Efficacy of Electronic Monitoring:

An Investigation of Electronic Data Logging Regulation and Motor Vehicle Crash Fatalities

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ABSTRACT

The use of electronic performance monitoring is becoming increasingly widespread in conjunction with the digitalization of today's supply chains, yet the efficacy of these systems to improve desired performance outcomes is still highly uncertain. This study examines the effect of a federal regulation mandating the adoption of electronic data logging devices for commercial truck drivers in late 2017 and the efficacy of this regulatory effort in improving safety through an analysis of motor vehicle fatalities pre- and post-mandate. Results of a difference in difference estimation show the ELD mandate failed to reduce motor vehicle fatalities, and, in fact, may have increased overall fatality rates. These findings suggest that the expected benefits of electronic monitoring are likely to be highly contingent on proper design and implementation and a failure to consider the broader effects may lead to negative outcomes.

KEYWORDS

Commercial Trucking, Difference in Difference, Electronic Performance Monitoring, Safety Performance

INTRODUCTION

The increasing digitalization of the supply chain enables firms to record and monitor the end to end activity of a supply chain, including individual employee behaviors (Dhamija et al., 2020). While much has been made of the potential operational benefits associated with these technologies (Baritto et al., 2020; Matani, 2020), scholars have also noted that the implementation of these digital tools often includes the ability of employers to closely monitor employee performance and compliance with policies (Daus, 2019; Laguir et al., 2022; Verma, 2017). This use of electronic performance monitoring (EPM) has met with mixed results in the extant literature, with some studies finding it can increase employee productivity and resource planning (Kalischko & Riedl, 2021) while others find the use of EPM can lead to lower morale, lower job satisfaction, higher stress (Jeske & Santuzzi, 2015; Kalischko & Riedl, 2021; Rafnsdóttir & Gudmundsdottir, 2011) and may incentivize counterproductive work behaviors (Shaffer & Darnold, 2020), especially behaviors not subject to increased monitoring (Scott et al., 2021).

One industry where the impacts of EPM on individual behaviors are of particular interest is that of the commercial trucking industry in the United States. Beginning December 2017, the US Department of Transportation mandated the use of electronic logging devices (ELDs) for all nonexempt interstate carriers. These ELDs represent a widespread, mandatory adoption of EPM as they use data from a

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truck's engine to automatically record information on the amount of time each driver operates their vehicle to allow inspectors to verify driver compliance with federal hours of service (HOS) regulations. Additionally, these data may also be accessed by employers to monitor driver activity for adherence to company policy and to maximize employee productivity (Trucker, 2017).

Importantly, research into the use of ELDs to affect driver behavior shows conflicting results. For example, Cantor et al. (2009) find that carriers with higher percentages of trucks with ELDs had fewer HOS violations as well as fewer crashes and Miller et al. (2018) demonstrate a significant link between a carrier's ability to monitor drivers using technology and compliance with HOS regulations. On the other hand, a recent study by Scott et al. (2021) reports that while the ELD mandate increase HOS compliance rates, it was also linked with a relative increase in unsafe driving and crashes, especially for small trucking firms. The impact of this ELD mandate thus, remains uncertain. Moreover, while studies have considered the associated effects on compliance rates and crashes, these fall short of linking the ELD regulation with is overarching purpose, to improve roadway safety (FMCSA 2015). With commercial truck drivers accounting for approximately 10% of all annual vehicle miles traveled in the United States and large trucks involved in over 4,000 fatal crashes per year (FMCSA, 2021), it is critical to understand how the use of EPM through ELDs may affect drivers of large trucks, especially any impacts on safety (Ravid et al., 2020). As such, this study attempts to answer the following research questions, 1) What is the effect of the ELD mandate on fatal crashes involving large trucks as well as the number of fatalities in these crashes? and 2) How did the ELD mandate affect fatal crashes and fatalities involving key factors not monitored using ELDs?

BACKGROUND

Commercial Trucking Industry

The trucking industry acts as a critical backbone of the US economy. Data from the Federal Motor Carrier Safety Administration (FMCSA) suggest that 64% of all freight moved in the United States by weight in 2018 was via truck and that between 2016 and 2019 large trucks represented nearly 10% of all vehicle miles traveled annually (FMCSA, 2021). Importantly, these large trucks were also involved in nearly 13% of all fatal crashes in the United States. The impacts of these crashes are not limited to the drivers of the trucks only, as data from 2017 show that 72% of people killed in large truck crashes were occupants of other vehicles (FMCSA, 2018). As such, measures taken to promote safety in the trucking industry have an impact on the broader public at large.

