and time fixed effects but also saturating the model with every conceivable combination of cohorts and times, given their alignment with effectively treated units. This strategy offers two alternatives, as outlined in the aforementioned equations. The first option entails using never-treated crossings as controls in equation 2, while the second approach as shown in equation 3 involves employing crossings that have not yet been treated as controls (Rios-Avila, 2023). In these two equations, estimated βs' are the average treatment effect for the treated for each group "g" cohort and calendar "t" cohort combination.

I also employ the doubly robust difference-in-differences methodologies introduced by Callaway and Sant'Anna (2021) to estimate the impacts of quiet zone implementation. This approach is chosen to account for potential variations in treatment effects across diverse scenarios and over multiple time periods.

V. Results

In the baseline regression model (Model 1), I employ the Poisson Pseudo-Likelihood Method (PPML) to estimate the impact of quiet zone status on the frequency of accidents, and the results are presented in table 2. The first column displays the outcomes with crossing and year fixed effects, while the second column includes state X year fixed effects. In both cases, the estimated coefficients are 0.24 and 0.247, respectively. Interpreting the rate ratio, it indicates that a railway crossing experiences a 1.27 times higher yearly accident rate when in a quiet zone. To ensure the robustness of these findings, I conduct additional empirical tests, replicating the main results through various methods proposed in the literature. This aims to assess the sensitivity of my results to heterogeneous treatment effects. Specifically, I employ three methods from the literature that consistently estimate a staggered Difference-in-Differences (DID) model, allowing for heterogeneous treatment effects across crossings and over time. Utilizing estimators developed by Borusyak, Jaravel and Spiess (2021), Callaway and Sant'Anna (2021), and Wooldridge (2021), my results consistently indicate a significant association between the establishment of quiet zones and an increase in the number of accidents. For Callaway and Sant'Anna (2021) and Wooldridge (2021), I present the results for both "Never Treated" and "Not Yet Treated" comparison groups. While most alternative estimates align with the same directional trend as the baseline estimates, they generally exhibit smaller magnitudes. Notably, the employment of the Callaway and Sant'Anna (2021) estimation method yields the same directional effect but lacks statistical significance. The lack of significance in this estimator could be attributed to two distinct factors: firstly, unlike Wooldridge (2021), this method lacks the capability to accommodate count variable outcomes; and secondly, unlike Borusyak, Jaravel and Spiess (2021), this estimation method considers only the last pre-period, omitting others. In essence, my analysis does not unveil compelling evidence supporting the notion that quiet zones result in a reduction in the number of accidents at grade crossings.

Just a reminder that these effects are aggregated. To observe how the treatment effects evolved across groups and over time, I also conduct event studies for these estimators. For Wooldridge (2021), I present four graphs: one for the not-yet-treated comparison group with 'group effects' in figure A1 and the not-yet-treated comparison group with 'calendar' effects in figure A3. Figures A2 and A4 depict the never-treated comparison group with 'group cohort' and 'calendar' effects, respectively. It is evident that there were minimal effects on the early quiet zones and earlier times, with the effects predominantly occurring from 2012 to just before the COVID-19 outbreak. As for Callaway and Sant'Anna (2021), the effects remain mostly near zero over time, with minimal changes, as shown in figures A6 and A7. In the case of Borusyak, Jaravel and Spiess (2021), figure A8 exhibits a similar trend to the not-yet-treated graphs of (Wooldridge, 2021).

It is plausible that even though the number of accidents increased in grade crossings within the quiet zone, the subsequent impacts of these accidents might be mitigated. To explore beyond accident frequency, I incorporate additional outcome variables, namely the cost of damaged vehicles, the number of crossing users killed, and the number of crossing users injured, employing equations 2 and 3. Table 3 reveals the results for the cost of damaged vehicles, indicating no significant effect of the quiet zone establishment on these costs. However, tables 4 and 5 indicate an increase in both the number of users killed and injured within quiet zones. It is worth noting that the magnitude of these coefficients is relatively low when compared to the results presented in Table 2.

	TWFE (PPML)		CSDID			BJS		ETWM	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment	0.240***	0.247***	0.002	0.002	0.016***	0.005**	0.004**	0.008***	0.003
	(0.044)	(0.045)	(0.005)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)
Crossing	Yes	Yes				Yes	Yes	Yes	Yes
Year	Yes	Yes			Yes	Yes	Yes	Yes	Yes
State X Year		Yes					Yes		
Not Yet Treated	NA	NA	Yes		NA	NA	NA	Yes	
Never Treated	NA	NA		Yes	NA	NA	NA		Yes
Observation	1164553	1163539	2,123,699	2,123,699	2,125,700	2,125,700	2,125,700	2,123,699	2,123,699

TABLE 2—RESULTS

Note: This table presents the impact of quiet zones on accidents at railway crossings across the United States from 1995 to 2023. The second and third columns showcase the estimated coefficients using the Two-Way Fixed Effects method for multiple time periods. Columns four and five display coefficients estimated according to the methodology outlined by Callaway and Sant'Anna (2021), while columns six to eight present estimates based on the imputation approach proposed by (Borusyak, Jaravel and Spiess, 2021). The final two columns depict coefficients based on the extended two-way Mundlak (ETWM) regression of (Wooldridge, 2021). Standard errors, clustered at the railway crossing level, are provided in parentheses. Statistical significance levels are denoted as follows: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$.

	TWFE		CSDID		BJS		ETWM
Treatment	7.14	29.46	54.663*	54.425*	12.824	37.204	12.77
	20.742	21.076	31.335	31.318	20.927	21.359	20.929
Crossing	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	
State X Year		Yes				Yes	
Not Yet Treated	NA	NA	Yes		NA	NA	Yes
Never Treated	NA	NA		Yes	NA	NA	
Observation	2,125,700	2,125,700	2,123,699	2,123,699	2,125,700	2,125,700	2,123,699

TABLE 3—RESULTS DAMAGE

Note: Note: This table presents the impact of quiet zones on accidents at railway crossings across the United States from 1995 to 2023. The second and third columns showcase the estimated coefficients using the Two-Way Fixed Effects method for multiple time periods. Columns four and five display coefficients estimated according to the methodology outlined by Callaway and Sant'Anna (2021), while columns six to eight present estimates based on the imputation approach proposed by (Borusyak, Jaravel and Spiess, 2021). The final two columns depict coefficients based on the extended two-way Mundlak (ETWM) regression of (Wooldridge, 2021). Standard errors, clustered at the railway crossing level, are provided in parentheses. Statistical significance levels are denoted as follows: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$.

