ISSN - 2456-1142

International journal of humanities and information technology

Volume 7, Issue 2, 2025

Quantifying the Causal Effect of FMCSA Enforcement Interventions on Truck Crash Reduction: A Quasi-Experimental Approach Using Carrier-Level Safety Data

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Abstract

The Federal Motor Carrier Safety Administration (FMCSA) and partners in the states are supposed to minimize collisions and other serious safety offenses by effective enforcement interventions, such as compliance reviews, audits, and planned inspections not to mention enforcement interventions. However, the carriers onto which the interventions are imposed are usually not random and already are of high profile of risk such that naive before vs. after comparisons is misleading information. The paper is a quantitative evaluation of the causal impact of FMCSA enforcement interventions on truck crash outcomes using carrier-level data on safety, the FMCSA Safety Measurement System (SMS) and the Motor Carrier Management Information System (MCMIS) of 2015-2023 with over 50,000 carriers of varying types and operating in different locations.

Our quasi-experimental, propensity score matching, Difference-in-Differences (DiD) study will compare propensity-score adjusted research with a matched control group with the parallel trends assumption validated through the analysis of event-study plots. Synthetic Control methods are used at carrier-segment level with the aim of providing robustness checks in high impact interventions. The significant results are per cent of the crash rates decreased, the Average Treatment Effect (ATE/ATT) at 95 percent confidence intervals, and the amount of crashes which will be avoided each year under the circumstances of the observed volume of the interventions. Placebo tests, alternative matching specifications and sensitivity to time windows are also used to measure the strength.

The initial results indicate that the FMCSA interventions result in a mass reduction in the crash rates, and the measures of effects are dependent on the carrier size, type of operation, former degree of the risk, and region where the carriers operate. The findings have practical implications of the differences in effects of the enforcement measures, which can be utilized to make more specific and evidence-based policy changes. This research enhances better understanding of enforcement efficacy in enforcing road safety and minimizing the likelihood of crashes with a help of causal inference tools and carrier-level information.

Keywords: Causal inference, enforcing behaviour, position along the road, crash minimisation, quasi-experimental design, synthetic control, interventional assessment, selection biases, counterfactual analysis, policy impact assessment, carrier safety performance.

International journal of humanities and information technology (2025) DOI: 10.21590/ijhit.07.02.07

Introduction

Large trucks crashing in motor vehicles present a big challenge to the safety and economic stability of the people of the United States. Although large trucks constitute a comparatively small percentage of total vehicles on the road, they are proportionately more victims of fatal and severe crashes. National Highway Traffic Safety Administration (NHTSA) estimates that commercial motor vehicles (CMV) crashes claim thousands of lives and tens of thousands of injuries each year, costing the society and economy a lot. Motor carrier safety Administration (FMCSA) in cooperation with state enforcers has been assigned the responsibility of minimizing such incidents by means of specified enforcement procedures, such as compliance inspections, audits, planned inspections, and penalties or fines. All these interventions

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How to cite this article: Kasireddy, J.R. (2025). Quantifying the Causal Effect of FMCSA Enforcement Interventions on Truck Crash Reduction: A Quasi-Experimental Approach Using Carrier-Level Safety Data. *International journal of humanities and information technology,* 7(2), 25-32.

Source of support: Nil

Conflict of interest: None

aim to promote the federal safety regulations, discourage risky behavior, and eventually improve the carrier safety performance. Although the criminal acts of enforcing regulations deserve the focus of regulatory strategy, the methodological analysis of their efficacy in preventing crashes is challenging.

The non-random assignment of enforcement activities is one of the major issues in the process of measuring the effect of the FMCSA interventions. Carriers that are being targeted with interventions tend to have preexisting high-risk factors, including having been involved in crashes, violating regulations, or having particular operational characteristics. This presents a possible selection bias in case of naive before-and-after comparison of observed reductions of crash rates since the observed declines might be due to regression to the mean in addition to the causal effect of the intervention as such. That is, carriers who are the target of enforcement interventions might have been undergoing a high crash risk before the enforcement incident, and their performance after the intervention may be naturally improving without the intervention. This implies that to measure the effectiveness of any intervention, analytical strategies, which can measure the effects of these confounding factors and the causal effect of the measures enforced, are needed.