One primary mechanism used by the FMCSA in their goal to improve safety associated with large trucks is regulations related to driver HOS. The Interstate Commerce Commission first introduced HOS limits to truck drivers in 1937 to address safety concerns related to driver fatigue, mandating 8 hours off after 10 hours of driving time. Since then, the HOS regulations have gone through numerous iterations to balance safety with the need to keep products moving (SCDigest, 2020). To enforce HOS regulations, the FMSCA requires commercial truck drivers to record their work hours in a log book which is reviewed for compliance during roadside inspections and/or carrier safety reviews (Pitera et al., 2013).

One of the most controversial changes to the HOS regulations was a federal mandate requiring all nonexempt interstate carriers to install ELDs as of December 18, 2017. Proponents of this ELD mandate argue that the use of electronic monitoring in this application can reduce driver fatigue and related accidents through improved compliance with HOS regulations and reduce aggressive driving such as speeding and aggressive braking maneuvers (Pauline, 2019). Others argue that the pressure to adhere to strict time limits regardless of adverse conditions and the ability of ELDs to enable dispatchers to force drivers to use all of their available driving hours could lead to drivers operating in unsafe manners (American Trucker, 2017), with one trucking company owner claiming the mandate, "…causes drivers to be more dangerous because they're losing their driving time on

these ELDs, and it's causing them to cut other drivers off, speed through school zones" (WHNT, 2017). Interestingly, researchers have found conflicting impacts related to the use of ELDs, with an FMSCA report prior to the mandate showing an 11.7% lower crash rate (5.1% lower preventable crash rate) for commercial drivers using electronic-logging (Hickman et al., 2014) but a more recent study after the enactment of the ELD mandate finding that smaller trucking firms had a significant increase in unsafe driving behaviors after the ELD mandate took effect and the crash rate across all trucking firms increased despite greater adherence to HOS regulations post-ELD mandate (Scott et al., 2021). While unsafe driving and crashes are important factors to evaluate, this paper specifically investigates the effect of the ELD regulation on motor vehicle fatalities to examine if the key goal of improving roadway safety (FMCSA 2015) was achieved.

To examine the effect of EPM in the form of ELDs on safety, this study builds on and extends work done by Scott et al. (2021). Their study considers the effect of the ELD mandate on HOS compliance rates in the initial 5 months after the mandate went into effect based on trucking company size. Importantly, they find that after the mandate took effect, HOS violations fell relative to a control group of 8 carriers that had implemented ELDs prior to the mandate. Additionally, they find a relative increase in moving violations related to unsafe driving as well as overall crash rates as compared to the control group of carriers. While this research provides an invaluable initial step into understanding the impacts of the ELD mandate, it opens the door to several more questions that have not yet been answered. Specifically, their study is limited to the short-term effects of the ELD mandate and impacts on moving violations and overall crash rates in comparison a control group of carriers. This study seeks to examine the longer-term effects of this regulation through analyzing data two years pre- and post-mandate and focuses on more salient measures of safety – the number of fatal crashes involving large trucks and the total number of deaths in these crashes. Additionally, this study investigates the impact of the ELD regulation on the broader public through examining the number of these fatalities associated with individuals not in a large truck (i.e., those in passenger vehicles, cyclists, pedestrians, etc.). Furthermore, this study examines fatal crashes that occurred under key factors not monitored through the ELD to shed light on how changes in driver operations under EPM may affect fatal accident rates.

ELECTRONIC PERFORMANCE MONITORING

Electronic performance monitoring has become increasingly ubiquitous in recent years as a tool for managers to assess employee behavior and evaluate performance (Rafnsdóttir & Gudmundsdottir, 2011). While EPM has been linked to improved employee performance through productivity increases and better resource planning (Kalischko & Riedl, 2021), much of that is predicated on the inclusion of employees in the decision-making process of which behaviors to monitor and how they are applied to ensure performance standards are met (Jeske & Santuzzi, 2015) and through linking employee behavior to positive incentives (Latack, 1986). Importantly, EPM has also been associated with higher employee stress, lower job satisfaction, lower morale, and lower affective commitment, especially when monitoring is continuous (Jeske & Santuzzi, 2015; Kalischko & Riedl, 2021; Rafnsdóttir & Gudmundsdottir, 2011). Research suggests the use of coercive control systems, those used to monitor employee behavior, measure compliance with organizational rules, and sanction punitive measures in the case of noncompliance (Adler & Borys, 1996; Weaver & Trevino, 2001), may, in fact, increase counterproductive work behaviors (Shaffer & Darnold, 2020).