	TWFE (PPML)		CSDID		BJS		ETWM
Treatment	0.309***	0.200**	0.0003	0.0004	0.001**	0.001*	0.001**
	0.106	0.114	0.002	0.002	0.0007	0.0007	0.001
Crossing	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	
State X Year		Yes				Yes	
Not Yet Treated	NA	NA	Yes		NA	NA	Yes
Never Treated	NA	NA		Yes	NA	NA	
Observation	190,211	185,196	2,123,699	2,123,699	2,125,700	2,125,700	2,123,699

Table 4—Results Killed

Note: Note: This table presents the impact of quiet zones on accidents at railway crossings across the United States from 1995 to 2023. The second and third columns showcase the estimated coefficients using the Two-Way Fixed Effects method for multiple time periods. Columns four and five display coefficients estimated according to the methodology outlined by Callaway and Sant'Anna (2021), while columns six to eight present estimates based on the imputation approach proposed by (Borusyak, Jaravel and Spiess, 2021). The final two columns depict coefficients based on the extended two-way Mundlak (ETWM) regression of (Wooldridge, 2021). Standard errors, clustered at the railway crossing level, are provided in parentheses. Statistical significance levels are denoted as follows: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$.

	TWFE (PPML)		CSDID		BJS		ETWM
Treatment	0.333***	0.409***	0.003	0.0003	0.003**	.004***	0.004**
	0.101	0.103	0.003	0.002	0.001	0.001	0.001
Crossing	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	
State X Year		Yes				Yes	
Not Yet Treated	NA	NA	Yes		NA	NA	Yes
Never Treated	NA	NA		Yes	NA	NA	
Observation	429,896	427,256	2,123,699	2,123,699	2,125,700	2,125,700	2,123,699

Table 5—Results Injured

Note: Note: This table presents the impact of quiet zones on accidents at railway crossings across the United States from 1995 to 2023. The second and third columns showcase the estimated coefficients using the Two-Way Fixed Effects method for multiple time periods. Columns four and five display coefficients estimated according to the methodology outlined by Callaway and Sant'Anna (2021), while columns six to eight present estimates based on the imputation approach proposed by (Borusyak, Jaravel and Spiess, 2021). The final two columns depict coefficients based on the extended two-way Mundlak (ETWM) regression of (Wooldridge, 2021). Standard errors, clustered at the railway crossing level, are provided in parentheses. Statistical significance levels are denoted as follows: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$.

VI. Heterogeneity Analysis

To unravel the potential mechanisms behind the observed results, I leverage the heterogeneity in my sample. By aggregating data on a yearly basis, thereby enhancing statistical power and reducing noise, I conduct a thorough heterogeneity analysis by segmenting the sample into subgroups based on diverse factors. These include weather conditions, visibility, reasons for accidents primarily attributed to motorists' actions, time of day, and the crossing's status in terms of being private or public. Within the sample, accidents occur under various weather conditions, such as clear, cloudy, fog, rain, sleet, or snow. Due to the limited occurrence of accidents in fog, sleet, and snow—constituting 1.75%, 0.25%, and 2.86% of total accidents, respectively—I focus the heterogeneity analysis exclusively on sub-samples of clear, cloudy, and rainy weather. Subsequently, I estimate equations 2 and 3 using Wooldridge (2021)'s extended two-way Mundlak regression, with the results presented in table 9. While the coefficients are statistically significant, their magnitudes are relatively low, ranging from 0.004 to 0.007. When interpreted as rate ratios, this implies that a crossing with "quiet zone" status has only 1.004 or 1.007 times more yearly accidents compared to a non-quiet zone crossing under clear or rainy weather conditions, respectively. Intriguingly, there are no statistically significant differences in accident frequency between quiet and non-quiet zones when the weather condition is cloudy.

Moving on to visibility conditions during accidents, which can be categorized as dark, day, dawn, or dusk, I focus exclusively on the sub-samples where visibility conditions are either dark or day. These two conditions comprise 93 percent of the total sample. Subsequently, I estimate both equations 2 and 3, and the results are presented in table 7. The findings indicate that quiet zones significantly increase the number of accidents in both visibility conditions, suggesting there are no heterogeneous effects on accidents based on visibility. Subsequently, I delve into the reasons for accidents primarily attributed to motorists' actions, such as failure to stop, stopping and then proceeding, and going around the gate. However, all of these effects prove statistically insignificant, as illustrated in table 6. This implies that there is no apparent treatment heterogeneity stemming from the establishment of quiet zones concerning accidents based on the reasons behind them. Within the sample, I also have a time variable that precisely denotes the hour-minute format of the accident, including am/pm information. This allows for an exploration of the time heterogeneity in the impact of quiet zones on accidents. The sample is stratified into four distinct bins or sub-samples based on time: 6 AM to 11:59 AM, 12 PM to 5:59 PM, 6 PM to 11:59 PM, and midnight to 5:59 AM. With the exception of midnight until morning, a statistically significant increase in accident frequency is observed, likely attributed to the lower traffic volume during these hours. Detailed results are presented in table 8.