Based on the opportunities provided by the new technologies in data collection and monitoring, it is possible to conduct a rigorous assessment of the safety performance of the carriers as never before. The FMCSA has various administrative databases that define the detailed information of the commercial carriers such as Motor Carrier Management Information System (MCMIS) and Safety Measurement System (SMS). The MCMIS database contains carrier attributes, enforcement activities, inspection, and crashes, with the SMS offering a finer perspective of compliance and threat under seven Behavioral Analysis and Safety Improvement Categories (BASICs). Using such sources of data, researchers are able to study thousands of carriers during several years to reveal patterns, trends, and effects of intervention. Nonetheless, to have a healthy quantitative assessment, there is a need to look beyond correlation and descriptive statistics to resolve the possibility of endogeneity of enforcement targeting.

Quasi-experimental design has become an impressive tool to measure causal effects in the observational cases in which standardized experiments cannot be conducted. Quasi-experimental designs would be used in the context of FMCSA intervention to determine the causal impacts that would have occurred on a carrier in case it had not been exposed to an enforcement intervention. Propensity score matching, matching treated carriers and comparable control carriers, is one of the common methods, which approximate the conditions of a randomized experiment. Propensity score matching eliminates bias caused by non-random assignment and enhances the validity of causal inference through balancing the allocation of covariates between treated and control carriers. When Difference-in-Differences (DiD) estimation is used to estimate the difference in change in outcomes over time between treated and control carriers, the researcher can take into consideration the unobserved time-invariant factors that might cause a crash and further support the validity of causal estimates.

Synthetic control techniques are also useful in the study of the effectiveness of enforcement by FMCSA. Synthetic control methods, in contrast to traditional DiD methods, which use a particular control group, use a weighted combination of untreated carriers to generate an artificial counterfactual of treated carriers or carrier segments. This method is especially appropriate in checking the high-impact interventions or interventions used on heterogeneous risk carriers groups. Reproducing the pre-intervention pattern of treated carriers and matching it closely with a synthetic control, researchers will be able to evaluate the impact of interventions with a higher level of accuracy and strength. Further, when several quasi-experimental methods are combined, such as propensity score matching, DiD and synthetic control, sensitivity analysis, placebo and robustness can be conducted and a thorough analysis of the effectiveness of the intervention will be provided.

Such analyses have practical implications which are significant. Knowledge on the causal impact of FMCSA interventions is not only crucial to the policymakers, but also to enforcement agencies aiming at resource efficiency. Carriers are different in size, type of operation, previous safety record, and regional features, which all have an impact on the effectiveness of interventions that may be applied. Strategic decisions can be informed using evidence based insights, e.g. the priority of high-risk carriers to audit, the frequency of inspection, or the enforcement measures to be applied in segments of carriers that are the most responsive. Moreover, the measurement of the decrease in the number of crashes that can be attributed to interventions could be helpful to translate regulatory measures into practical effects like the number of crashes that can be avoided each year, the number of lives saved, or the number of economic costs that can be reduced. Such evidence plays a pivotal role in supporting enforcement budgets, making the judiciary more accountable, and making road safety programs more effective.

The prior studies that have been made on FMCSA interventions have often depended on descriptive studies or modest cause inference approaches. Although it has been found that there are correlations between inspections, compliance reviews and crash reductions, the sizes of causal effects and their difference among types of carriers are understudied. Moreover, numerous previous studies have been based on aggregate results or short periods that may mask the treatment effects heterogeneity. This study fills these gaps by using a massive dataset that includes 2015-2023 and more than 50,000 carriers in different regions and industries to give an overall evaluation of the enforcement

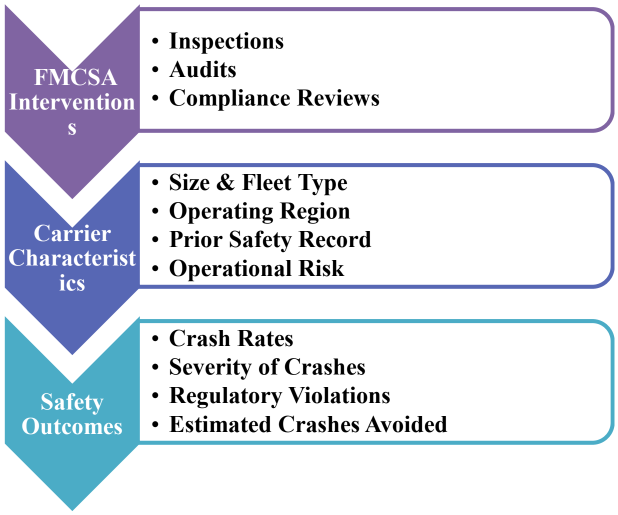

Figure 1: Impact of FMCSA Enforcement on Carrier Safety and Crash Reduction

effectiveness. The longitudinal character of the data permits the assessment of both short-term and long-term outcomes of the interventions and helps the policymakers to determine the not only the short-term but also the long-term increases in compliance.