Extending the application of EPM to the trucking industry, it is not clear, ex ante, how ELD and the continuous monitoring of driver behavior may affect safety performance. For example, Bates and Gawande (2003) suggest that the monitoring of tasks that require attention and safety increase safety behavior and Scott et al. (2021) find that while the ELD mandate increased driver compliance with HOS regulations, the associated dissatisfaction and stress may negatively affect other driver behaviors. Indeed, the trucking industry is one that features high levels of driver autonomy and discretion,

characteristics that have been linked to more significant negative impacts from the introduction of close monitoring practices (Carter et al., 2011).

In situations where employees react negatively to tracking technologies, research shows there is a greater probability of deviant behavior and attempts to circumvent electronic monitoring, substantially reducing the efficacy of such technology implementations (Duane & Finnegan, 2007). Moreover, with driver pay typically linked to miles traveled, exerting greater rigidity with respect to driver HOS compliance creates incentives for drivers to find alternate means to drive further in a set period of time, such as increasing speeds and/or operating in riskier conditions (Trucker, 2017). This is particularly salient as work by Brewer (1995) finds that monitoring specific tasks leads individuals to focus on satisfying the performance expectations of the monitored tasks at the expense of other, unmonitored tasks. In this case, the monitoring of HOS and associated need for drivers to adhere to those requirements may come at the expense of driving within the speed limit or operating only in safe conditions. Furthermore, the voluntary use of electronic-logging has been associated with a lower crash rate (Hickman et al., 2014) while the mandated use of ELDs has been linked to an increase in unsafe driving behaviors and crash rates (Scott et al., 2021). Thus, it is an unclear and important question to consider if the electronic monitoring implemented via the ELD mandate has successfully reduced large truck-related traffic fatalities or not.

DATA AND METHODOLOGY

To examine the effect of the ELD mandate on fatal motor vehicle crashes, this study takes advantage of the quasi-experimental nature of the federal legislation to compare the outcomes of a treated group (drivers of large trucks) with a control group (all other motor vehicle drivers) using a difference in difference (DID) estimation approach. This legislative phenomenon provides a mechanism to infer causality through the use of fixed effects to control for ex ante differences in the units of observation (states), a common practice in economics and social science (Bertrand et al. 2002). This entailed collecting data on all fatal crashes in the United States from approximately two years prior to the mandate (January 2016) through approximately two years after it was enacted (December 2019). The Fatality Analysis Reporting System (FARS) was the primary source of these data as it contains a census of fatal traffic crashes within the United States. Federal law requires local police departments to submit detailed information related to vehicles and people involved in any fatal motor vehicle accidents. This information is collected and made publically available through the US Department of Transportation and the National Highway Traffic Safety Administration via FARS. The data are broken out into separate files on an annual basis that provide information on each accident, the vehicles, and each person involved. Importantly, the FARS data include an indicator for vehicles defined as large trucks based on gross vehicle weight and body type. Using this as an initial filter, these vehicles were then reviewed for accuracy and were reclassified if identified as a medium/heavy pickup, step van, or unknown (fewer than 10% of the vehicles identified as large trucks in the sample), to provide a more accurate examination of the ELD mandate as the regulation only applies to interstate commercial trucking and these vehicles are more typically used in local deliveries (e.g., FedEx, UPS), as food trucks, or represent large pickups like the Ford Super Duty.

Using common case identifiers, it was possible to construct a large panel set of data containing details on 136,206 fatal crashes across the United States from 2016-2019, of which 17,437 involved a large truck as defined in this study. To conduct the DID analysis, the data were aggregated to reflect 4896 observations spanning 48 months and 51 states (including Washington, D.C). A full set of descriptive statistics and correlations are provided in Tables 1 and 2, respectively.