Within the dataset spanning from 1995 to 2023, a mere 7 percent of accidents occurred at private crossings, distinctly fewer than those at public crossings. Public grade crossings fall under the jurisdiction and maintenance of public authorities, whereas private grade crossings are situated on privately owned roadways, often within farms or industrial areas, exclusively intended for the owner's use or that of their licensees and invitees. Notably, private crossings lack public use intent and aren't maintained by a public highway authority, with 2015 recording 129,582 public crossings compared to 80,073 private crossings (Federal Railway Administration, 2019). Upon segmenting the sample into public and private crossings, I observe an increase in accidents at public crossings designated as "quiet zones," as detailed in table 10. Interestingly, this effect is found to be insignificant at private crossings. This discrepancy could be attributed to the lower number of private crossings, resulting in fewer accidents regardless of quiet zone status. Alternatively, it is plausible that private quiet zone crossings are equipped with enhanced safety measures, contributing to the observed difference in accident frequency.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treatment	-0.004***	0.001	0.001	0.003	0.001	-0.004**	-0.004
	(0.001)	(0.002)	(0.002)	(0.009)	(0.002)	(0.001)	(0.006)
Not Yet Treated	Yes		Yes		Yes	Yes	
Never Treated		Yes		Yes			Yes
Reasons	Did not stop	Did not stop	Stopped on crossing	Stopped on crossing	Went around the gate	Stopped and then proceeded	Stopped and then proceeded
Observation	1,436,892	1,436,892	869,188	869,188	282,199	248,878	248,878

Table 6—Heterogeneity Analysis of the Reasons of Accidents Due to Highway User's Action

Note: This table presents the effects of establishing quiet zones on accidents across all railway crossings in the U.S. spanning the years 1995 to 2023, stratified by by the reasons for accidents attributed to the actions of highway users. The estimated coefficients are derived from the extended two-way Mundlak (ETWM) regression method proposed by (Wooldridge, 2021). The primary comparison group is "Not Yet Treated" , with additional insights provided using the "Never Treated" comparison group whenever available. The analysis incorporates railway crossing and year fixed effects to enhance precision. Standard errors, clustered at the level of railway crossings, are reported in parentheses. Statistical significance levels are denoted by asterisks: *** indicates $p < 0.01$, ** indicates $p < 0.05$, * indicates $p < 0.1$.

	1	2	3	4
Treatment	.005***	-0.001	0.006***	0.006**
	(0.001)	(0.004)	(0.001)	(0.003)
Not Yet Treated	Yes		Yes	
Never Treated		Yes		Yes
Visibility	Dark	Dark	Day	Day
Observation	1,026,281	1,026,281	1,616,112	1,616,112

Table 7—Heterogeneity Analysis of the Visibility Factors of Accidents

Note: This table presents the effects of establishing quiet zones on accidents across all railway crossings in the U.S. spanning the years 1995 to 2023, segmented by visibility factors of accidents, distinguishing between occurrences in dark and daylight conditions. The estimated coefficients are derived from the extended two-way Mundlak (ETWM) regression method proposed by (Wooldridge, 2021). The primary comparison group is "Not Yet Treated" , with additional insights provided using the "Never Treated" comparison group whenever available. The analysis incorporates railway crossing and year fixed effects to enhance precision. Standard errors, clustered at the level of railway crossings, are reported in parentheses. Statistical significance levels are denoted by asterisks: *** indicates $p < 0.01$, ** indicates $p < 0.05$, * indicates $p < 0.1$.

	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	0.002*	-0.00005	0.004***	0.005	0.005***	0.003
	(0.001)	(0.006)	(0.001)	(0.006)	(0.001)	(0.002)
Not Yet Treated	Yes		Yes		Yes	Yes
Never Treated		Yes		Yes		
Time Range	6 AM to 11:59 AM	6 AM to 11:59 AM	12 PM to 5:59 PM	12 PM to 5:59 PM	6 PM to 11:59 PM	12 AM to 5:59 AM
Observation	968,310	968,310	1,126,650	1,126,650	846,655	535,369

Table 8—Heterogeneity Analysis of the Timing of Accidents

Note: This table presents the effects of establishing quiet zones on accidents across all railway crossings in the U.S. spanning the years 1995 to 2023, stratified by the timing of accidents, including intervals such as 6 AM to 11:59 AM, 12 PM to 5:59 PM, 6 PM to 11:59 PM, 12 AM to 5:59 AM, and so forth. The estimated coefficients are derived from the extended two-way Mundlak (ETWM) regression method proposed by (Wooldridge, 2021). The primary comparison group is "Not Yet Treated" , with additional insights provided using the "Never Treated" comparison group whenever available. The analysis incorporates railway crossing and year fixed effects to enhance precision. Standard errors, clustered at the level of railway crossings, are reported in parentheses. Statistical significance levels are denoted by asterisks: *** indicates $p < 0.01$, ** indicates $p < 0.05$, * indicates $p < 0.1$.

	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	.007***	0.004	0.001	-0.005	0.004**	-0.002
	(0.001)	(0.003)	(0.001)	(0.004)	(0.002)	(0.005)
Not Yet Treated	Yes		Yes		Yes	Yes
Never Treated		Yes		Yes		
Weather	Clear	Clear	Cloudy	Cloudy	Rain	Rain
Observation	1,709,347	1,709,347	787,582	787,582	330,716	330,716

Table 9—Heterogeneity Analysis of the Weather at the Time of Accidents

Note: This table presents the effects of establishing quiet zones on accidents across all railway crossings in the U.S. spanning the years 1995 to 2023, stratified by distinct weather conditions—namely, yearly accidents occurring during clear, cloudy, and rainy weathers. The estimated coefficients are derived from the extended two-way Mundlak (ETWM) regression method proposed by (Wooldridge, 2021). The primary comparison group is "Not Yet Treated" , with additional insights provided using the "Never Treated" comparison group whenever available. The analysis incorporates railway crossing and year fixed effects to enhance precision. Standard errors, clustered at the level of railway crossings, are reported in parentheses. Statistical significance levels are denoted by asterisks: *** indicates $p < 0.01$, ** indicates $p < 0.05$, * indicates $p < 0.1$.

	(1)	(2)	(3)
Treatment	0.010***	0.002	-0.024***
	(0.002)	(0.004)	(0.008)
Not Yet Treated	Yes		Yes
Never Treated		Yes	
Public or Private	Public	Public	Private
Observation	1,899,413	1,899,413	272,774

Table 10—Heterogeneity Analysis of the Accidents Occurring at Public or Private Highway Crossings

Note: This table presents the effects of establishing quiet zones on accidents across all railway crossings in the U.S. spanning the years 1995 to 2023, with a breakdown of samples based on whether the accidents occurred at public or private highway crossings. The estimated coefficients are derived from the extended two-way Mundlak (ETWM) regression method proposed by (Wooldridge, 2021). The primary comparison group is "Not Yet Treated" , with additional insights provided using the "Never Treated" comparison group whenever available. The analysis incorporates railway crossing and year fixed effects to enhance precision. Standard errors, clustered at the level of railway crossings, are reported in parentheses. Statistical significance levels are denoted by asterisks: *** indicates $p < 0.01$, ** indicates $p < 0.05$, * indicates $p < 0.1$.