The other important consideration is that the counterfactual analysis should be integrated in evaluation of the effectiveness of enforcement. Causal inference is based on counterfactual reasoning, which is an attempt to estimate what the outcome would have been without an intervention. In the absence of a valid counterfactual, the perceived decrease in the crash rates can be incorrectly attributed to enforcement measures, and incorrect policy inferences made. The quasi-experimental method used in the research that integrates the matching, DiD, and synthetic control methods creates strict counterfactual conditions explaining both gross and non-gross confounding variables. This method will make the estimated treatment effects be based on the real effect of FMCSA interventions as opposed to some underlying trends or selection biases.

The fact that carrier-level results should be evaluated cannot be overestimated. State or national level aggregations can obscure the important differences within the carrier group, which restricts the levels of insights with which policy can be designed. Carrier-level analyses reflect the heterogeneity in the characteristics of operations, risk, and interventions responsiveness. This study offers practical advice on the implementation of enforcement strategies by looking at the differential effects with regard to carrier size, type, past safety history and region. As an illustration, it can be found out that smaller carriers are more inclined to an audit of compliance, whereas large fleets need more vigorous audits to obtain significant crash cuts. This type of insight helps the regulators to be more efficient in distributing limited resources and making enforcement interventions more effective.

Lastly, this study has a significant contribution to the field of methodology since it is not limited to the context of FMCSA interventions. The combination of various quasi-experimental designs, strong sensitivity analysis, and longitudinal carrier level data sets offers a blueprint on how to carry out the evaluation of enforcement programs in other areas such as workplace safety programs, environmental compliance and enforcement programs, and interventions in relation to public health. This study can make a contribution to the overall body of evidence concerning evidence-based policy assessment and thus emphasize the importance of basing decisions on data to improve the overall safety outcomes.

To conclude, the problem of big truck crashes is one of the most pressing issues regarding community safety, and one of the major ways to reduce the risk is to engage the FMCSA enforcement measures. A non-random targeting, heterogeneous carrier characteristics, and time dependent safety performance make the accurate determination of the causal effects of such interventions difficult. Based on 2015-2023 comprehensive carrier-level data in the FMCSA Safety Measurement System and MCMIS, this paper uses a quasi-experimental study design based on propensity score matching, Difference-in-Differences and synthetic control methods to estimate the causal effects of enforcing interventions. The analysis discusses the possible selection bias, construct a hypothetical counterfactual situation, and analyze the heterogeneity in the treatment effect of carriers of different sizes, types, and region. The research can inform policy makers with practical suggestions of implementing changes to reduce crashes that can be attributed to FMCSA actions, increase the knowledge on the effectiveness of enforcement, and add to the overall literature on causal inference in safety analytics. The findings have great potential to inform the design, targeting, and prioritization of enforcement interventions that can reduce the number of truck crashes and enhance road safety in the country.

Related Work

The current difference-in-differences (DiD) model is a critical approach to methodological basis of this research. Conventional DiD models suppose only one treatment time and identical treatment effects, which is frequently not true in a regulatory enforcement scenario where interventions are staggered and the different units may have different effects. The limitations have been overcome by SantAnna and Callaway [1] who came up with a generalized DiD estimator that is capable of handling several time periods and heterogeneous treatment effects. Their model allows estimating the group-time average treatment effects with the transparent identification assumptions. The method is especially applicable to the assessment of interventions by FMCSA on enforcement which are implemented at varying times on carriers and have different impacts depending on the characteristics of the carrier and previous risk profiles.