VARIABLE DEFINITIONS

Dependent Variables

This study makes use of several related, but distinct measures of motor vehicle fatal incidents. *Crashes* is a count of fatal motor vehicle crashes, *Crashes - Speeding* is a count of fatal motor vehicle crashes where at least one vehicle involved was speeding, and *Crashes - Weather* is a count of fatal motor vehicle crashes occurring in inclement weather conditions (e.g., snow, fog, rain). *Deaths* is a sum of fatalities caused by motor vehicle accidents (including drivers, passengers, and pedestrians). *Non-LT Deaths* represents the sum of fatalities of individuals not seated in a large truck at the time of the crash. *Deaths - Speeding* and *Deaths - Weather* are total number of fatalities of individuals in crashes where either at least one vehicle was speeding or there were inclement weather conditions, respectively.

Independent Variable

The primary independent variable of interest is *Post-ELD Regulation*, which is a dichotomous treatment indicator that indicates the enactment of the ELD mandate for large trucks. This variable is coded as 1 for the large truck sample for all subsequent time periods beginning when the ELD legislation went into effect, December 2017.

Control Variables

Total vehicles is a control variable that captures the total number of vehicles involved in fatal accidents where either large trucks are involved (treated sample) or no large trucks are involved (control sample) in each state and month. *Owner-Operator* captures the number of large truck involved in fatal accidents that were driver by an owner-operator, as previous research suggests a difference in safety performance for owner-operators as compared to commercial drivers (Cantor, 2016; Cantor et al., 2013). *Large Truck Dummy* is an indicator variable that takes the value of 1 if the sample group represents fatal crashes involving large trucks and 0 otherwise. Additional data on the total vehicle miles traveled on a monthly basis per state, *VMT (log)*, were collected from the Federal Highway Administration's Traffic Volume Trends data, a monthly report based on hourly traffic count data reported by each state, and was log transformed to account for skewness in the data. Finally, previous research suggests that traffic fatalities are procyclic and as such, monthly state *unemployment* rates are included as a control variable (Jacobson, 2003).

Table 1. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Crashes	4,896	27.82	44.19	0	304
Crashes - Speeding	4,896	7.19	11.96	0	97
Crashes - Weather	4,896	6.81	11.62	0	137
Deaths	4,896	30.22	47.85	0	331
Non-LT Deaths	4,896	23.56	36.09	0	266
Deaths - Speeding	4,896	7.56	12.21	0	94
Deaths - Weather	4,896	6.04	9.85	0	96
Post-ELD Regulation	4,896	0.26	0.44	0	1
Total Vehicles	4,896	43.79	67.24	0	483
Owner-Operator	4,896	1.08	2.60	0	30

Table 1 continued

Variable	Obs	Mean	Std. Dev.	Min	Max
Large Truck Dummy	4,896	0.50	0.50	0	1
VMT (log)	4,896	8.09	1.03	5.32	10.41
Unemployment	4,896	4.04	1.07	1.50	7.60

Table 2. Correlation matrix

|	Variable	1	2	3	4	5
1	Post-ELD Regulation	1.000				
2	Total Vehicles	-0.002	1.000			
3	Owner-Operator	0.243	0.007	1.000		
4	Large Truck Dummy	0.593	-0.006	0.388	1.000	
5	VMT (log)	0.004	0.019	0.367	0.000	1.000
6	Unemployment	-0.201	-0.010	0.033	0.000	0.066

EMPIRICAL ESTIMATION

To examine the effects of the ELD mandate on fatal traffic accidents, this study considers both broad impacts on the total number of fatal crashes and associated fatalities as well as the impacts on fatal crashes where speeding or adverse weather conditions were involved in the accident and the impact of the ban on deaths of individuals not in a large truck (representing the broader public). In this way, it is possible to examine how the ELD legislation has affected crash rates in a variety of operating conditions, including those that drivers may feel obligated to operate within based on increased monitoring. The effect of the ELD mandate on motor vehicle fatalities is modeled using the following equation:

$$Y_{gst} = A_g + B_t + cX_{gst} + \beta_{gt} + \varepsilon_{gst} \qquad (1)$$

Where Y_{gst} represents motor vehicle fatalities of group g (large truck involved accidents or non-large truck involved accidents) in state s at time t and T_{gt} is a dummy indicating whether the intervention has affected group g at time t. A_g and B_t are fixed effects for the group and months and X_{gst} represents relevant state-level controls. indicates the error term. One important assumption in a DID model is that of common trends, that is, the treatment and control groups demonstrate parallel trends over time prior to the introduction of the treatment effect (Angrist & Pischke, 2008; Wing et al., 2018). As shown in Figure 1, the pre-treatment trends for the 23 months prior to the effective date of the ELD mandate demonstrate both large truck-involved fatalities and all other traffic fatalities follow significantly parallel trends, with a correlation coefficient of 0.867. Additionally, the use of DID estimation techniques in panel data creates concerns of serial correlation in the dependent

variable, especially when a treatment variable is not expected to change within a state over time, such as with the passage of legislation (Bertrand et al., 2004). This serial correlation may therefore lead to bias in the standard errors of regression coefficient. To correct for this concern, all standard errors are clustered at the state level, an effective mitigation technique when using a large number of treated units (states) (Bertrand et al., 2004). Given the non-negative, count nature of the dependent variable the equation is estimated using a Poisson regression model. Results are reported in Table 3.