VII. Policy Implications

The findings of this paper carry substantial policy implications; should quiet zones prove ineffective in reducing accidents at grade crossings or, worse, contribute to an increase, it prompts a critical examination of the safety standards governing quiet zones and the effectiveness of diagnostic teams approving their establishment. Considering the substantial cost associated with establishing quiet zones, where the additional safety measures alone amount to $200,000 per crossing, the results of this study raise questions about the viability of quiet zones passing the cost-benefit analysis test. Specifically, if the number of accidents and fatalities rises in quiet zones, the likelihood is significant that the costs would outweigh any potential benefits derived from reducing noise pollution caused by train whistles. To illustrate, aggregating the Value of Statistical Life (VSL) – ranging from 1 million to 10 million USD – for the marginal effect of quiet zones on death tolls, in addition to the safety measures cost of $200,000, results in a substantial cost that far exceeds potential benefits.

The findings of this study extend to legal considerations as well. FRA's final rule in 2005 was designed to prevent the failure to sound the train horn from being used as a legal argument in lawsuits related to collisions at grade crossings within designated quiet zones. This suggests that, in such situations, the absence of horn sound may not be considered a factor for legal action. However, if accidents are indeed attributable to the absence of whistles or horns, the FRA may need to assume greater liability and provide compensation in more cases than it currently covers.

In contrast to the substantial installation expense of a crossing gate in a quiet zone, which can reach up to $250,000, there are also ongoing annual maintenance costs amounting to $5,000. On the other hand, opting for the wayside horn presents a more economical solution, with equipment costs for the Automated Horn System (AHS) standing at approximately $25,000 per crossing (Hummer and Jafari, 2007). Given this cost-effectiveness of wayside horns and their associated positive benefits, a crucial policy question emerges: which noise reduction option performs better, the wayside horn or the quiet zone? Although this question constitutes a distinct research inquiry, the implications of this paper's findings may lean towards favoring wayside horns.

The emergence of "self-driving" or "autopilot" features in modern vehicles raises the risk of accidents at grade crossings. Notably, Tesla's "full self-driving" beta version attempted to drive beneath a grade crossing arm in 2021, highlighting the potential hazards (Hammer, 2022). Given that a significant number of fatal accidents at crossings involve cars, it is crucial to integrate safety features designed specifically to prevent collisions with trains. In response to this need, Ford submitted a patent in 2021 for a driver-assist system focused on averting collisions with oncoming trains to the United States Patent and Trademark Office (USPTO). The proposed system offers two approaches: the first uses sensors on both sides of the crossing to alert sensors on the car and warn the driver, while the second utilizes cameras and LiDAR (Light Detection and Ranging) to identify the grade crossings' crossbars and warning lights (Edelstein, 2023). Implementing such technology has the potential to enhance the safety of quiet zones, cut down on associated safety costs, and reduce accidents linked to the lack of whistles in these areas. Considering the conclusions drawn in this paper, indicating that quiet zones may lack sufficient safety measures, and could potentially increase accidents, it becomes essential for government entities and car manufacturers to expedite the development and deployment of this new technology. This can be achieved by allocating increased research funds to projects aimed at advancing safety technologies designed to prevent accidents at grade crossings involving autonomous or semi-autonomous vehicles.

VIII. Conclusion

This study investigates how the creation of quiet zones affects fatal accidents at railway-grade crossings in the United States. I analyze data from highway-rail grade crossing accidents, sourced from the Office of Railroad Safety of the Federal Railroad Administration, and quiet zone data from the Federal Railroad Administration (FRA). Employing event-study and difference-in-difference frameworks, I explore the impact of staggered railway quiet zone implementations on the number of accidents at these crossings. Employing the traditional two-way fixed effect difference-in-differences (TWFE DID) model with Poisson Pseudo Maximum Likelihood estimation, the analysis reveals that railway crossings in quiet zones experience a 1.27 times higher yearly accident rate compared to those outside quiet zones. Utilizing estimators devised by Borusyak, Jaravel and Spiess (2021), Callaway and Sant'Anna (2021), and Wooldridge (2021), my findings consistently indicate that the establishment of quiet zones is significantly associated with an increase in the number of accidents. While most alternative estimates share the same directional trend as the baseline estimates, they tend to be smaller in magnitude. Notably, employing the Callaway and Sant'Anna (2021) estimation method yields the same directional effect, but it lacks statistical significance. The lack of significance in this estimator could stem from two distinct reasons: unlike Wooldridge (2021), this method does not extend to count variable outcomes, and unlike Borusyak, Jaravel and Spiess (2021), this estimation method uses only the last pre-period, not all of them. Put differently, my analysis does not reveal any compelling evidence that quiet zones lead to a reduction in the number of accidents at grade crossings. Additionally, the impact of quiet zones appears more pronounced in grade crossings that joined a quiet zone later than those included in earlier quiet zones.

Beyond examining the frequency of accidents, I also delve into the cost of damaged vehicles, the number of crossing users killed, and the number of injured crossing users. The results show no significant effect on the cost of damaged vehicles; however, an increased number of user fatalities and injuries are associated with the establishment of quiet zones. Furthermore, exploring the varied impacts of 'quiet zone' status on accident frequency at railway grade crossings, I consider different weather and visibility conditions, time of day, and distinctions between public and private crossings and find heterogeneous effects in these scenarios. However, when examining sub-samples based on the reasons behind accidents, no significant differences in accident frequency emerge.