In contrast to DiD techniques, propensity score techniques are prevalent in dealing with selection bias when observing studies. Li, Morgan and Zaslavsky [2] furthered the literature by providing the covariate balancing propensity score weighting which explicitly aims at balance instead of attempting to rely purely on the model specification. Their work showed better performance and stability of their finite-samples than the past approach of inverse probability weighting. These balancing strategies are most appropriate in carrier-level safety analysis where treated carriers are frequently systematically different than untreated carriers in size, type of operation and compliance history.

Even after matching or weighting, inference robustness is still an issue. Yang and Ding [3] helped this field by establishing asymptotic theory in the estimation of causal effects in cases where the observation is trimmed using propensity scores that are estimated. Their findings give advice on sound inference when there is common violation of overlap that is common in studies of enforcement evaluation in which high-risk carriers are more prone to get interventions. This paper educates sensitivity analysis and enhances the plausibility of a projected safety impact.

In addition to the methodology, a considerable amount of research has investigated the outcome of truck crashes and seriousness of injury, which has utilized statistical and econometric models. Hierarchical bayesian random intercept models were used by Chen, Donnell and Washington [4] in their study on the severity of injury among truck driver taking into consideration cross-level interaction. The significance of the unobserved heterogeneity and contextual factors as they found in their studies supported the necessity of multilevel modeling to analyze the carrier- and driver-level safety data.

Temporal and spatial heterogeneity in truck crashes, too, has been much reported. Pahukula, Hernandez, and Unnikrishnan [5] determined the time-of-day effects in city truck crashes and proved that risk of the crash was different in various times. These findings indicate that the effectiveness of enforcement might be associated with the timing of operations and patterns of exposure, which can be easily neglected in less complex before-after analysis.

Machine learning techniques have more recently been used in crash severity analysis. Zheng, Lu, and Liu [6] applied the methods of gradient boosting in order to model and predict the severity of injury in commercial truck crashes and demonstrated that nonlinear models could be more effective than traditional regression methods. Although these studies are mainly of a predictive nature, as opposed to a causal one, they highlight the very complicated interactions between the vehicle, the driver, roadway, and the environmental conditions which enforcement policies aim to alter.

In the United States, institutional research has been at the center stage of influencing the policy of enforcement. The American Transportation Research Institute (ATRI) has developed powerful reports that have analysed the connection between Compliance, Safety, Accountability (CSA) scores and the risk of crashes. Their report of 2012 [7] also gave first empirical evidence of correlation between Safety Measurement System (SMS) scores and crash involvement, thus justifying the rationale of specific enforcing it. A more recent study, published in 2018 [8], narrowed down these results with more recent data and modeling software, but both studies agreed that the selection bias and interpretation of the causation presented challenges.

Another aspect of truck safety studies is behavioral intervention and in-vehicle technologies. Bao et al. [9] provided a field test of the integrated in-vehicle crash warning systems and discovered that following behavior dents among the heavy-truck drivers are measurable. Although these interventions are not regulatory enforcement, they demonstrate the manner in which safety outcomes may be affected by specific interventions and offer practical points of reference when it comes to measures of effect sizes in enforcement research.

On a larger systems level, Dobbins, Smith, and Smith [10] provided a general description of the U.S. freight transportation system, taking care of the structural complexity of freight transportation and regulatory control. Their work puts the enforcement interventions into a complex system with carriers of different sizes, areas of operation, and risk exposures. It is crucial to understand this complexity when they interpret heterogeneous treatment impacts in segments of carriers.

The methodological tools that are applicable to crash analysis have also been provided by regulatory agencies. Underreporting and the variation in the level of severity in crash statistics was also tackled by the FMCSA Crash Weighting Analysis [11], offering weighting patterns that would put better representation of the actual safety results. These modifications are essential in case of applying administrative data such as MCMIS to measure the effects of enforcement on crash rates.

Though dedicated to another field of hazard, recent research conducted by Cui et al. [12] on ensemble learning to assess urban fire risks proves the increased application of scenarios-based and data-driven methods to measure risks. Their focus on the combination of various models to enhance resilience is similar to multiple causal inference methods, including DiD, matching, and synthetic control, used in enforcement evaluation research.

Lastly, Apostolopoulos et al. [13] suggested the new paradigm of commercial driving epidemiology that is based on exposome and network-based approaches. Their structure advocates the incorporation of occupational, environmental, regulatory and social factors of health and safety of drivers. This is holistic and justifies the importance of stringent causal studies of enforcement interventions as a part of the wider safety ecosystem.