Figure 1. Pre-treatment trends of motor vehicle fatalities
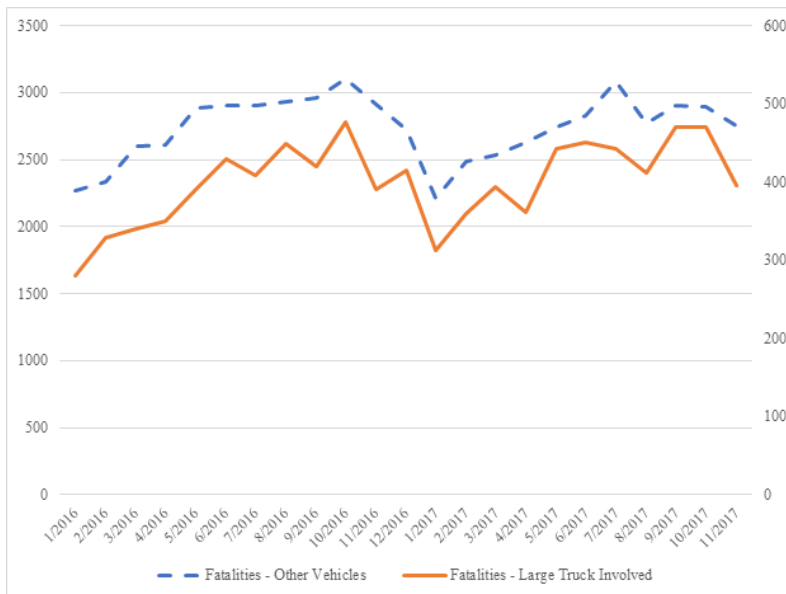
RESULTS

The results of the DID estimation are provided in Table 3. Model 1 reports the results of the ELD regulation treatment effect on fatal crashes in the United States. The positive and significant effect of *Post-ELD Regulation* indicates that rather than reducing the total number of fatal motor vehicle crashes, the enactment of the ELD regulations actually leads to an overall increase in fatal crash rates. To further consider how this regulation may have affected motor vehicles crashes, Model 2 introduces a dependent variable that represents fatal crashes where at least one vehicle was speeding and Model 3 represents fatal crashes that occurred under adverse weather conditions (e.g., rain, snow, fog). Here again the results suggest that the rollout of the ELD regulation has led to increasing numbers of fatal accidents in poor weather conditions and where speeding is involved. The analysis next turns to the overall number of fatalities associated with these crashes. Model 4 again shows the increase in overall deaths after the ELD regulation went into effect. In Model 5, only deaths of individuals not in a large truck were considered (essentially, an analysis of the impact of this regulation on the safety of the broader public), with another positive and significant result. Finally, Models 6 and 7 replicate Models 2 and 3 using the total number of deaths and again demonstrate the resulting increase in deaths in fatal crashes occurring under these conditions.