The outcomes of my study prompt two potential questions for future investigation. Firstly, there's a need to assess whether establishing quiet zones withstands a cost-benefit analysis. This involves evaluating whether the benefits of noise reduction outweigh the costs linked to purchasing and maintaining safety equipment at each grade crossing, alongside potential increases in accidents, fatalities, and injuries associated with quiet zones. Secondly, it's worthwhile exploring whether wayside horns surpass quiet zones in terms of safety, given their lower equipment costs.

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1. *Appendix A*

	(Non-Quiet Zone)		(Quiet Zone)			
	mean	sd	mean	sd	Difference	p-value
Accidents Per Month	0.003	0.053	0.004	0.064	-0.001***	(0.000)
Highway Public or Private	0.879	0.326	0.973	0.161	-0.094***	(0.000)
Crossing Warning Both Sides	0.935	0.246	0.943	0.232	-0.008	(0.064)
Crossing Illuminated	0.291	0.454	0.563	0.496	-0.272***	(0.000)
Time (AM)	0.428	0.495	0.429	0.495	-0.001	(0.895)
Visibility (Dark)	0.304	0.460	0.386	0.487	-0.082***	(0.000)
Weather (Clear)	0.691	0.462	0.655	0.475	0.036***	(0.000)
View Obstruction	0.044	0.206	0.047	0.211	-0.003	(0.495)
Estimated Vehicle Speed	9.826	13.054	7.601	11.380	2.225***	(0.000)
Temperature	60.076	22.000	56.371	23.076	3.705***	(0.000)
Train Speed	30.060	18.883	27.772	17.403	2.288***	(0.000)
Crossing Users Killed	0.129	0.395	0.154	0.398	-0.025***	(0.000)
Crossing Users Injured	0.339	0.699	0.319	0.770	0.020	(0.131)
Vehicle Damage Cost	6336.882	17066.251	4954.945	10503.738	1381.937***	(0.000)
Employees Killed	0.001	0.025	0.000	0.017	0.000	(0.478)
Employees Injured	0.033	0.256	0.014	0.165	0.019***	(0.000)
Passengers Injured	0.031	0.814	0.021	0.426	0.010	(0.233)
Observations	67017		3425		70442	

TABLE A1—SUMMARY STATISTICS

Note: This table presents summary statistics based on the sample used in the main specifications, comprising all the railway crossings in the U.S. from 1995 to 2023. The second and third columns of the table reports mean and standard deviation of the variables for the non-quiet zones used in the analysis, respectively. Columns four and five present the mean and standard deviation of the variables for the quiet zones, respectively. Additionally, column six display the difference of each variable for non-quite and quiet zone crossings for each variable used in the estimation. The last column shows the p-value for the difference-in-means test. If present, statistical differences would be denoted by *** denotes $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	(Non-Quiet Zone)		(Quiet Zone)			
	mean	sd	mean	sd	Difference	p-value
Accidents Per Month	0.003	0.059	0.005	0.068	-0.001***	(0.000)
Highway Public or Private	0.857	0.350	0.980	0.141	-0.123***	(0.000)
Crossing Warning Both Sides	0.935	0.247	0.938	0.241	-0.003	(0.617)
Crossing Illuminated	0.311	0.463	0.591	0.492	-0.280***	(0.000)
Time (AM)	0.429	0.495	0.426	0.495	0.004	(0.756)
Visibility (Dark)	0.297	0.457	0.382	0.486	-0.085***	(0.000)
Weather (Clear)	0.697	0.460	0.661	0.473	0.036**	(0.002)
View Obstruction	0.037	0.189	0.046	0.209	-0.009	(0.086)
Estimated Vehicle Speed	8.554	12.140	6.786	10.950	1.768***	(0.000)
Temperature	60.709	21.834	58.057	23.057	2.652***	(0.000)
Train Speed	30.338	19.099	29.046	17.091	1.292*	(0.025)
Crossing Users Killed	0.131	0.388	0.163	0.396	-0.032**	(0.002)
Crossing Users Injured	0.326	0.678	0.327	0.849	-0.000	(0.982)
Vehicle Damage Cost	7438.822	19693.677	5351.787	10635.797	2087.035***	(0.000)
Employees Killed	0.001	0.026	0.000	0.022	0.000	(0.863)
Employees Injured	0.037	0.276	0.016	0.162	0.020***	(0.000)
Passengers Injured	0.051	1.068	0.023	0.381	0.027**	(0.009)
Observations	36312		2023		38335	

Table A2—Summary Statistics for Pre-Quiet Zone Rule

Note: This table presents summary statistics based on the sample used in the main specifications, comprising all the railway crossings in the U.S. from 1995 to 2005. The second and third columns of the table reports mean and standard deviation of the variables for the non-quiet zones used in the analysis, respectively. Columns four and five present the mean and standard deviation of the variables for the quiet zones, respectively. Additionally, column six display the difference of each variable for non-quite and quiet zone crossings for each variable used in the estimation. The last column shows the p-value for the difference-in-means test. If present, statistical differences would be denoted by *** denotes $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

	TWFE (PPML)		CSDID		BJS			Mundlak Regression	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment	0.05	0.138	-0.003	-0.003	0.005**	-0.001	-0.0004	0.001	-0.001
	(0.088)	(0.091)	(0.008)	(0.008)	(0.002)	(0.004)	(0.004)	(0.003)	(0.006)
Crossing	Yes	Yes			Yes	Yes		Yes	Yes
Year	Yes	Yes				Yes			
State X Year		Yes					Yes		
Not Yet Treated	NA	NA	Yes		NA	NA	NA	Yes	
Never Treated	NA	NA		Yes	NA	NA	NA		Yes
Observation	1129985	1128884	2,073,558	2,073,558	2,073,558	2,073,558	2,073,558	2,073,558	2,073,558

TABLE A3—RESULTS 2005 COHORT

Note: This table presents the impact of quiet zones on accidents based on the sample comprising only the 2005 cohort of quiet zone and never-quiet zone railway crossings in the U.S. from 1995 to 2023. The second and third columns showcase the estimated coefficients using the Two-Way Fixed Effects method for multiple time periods. Columns four and five display coefficients estimated according to the methodology outlined by Callaway and Sant'Anna (2021), while columns six to eight present estimates based on the imputation approach proposed by (Borusyak, Jaravel and Spiess, 2021). The final two columns depict coefficients based on the extended two-way Mundlak (ETWM) regression of (Wooldridge, 2021). Standard errors, clustered at the railway crossing level, are provided in parentheses. Statistical significance levels are denoted as follows: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$.