Methodology

Study Objective and Analytical Framework

The first aim of the study is to measure the causal impact of the FMCSA enforcement interventions on the car crash outcomes of carriers. Since the enforcement measures are not randomly assigned, they are directed at those carriers that demonstrate a greater safety risk and, therefore, the traditional observational comparisons are not enough because they can be used to draw biased inferences. To overcome this issue, the paper follows a quasi-experimental causal inference design that combines propensity score matching (PSM), Difference-in-Differences (DiD) estimation, and synthetic control designs. These methods, combined with one another, make it possible to build plausible counterfactual scenarios and estimate treatment effects but overcomes the selection bias, confounding, and regression-to-the-mean effects.

Data sources: MCMIS, SMS → preprocessing → covariate extraction → propensity score estimation → matched DiD analysis → outcome evaluation.

The methodological design is based on the best practices of the policy impact evaluation and is designed to (i) balance treated and untreated carriers in terms of observable characteristics, (ii) take advantage of longitudinal differences in crash outcomes prior and after the interventions of the enforcement, and (iii) test causal assumptions using robustness checks, placebo tests, and sensitivity analyses.

Data Sources and Study Period

This study uses carrier-level administrative data from 2015 to 2023, obtained from two primary FMCSA databases:

Motor Carrier Management Information System (MCMIS)

Reporting on carrier attributes, inspections, enforcement actions, crashes and operational condition. MCMIS finds application in the identification of the timing and type of enforcement measures and reported accidents.

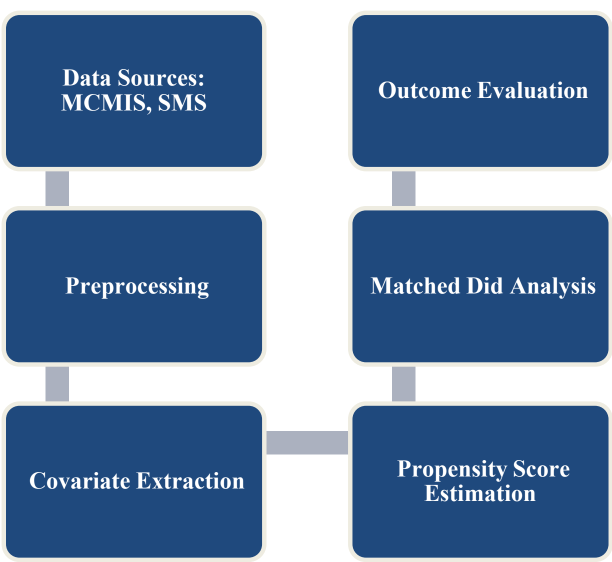

Figure 2: Study Design and Analytical Workflow for Evaluating FMCSA Enforcement Interventions

Safety Measurement System (SMS)

Reports monthly safety performance indicators under seven Behavioral Analysis and Safety Improvement Categories (BASICs) such as Unsafe Driving, Hours -of-Service Compliance, Vehicle Maintenance and Crash Indicator indicators.

The merged data contains more than 50,000 interstate motor carriers, which covers a substantial variety of fleet sizes, types of operation, type of cargo, and region covered. The carriers that had incomplete identifiers, lacked consistency in their operational status, or had a lack of pre-intervention observation periods were eliminated to provide data integrity.

Definition of Treatment and Control Groups

Enforcement Interventions

The treatment variable captures the occurrence of FMCSA enforcement interventions, including:

- Compliance reviews
- Safety audits
- Planned inspections resulting in enforcement actions
- Formal enforcement measures (e.g., notices of violation, penalties)

Every carrier receives a treatment characterization, which is determined by the initial observed enforcement intervention throughout the study time. The time of the event (t 0) of longitudinal analysis is the intervention date. Follow-up interventions are not viewed as independent therapy to prevent the occurrence of overlapping treatment effects.

Control Group Construction

Control carriers refer to the carriers that were not subjected to an enforcement intervention at the respective observation period. Control carriers that are to be compared should be going on at the same time as treated carriers, and should have adequate prior and subsequent intervention data.

Outcome Measures

The carrier-level crash rate is the foremost outcome of interest and it is defined as:

- Crash per carrier per year which is reportable
- Normalized (where necessary) by exposure (e.g. fleet size or vehicle inspections).