Table 3. Poisson difference in difference estimation

VARIABLES	Model 1 Crashes	Model 2 Crashes - Speeding	Model 3 Crashes - Weather	Model 4 Deaths	Model 5 Non-LT Deaths	Model 6 Deaths - Speeding	Model 7 Deaths - Weather
Post-ELD Regulation	0.0788***	0.112***	0.0821***	0.0758***	0.0811***	0.0907**	0.0941***
	(0.0166)	(0.0325)	(0.0298)	(0.0181)	(0.0207)	(0.0368)	(0.0338)
Total Vehicles	2.74e-05	-0.000139	-4.83e-05	2.80e-05	2.62e-05	-0.000185*	-0.000112
	(4.94e-05)	(0.000108)	(0.000147)	(5.37e-05)	(6.21e-05)	(0.000104)	(0.000165)
Owner-Operator	0.0182***	0.0351***	0.0171***	0.0189***	0.0207***	0.0382***	0.0197***
	(0.00427)	(0.00335)	(0.00440)	(0.00404)	(0.00254)	(0.00405)	(0.00318)
Large Truck Dummy	-2.053***	-2.466***	-1.941***	-2.019***	-2.132***	-2.388***	-1.806***
	(0.0448)	(0.0515)	(0.0453)	(0.0457)	(0.0385)	(0.0562)	(0.0445)
VMT (log)	0.604***	0.333***	-0.463	0.574***	0.610***	0.275**	-0.411
	(0.133)	(0.108)	(0.310)	(0.138)	(0.151)	(0.115)	(0.316)
Unemployment	-0.0597***	-0.0201	-0.0251	-0.0625***	-0.0665***	-0.0326	-0.0220
	(0.0205)	(0.0375)	(0.0330)	(0.0217)	(0.0221)	(0.0396)	(0.0346)
Month Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,896	4,896	4,896	4,896	4,896	4,896	4,896
Robust standard errors clustered on state in parentheses							
*** p<0.01, ** p<0.05, * p<0.1							

One limitation of difference in difference models is the potential confounding influence of ex-ante differences between treatment and control samples (Blackwell et al., 2009). While the previous analysis is conceptually sound (and supported by the parallel trends shown in Figure 1), it is possible that ex-ante differences between the control and treatment samples exist. Addressing this concern requires balancing the empirical distributions of the treated and control groups to eliminate any associated effects of these covariates on the treatment variable (Blackwell et al., 2009; Iacus et al., 2012).

To create this balance, coarsened exact matching (CEM) was implemented using Stata15 to identify control observations that are closest to the treated observations over a defined covariate set (Iacus et al., 2011). In this study, *total vehicles, unemployment,* and *VMT (log)* were used to define the pretreatment covariates and to match the treatment and control groups. Essentially, CEM coarsens the identified control variables using a binning algorithm and then applies an exact matching algorithm to match observations across treatment and control conditions. Any unmatched observations are then pruned. Next, the variables are uncoarsened for the retained matched observations and a weighting variable generated by the CEM method is applied to observations in the control group to equalize the number of observations in the treatment and control groups (this application of CEM creates a 1-to-many match between treatment and control groups across different strata, necessitating the application of a weighting factor to observations in the control group to achieve the desired balance). After implementing the CEM procedure, the analysis was replicated and the results are reported in Table 4. Models 8-14 mirror Models 1-7 on the matched samples. As demonstrated by the results, the effect of the ELD regulation on fatal crashes and deaths remains positive and significant across

all tested dependent variables, further supporting the contention that the ELD regulation did not result in improved road safety.

Table 4. Poisson difference in difference estimation with coarsened exact matching

VARIABLES	Model 8 Crashes	Model 9 Crashes - Speeding	Model 10 Crashes - Weather	Model 11 Deaths	Model 12 Non-LT Deaths	Model 13 Deaths - Speeding	Model 14 Deaths - Weather
Post-ELD Regulation	0.0673***	0.0958***	0.0984***	0.0636***	0.0726***	0.0845**	0.112***
	(0.0178)	(0.0357)	(0.0321)	(0.0201)	(0.0221)	(0.0386)	(0.0360)
Owner-Operator	0.0174***	0.0351***	0.0149***	0.0179***	0.0196***	0.0374***	0.0171***
	(0.00485)	(0.00367)	(0.00403)	(0.00451)	(0.00277)	(0.00479)	(0.00296)
Large Truck Dummy	-2.042***	-2.453***	-1.933***	-2.007***	-2.122***	-2.375***	-1.798***
	(0.0446)	(0.0554)	(0.0452)	(0.0450)	(0.0380)	(0.0602)	(0.0419)
Constant	3.973***	2.683***	3.201***	4.054***	3.857***	2.754***	3.109***
	(0.0254)	(0.0581)	(0.0674)	(0.0258)	(0.0284)	(0.0600)	(0.0596)
Month Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,575	4,575	4,575	4,575	4,575	4,575	4,575
Robust standard errors clustered on state in parentheses							
*** p<0.01, ** p<0.05, * p<0.1							