	TWFE (PPML)		CSDID		BJS			Mundlak Regression	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment	0.301***	0.278***	0.004	0.004	0.022***	0.008***	0.007***	0.012***	0.005
	(0.05)	(0.05)	(0.006)	(0.006)	(0.002)	(0.003)	(0.003)	(0.002)	(0.005)
Crossing	Yes	Yes			Yes	Yes		Yes	Yes
Year	Yes	Yes				Yes			
State X Year		Yes					Yes		
Not Yet Treated	NA	NA	Yes		NA	NA	NA	Yes	
Never Treated	NA	NA		Yes	NA	NA	NA		Yes
Observation	1153417	1152403	2,104,153	2,104,153	2,106,154	2,073,558	2,073,558	2,104,153	2,104,153

Table A4—Results Post 2005 Cohort

Note: This table presents the impact of quiet zones on accidents based on the sample comprising only the post 2005 cohort of quiet zone and never-quiet zone railway crossings in the U.S. from 1995 to 2023. The second and third columns showcase the estimated coefficients using the Two-Way Fixed Effects method for multiple time periods. Columns four and five display coefficients estimated according to the methodology outlined by Callaway and Sant'Anna (2021), while columns six to eight present estimates based on the imputation approach proposed by (Borusyak, Jaravel and Spiess, 2021). The final two columns depict coefficients based on the extended two-way Mundlak (ETWM) regression of (Wooldridge, 2021). Standard errors, clustered at the railway crossing level, are provided in parentheses. Statistical significance levels are denoted as follows: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$.