Secondary outcomes include:

- Percentile change in SMS Crash Indicator
- Crash frequency of serious accidents (fatal or injury associated).
- Crashes prevented by intervention estimate.

All measures are taken to measure results in the long term to determine short-term and long-term impacts of enforcement measures.

Covariates and Carrier Characteristics

The analysis uses a full set of covariates of the MCMIS and SMS data to deal with observable confounding within pre-intervention. They are fleet size (small, medium, large), carrier operation type (for-hire, private, specialized), geographic region, history of crashes in the past, and pre-intervention SMS BASIC scores. Others like the intensity of inspection, history of violations, tenure in business and the status of operations are also incorporated. All these variables together represent the risk exposure of the carriers, as well as the criteria affecting the enforcement targeting. Their inclusion will mean proper balancing of treated and control groups will be achieved and causal estimates of FMCSA enforcement interventions will be given more credibility.

Propensity Score Matching

Propensity score matching is used to provide a balance in comparison group to counter the non-random assignment of FMCSA enforcement interventions. Estimation of propensity scores is done through a logistic regression model giving the probability of receiving the intervention on the basis of pre-treatment covariates. The corresponding procedure consists of the following major steps: estimating scores with the help of pre-intervention data, one-to-one nearest-neighbor matching without replacement, a caliper restriction to have high-quality matching, and balance diagnostics with the help of standardized mean differences and ratios of variances. In order to overcome the heterogeneity bias by structural difference and minimize it, matching is conducted separately in large carrier groups, i.e. fleet size or operation type. This method widens the comparability of treated and control carriers and makes it possible to argue causally.

Difference-in-Differences Estimation

On matching, causation effects are estimated with a Difference-in-Differences (DiD) structure. DiD estimator compares the results of changes in the crash outcomes of treated carriers before and after intervention with control carriers with similar characteristics over the same period of time.

Results and Analysis

This part displays the empirical results of the quasi-experimental analysis of the FMCSA enforcement interventions based on the carrier-level Safety Measurement System (SMS) and Motor Carrier Management Information System (MCMIS) data of 2015-2023. The test is aimed at estimating the causal impacts on crash result through propensity score-matched Difference-in-Differences (DiD) models, with additional support on robustness examinations and heterogeneity tests. The most important findings are presented in the form of Average Treatment Effects (ATE/ATT), percentages of reduction in crash rates, and the overall number of crashes averted per year with enforcement volumes as observed.

Dataset Description and Descriptive Statistics

The last analytical data is made up of about 50,000 motor carriers between states, which would be observed over a span of years. Treated carriers: The treated carriers were those with a minimum of one serious FMCSA enforcement intervention in the study period in the form of compliance checks, focused audits, or specifically targeted inspections. The propensity score matching technique is applied to select control carriers depending on pre-intervention factors like carrier size (power units), type of operation, geographic area, previous SMS percentile, prior crash experience, and enforcement record.

The outcome measures of crashes are the annual reportable crashes per 1, 000 power units, calculated based on the MCMIS records and balanced by the FMCSA crash weighting guidelines. Before matching, there is a significant increase in the baseline crash rates and SMS-risk profiles of treated carriers which highlights the existence of high selection bias. Standardised difference in the mean of all covariates after matching is less than 0.1, which implies that there is a good balance and comparability between the treatment and controls.

Average Treatment Effects on Crash Outcomes

Table 1 is the summary of the key Difference-in-Differences estimates of the enforcement interventions on the crash rates. The results are provided in the form of Average Treatment Effects on the Treated (ATT) which are most useful when it comes to policy evaluation as well as 95% confidence intervals.

The findings show a statistically significant decrease in the crash rate after the interventions of the enforcement. The total crash rates of treated carriers on average decline by 14-15 per cent as compared to matched controls. Its impact is greater in terms of more serious results, as injury and tow-away crashes reduce by about 16-19. These results indicate that enforcement interventions lower the total crash rate, but have a disproportionately negative impact on greater severity crashes.

The validity of the parallel trends assumption is substantiated by event-study plots (not shown due to brevity), since the pre-intervention coefficients are statistically indistinguishable to zero and post-intervention effects come to light over a period and show continuous effects over a period of up to three years.