To further examine the impact of the ELD mandate, a secondary analysis based on Poisson regression models was conducted using only those fatal crashes involving large trucks. This creates an opportunity to further validate the previous results as well as making it possible to examine the characteristics of the drivers of the large trucks involved in the fatal accident to glean additional insights. As shown in Table 5, the previous results are further supported with the number of fatal crashes, deaths, and deaths of individuals not in large trucks (Models 15-17) all increasing after enactment of the ELD regulation. Interestingly, the effect on deaths of individuals in large trucks (Model 18) is not statistically significant, suggesting that the ELD regulation did not adversely affect fatality rates of drivers of large trucks but was more concentrated on other individuals involved in the fatal accident (e.g., drivers/passengers in other vehicles, pedestrians, cyclists). Model 19 considers fatal crashes where the driver of a large truck was speeding, again finding a positive and significant effect of the ELD dummy. Model 20 investigates the effects on crashes where the driver of a large truck was operating in adverse weather conditions, supporting the findings in Tables 3 and 4. Finally, Models 21 and 22 investigate the owner of the large trucks involved in fatal crashes. These results suggest that there was an increase in fatal crashes for both trucks driven by owner-operators and those driving trucks owned by a commercial enterprise, though the magnitude of the effect was larger for owner-operators.

Table 5. Poisson regression of large truck-involved fatal crashes

VARIABLES	Model 15 Crashes	Model 16 Deaths	Model 17 Non-LT Deaths	Model 18 LT Deaths	Model 19 Speeding	Model 20 Weather	Model 21 Owner-Operator	Model 22 Commercial Owner
Post-ELD Regulation Dummy	0.314**	0.201*	0.444**	0.0127	2.093***	0.894***	0.529**	0.249*
	(0.132)	(0.109)	(0.172)	(0.208)	(0.549)	(0.310)	(0.232)	(0.144)
VMT (log)	0.182	0.366**	0.0988	0.0995	-0.947	-1.083***	0.769**	-0.0336
	(0.179)	(0.182)	(0.290)	(0.292)	(0.582)	(0.377)	(0.319)	(0.212)
Unemployment	0.00308	-0.0232	0.0222	-0.0393	0.147	0.113*	-0.101	0.0371
	(0.0268)	(0.0249)	(0.0449)	(0.0752)	(0.115)	(0.0606)	(0.0693)	(0.0303)
Month Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations[a]	2,448	2,448	2,448	2,400	2,400	2,352	2,400	2,448
[a] states with all 0 values caused observations to be dropped from the analysis in Models 18-21 Robust standard errors clustered on state in parentheses								
*** p<0.01, ** p<0.05, * p<0.1								

DISCUSSION

The findings reported in Tables 3-5 provide valuable insights into the effects of a widespread, mandatory rollout of electronic monitoring. Importantly, these results demonstrate electronic monitoring programs, if not carefully developed and embraced by the individuals being monitored, may ultimately fail to bring about the intended effects or even lead to worse overall outcomes. This analysis suggests the decision made by the federal government to force adoption of ELDs across all interstate commercial truck drivers was not an effective means to reduce motor vehicle fatalities. Specifically, the difference in difference estimation found that both the number of fatal crashes involving large trucks and the total fatalities of individuals in these crashes increased after the ELD legislation was enacted, and the magnitude of the effect was greater for fatal crashes involving a speeding vehicle and fatal crashes occurring during adverse weather conditions. This suggests that the electronic monitoring of drivers of large trucks to ensure compliance with HOS requirements represents a form of coercive control that result in increased workplace deviance (Lawrence & Robinson, 2007), such as exceeding speed limits and operating in adverse weather conditions. These behaviors further align with reactions to perceived unfairness on the part of the drivers who are given no control over the monitoring (McNall & Stanton, 2011).

Importantly, truck drivers represent a population of individuals which has historically been granted a high degree of autonomy with minimal oversight due to the nature of their work. These findings, then, support previous research that suggests implementing EPM with individuals that have a high degree of discretion in their jobs is particularly likely to result in resistance to the technology and counter-productive work behaviors (Shaffer & Darnold, 2020; Tomczak et al., 2020). This is demonstrated with the finding that the effect on fatal crashes where the truck driver was an owner-operator was of substantially higher magnitude than for drivers of commercially owned trucks. Owner-operators

have a broad latitude to operate their vehicles and set work schedules as they see fit whereas drivers of company owned vehicles are subject to much greater oversight and control from their employers. Furthermore, the effect of this regulatory effort was not limited to commercial truck drivers, but also resulted in higher fatalities for the general public who were involved in these crashes. While previous research has found that truck drivers who are owner-operators tend to operate in a safer manner than commercial truck drivers (Cantor, 2016; Cantor et al., 2013), the post-hoc analysis reveals that the ELD regulation had a larger effect on fatal accidents in which the driver was an owner-operator. This may be caused by the fact that larger trucking companies were more likely to voluntarily invest in ELDs prior to the federal mandate, whereas fewer than 15% of smaller trucking companies (including owner-operators) had begun adoption ELDs just three months prior to the deadline (Miller et al., 2020). Furthermore, these small and mid-sized carriers strongly opposed the ELD mandate (Johnston et al., 2014) increasing the likelihood of backlash associated with forced implementation of coercive control systems for these drivers.