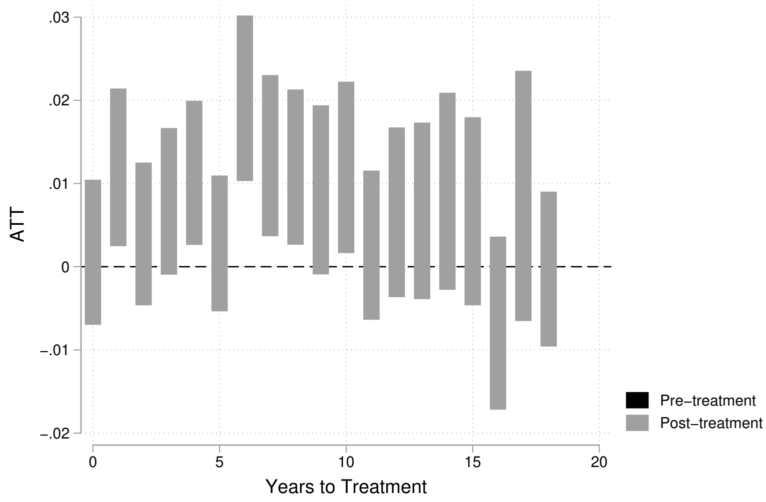

Figure A1. Extended Two-way Mundlak (ETWM) Regression, Event Not Yet Treated

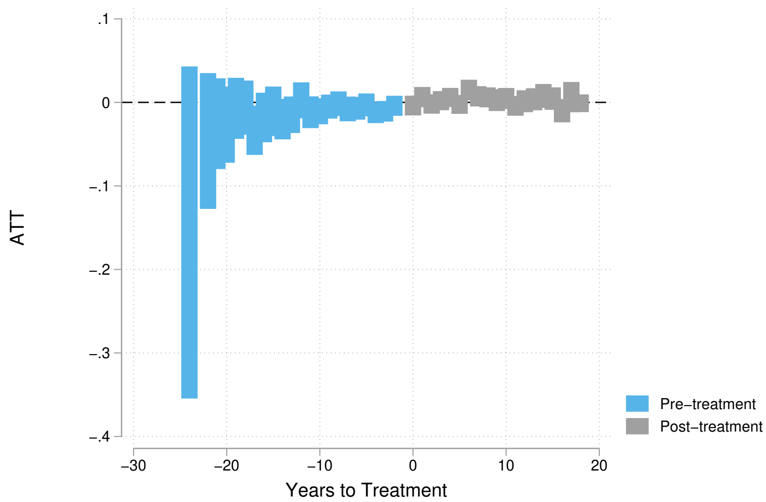

Figure A2. Extended Two-way Mundlak (ETWM) Regression, Event Never Treated

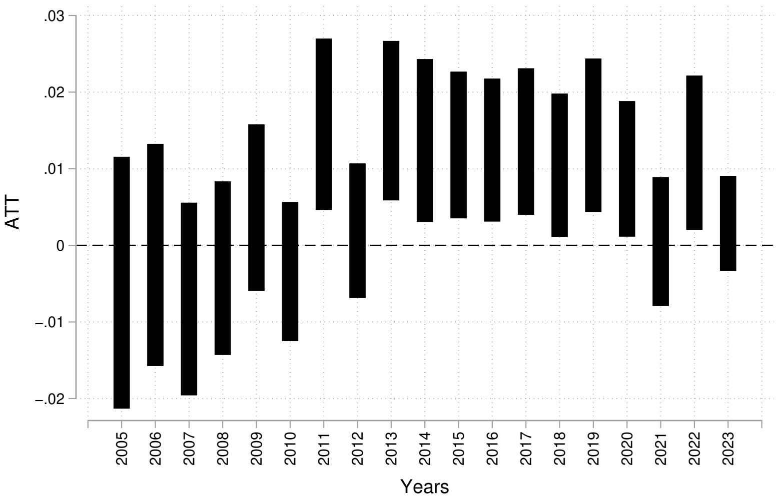

Figure A3. Extended Two-way Mundlak (ETWM) Regression, Calendar Not Yet Treated

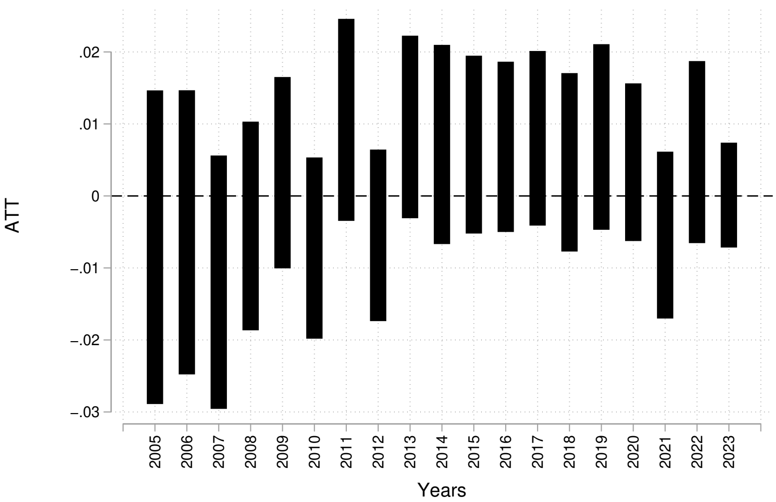

Figure A4. Extended Two-way Mundlak (ETWM) Regression, Calendar Never Treated

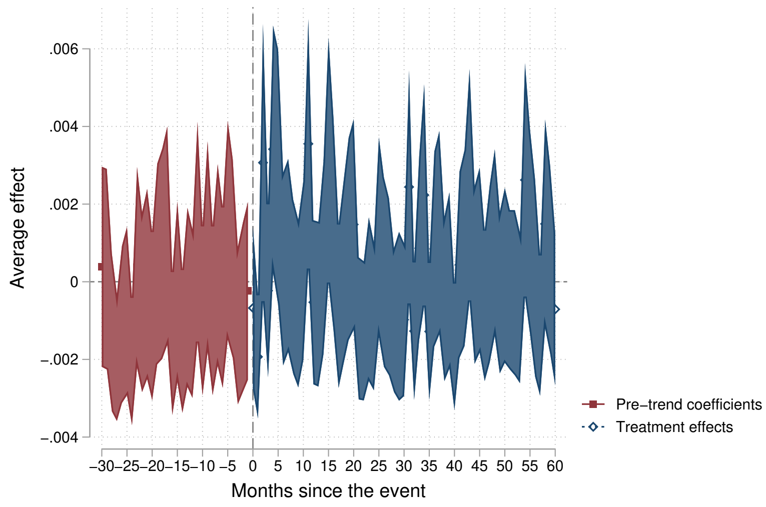

Figure A5. Extended Two-way Mundlak (ETWM) Regression, Event 30 Pre and 60 Post Treated Monthly