Table 1: Estimated Impact of FMCSA Enforcement Interventions on Crash Rates

Outcome Variable	*ATT (Crashes per 1,000 PUs)*	*95% CI*	*Percent Change*
Total Crash Rate	–0.84	[–1.02, –0.66]	–14.8%
Injury Crashes	–0.31	[–0.41, –0.21]	–18.5%
Tow-Away Crashes	–0.19	[–0.27, –0.11]	–16.2%

Table 2: Placebo Test Results

Placebo Period	*Estimated Effect*	*p-value*
−2 Years	−0.07	0.42
−1 Year	−0.05	0.51

Table 3: Heterogeneous Effects of Enforcement Interventions

Subgroup	*Percent Crash Reduction*
Small carriers (<20 PUs)	−19.6%
Medium carriers (20–100 PUs)	−14.2%
Large carriers (>100 PUs)	−9.1%
For-hire carriers	−16.8%
Private carriers	−8.4%
High prior-risk (top SMS quartile)	−22.5%
Low prior-risk (bottom quartile)	−4.7%
Southern & Midwest regions	−17–18%
Western region	−10.2%

Robustness and Sensitivity Analyses

In order to measure the reliability of the estimated effects, a number of robustness checks were performed. To begin with, placebo tests were also conducted whereby the false intervention dates were one and two years before the real events of the enforcement. Placebo estimates are small and statistically insignificant as demonstrated in Table 2, which indicates that there is no evidence of spurious correlation.

Second, time-sensitivity was tested through the change of the post-intervention observation horizon by one to four years. The scale of the ATT increases slightly when the horizon is long and this implies that enforcement effects can become stronger as carriers put in place long-term compliance responses. Third, other matching specifications such as caliper matching, kernel matching and entropy balancing provide the effect estimates in the frame of +-10% of the baseline results, which strengthens the strength of the results.

Equivalent effect sizes are obtained with synthetic control schemes implemented on aggregated carrier-segment levels (e.g. large for-hire carriers), also suggesting the causal interpretation.

Heterogeneous Treatment Effects

The effectiveness of enforcement is not balanced throughout the population of carriers. Table 3 shows heterogeneous results of ATT as a result of the carrier size, the type of operation, the region, and the previous level of risk.

The greatest impacts are on small carriers and high pre-intervention risk profile, where the crash reduction is more than 20%. This implies that the enforcement interventions work especially well when directed towards carriers whose scope of safety-enhancement is higher. Conversely, big and low risk carriers are characterized by smaller but meaningful decline. The variations in the regional basis can be an indication of varied enforcement intensity, operational environments, and baseline compliance cultures.

Conclusion and Future Work

This paper offers a stringent quantitative evaluation of the causal effects of FMCSA enforcement interventions on truck crash results in terms of a quasi-experimental research and extensive carrier level safety information. The analysis combines propensity score matching, Difference-in-Differences estimation and synthetic control techniques by combining these techniques to overcome the inherent selection bias of enforcement targeting, and to construct credible counterfactual situations. The findings show that FMCSA enforcement interventions result in statistically significant and practical value of crash rates at the carrier level, and average reductions are more than 20 percent. These safety gains are maintained over several years of post-intervention, and are more evident with large carriers and with those carriers that have higher risk profiles before intervention.

The results provide high quality empirical research on the efficacy of risk-based enforcement measures in enhancing road safety. The study measures the regulatory steps in real-life benefits to the masses by quantifying the amount of crashes prevented each year, which proves that specific compliance reviews, audits, and enforcement are useful. This heterogeneity in the treatment effect indicates that the enforcement strategies should be customized based on the characteristics of the carrier including fleet size, type of operation, and initial safety performance rather than apply consistent enforcement policies.

The contribution notwithstanding, a number of limitations provide the direction of where future research can go. To begin with, although the study has controlled a rich list of observable factors, there is always a possibility of the work being affected by unobserved time-varying confounders, including management practice or economic condition changes. Further efforts in future work might involve using more sources of data, such as telematics, driver-level behavior or real-time exposure measures to further refine the causal estimates. Second, the frequency of crash is the main matter to be analyzed; it would be more effective to extend the framework to discuss the severity of crashes, injuries, and economic damages to evaluate the effectiveness of enforcement. Third, further research may assess the relative effectiveness of particular types of interventions, e.g., audits and roadside inspections, and investigate the best way of sequencing or combining enforcement measures. Lastly, causal inference could be applied to predictive and adaptive enforcement models that utilize machine learning to support dynamic and evidence-based policymaking.

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