Generalizing these results to a broader context, managers looking to establish widespread electronic monitoring of employees should be particularly cognizant of the likely response to these systems. This is especially true of organizations that may have drastically increased remote work in a short time period (such as in response to the COVID-19 pandemic) and created a work environment characterized by high degrees of self-autonomy and self-direction (Tomczak et al., 2020). As seen in the commercial trucking industry, the clash of the existing work design with new external controls may lead to undesirable behaviors, either through making sacrifices in other performance areas to meet the performance expectations of the monitored metrics (i.e., operating at higher speeds or in suboptimal weather conditions to ensure compliance HOS requirements) or via increased psychological stress, task anxiety, and perceived procedural injustice (Tomczak et al., 2018), especially if the employees are conducting complex tasks (Davidson & Henderson, 2000). These results underscore the need of managers to empower employees (Martin et al., 2018) through these monitoring programs, such as through including them in the development and rollout process, prioritizing development opportunities, and providing a channel for employees to voice complaints and provide meaningful feedback regarding the system (Jeske & Santuzzi, 2015; Lawrence & Robinson, 2007).

LIMITATIONS AND FUTURE RESEARCH OPPORTUNITIES

Importantly, this study does have some limitations that should be addressed in future studies. One important limitation of this study is its focus on a single industry: drivers of large trucks in the United States. Joglekar et al. (2016) note that single industry studies necessarily face a trade-off between generalization and specificity, especially when advancing and testing theories regarding operating practices, such as the use of ELD's, but are still of immense practical value. While individuals in the trucking industry share many commonalities with workers across other industries, there are also important differences in the nature of the work that may affect the outcome of EPM system implementation. Specifically, the working conditions, the operation of the EPM, and the anxiety stress may be industry specific, impeding generalizability. Additionally, the hourly limitations and the associated motivation to meet the daily goals or limits are unique to the commercial trucking industry and may engender different responses in other industries, though it is common in many manufacturing industries to have limited working hours and piece-rate pay or production bonuses (Bucklin & Dickinson, 2001) which may offer relevant parallels. Future research should extend this analysis to additional industries and examine how different operating dynamics as well as pay systems are impacted by the use of EPM. Furthermore, the ELD mandate was an exogenous event that individuals and companies were forced to comply with due to federal law. The associated response from truck drivers may not directly mirror the response from employees in organizations that introduce EPM as these individuals may be able to affect the scope of the rollout of these systems or may be more easily able to leave an organization and change jobs if significantly affected by an EPM program. Again, a

broader examination of different industries would help to generalize the findings of this study. Finally, the findings of this study suggest the use of EPM was not effective in achieving the ultimate desired outcome of improved motor vehicle safety. This suggests a valuable avenue for future research to identify effective solutions and develop methods of evaluating the efficacy of proposed solutions.

CONCLUSION

The ELD mandate for commercial truck drivers may have increased adherence to the specific metrics being evaluated (Scott et al., 2021), but the findings reported here suggest the broader effort to increase road traffic safety and reduce motor vehicle fatalities was not successful. These findings echo the sentiments of Scott et al. (2021) that the use of ELDs likely increase counterproductive behaviors that actually increase not only moving violations and crashes, but deaths. Indeed, the number of fatal crashes and deaths when drivers of large trucks were speeding or operating in adverse weather conditions increased post-mandate. Furthermore, these fatal crashes resulted in increased deaths among the general public in the form of individuals in passenger vehicles, cyclists, and pedestrians. This suggests a need to consider alternative strategies to promote greater roadway safety. Furthermore, this study highlights the need for managers and policymakers to carefully consider potential negative ramifications from implementing EPM, particularly those related to activities that may not be monitored.

CONFLICT OF INTEREST

The author of this publication declares there is no conflict of interest.

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