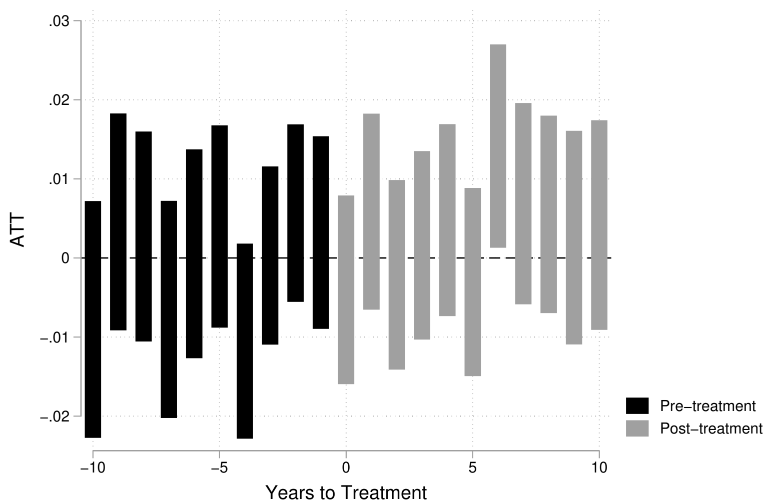

Figure A6. CSDiD Event Plot for Not Yet Treated

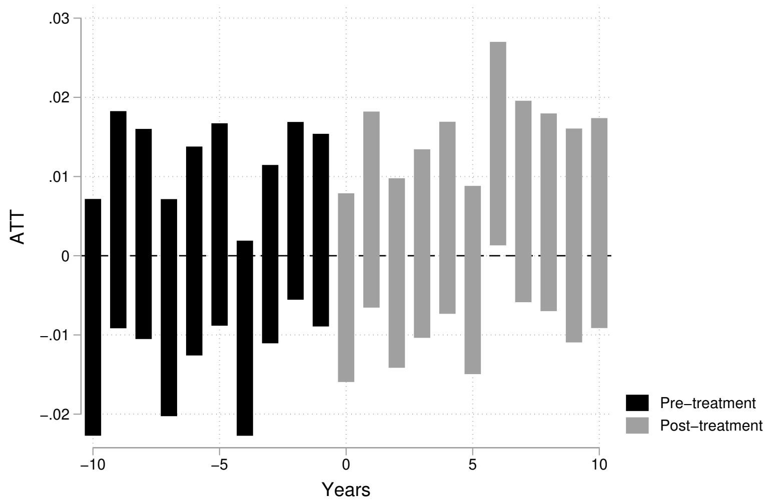

Figure A7. CSDiD Event Plot for Never Treated

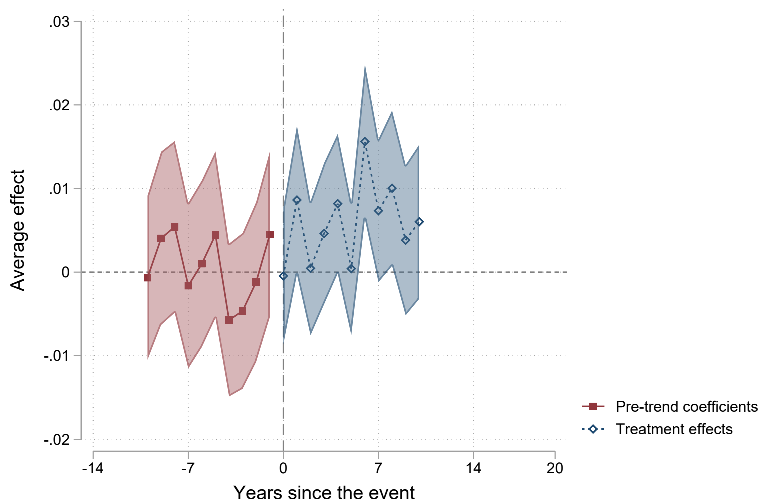

Figure A8. Imputation Event Plot

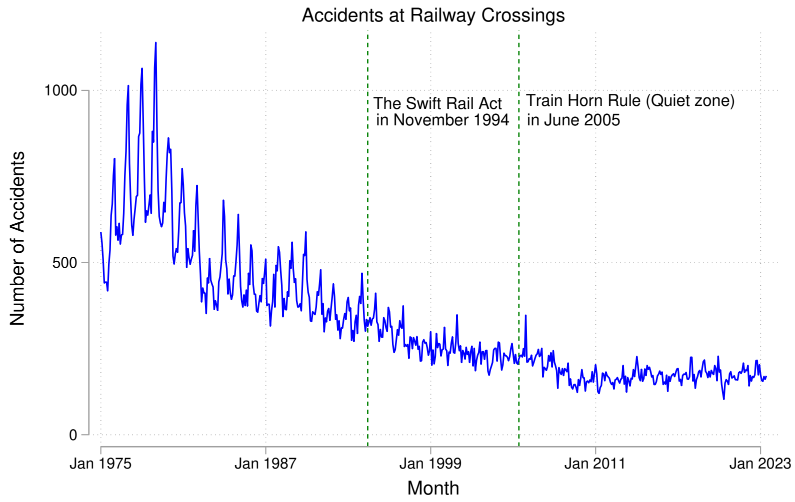

Figure A9. Accidents at Railway Crossings From 1975 to 2023

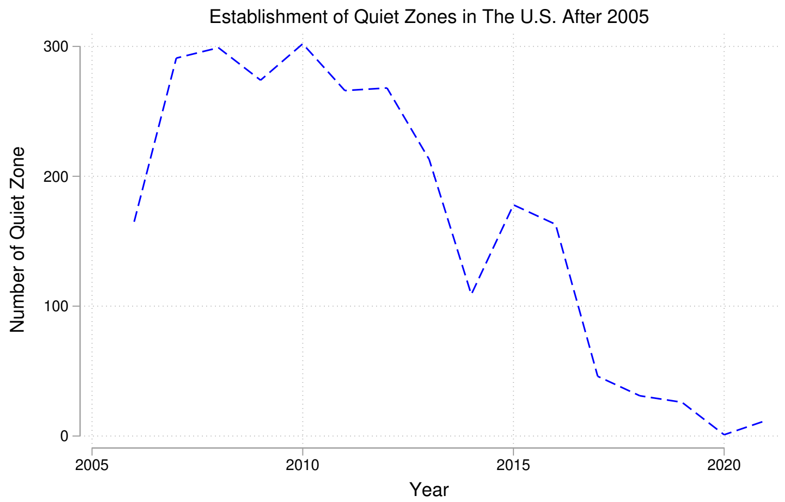

Figure A10. Establishment of Quiet Zones in The U.S. After 2005

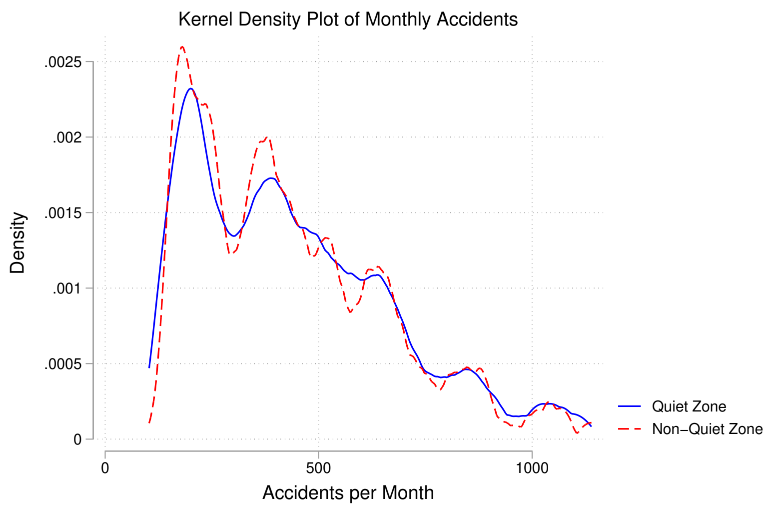

Figure A11. Kernel Density Plot of Monthly Accidents at Quiet Zone and Non-quiet Zone

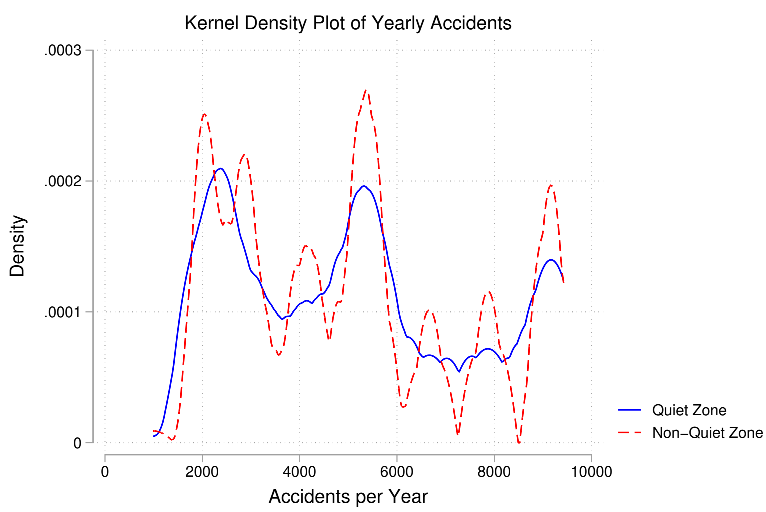

Figure A12. Kernel Density Plot of Yearly Accidents at Quiet Zone and Non-quiet Zone