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Multivariate dynamic Tobit models with lagged observed dependent variables: An effectiveness analysis of highway safety laws

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ABSTRACT

Highway safety laws aim to influence driver behaviors so as to reduce the frequency and severity of crashes, and their outcomes. For one specific highway safety law, it would have different effects on the crashes across severities. Understanding such effects can help policy makers upgrade current laws and hence improve traffic safety. To investigate the effects of highway safety laws on crashes across severities, multivariate models are needed to account for the interdependency issues in crash counts across severities. Based on the characteristics of the dependent variables, multivariate dynamic Tobit (MVDT) models are proposed to analyze crash counts that are aggregated at the state level. Lagged observed dependent variables are incorporated into the MVDT models to account for potential temporal correlation issues in crash data. The state highway safety law related factors are used as the explanatory variables and socio-demographic and traffic factors are used as the control variables. Three models, a MVDT model with lagged observed dependent variables, a MVDT model with unobserved random variables, and a multivariate static Tobit (MVST) model are developed and compared. The results show that among the investigated models, the MVDT models with lagged observed dependent variables have the best goodness-of-fit. The findings indicate that, compared to the MVST, the MVDT models have better explanatory power and prediction accuracy. The MVDT model with lagged observed variables can better handle the stochasticity and dependency in the temporal evolution of the crash counts and the estimated values from the model are closer to the observed values. The results show that more lives could be saved if law enforcement agencies can make a sustained effort to educate the public about the importance of motorcyclists wearing helmets. Motor vehicle crash-related deaths, injuries, and property damages could be reduced if states enact laws for stricter text messaging rules, higher speeding fines, older licensing age, and stronger graduated licensing provisions. Injury and PDO crashes would be significantly reduced with stricter laws prohibiting the use of handheld communication devices and higher fines for drunk driving.

1. Introduction

States across the United States (US) have enacted highway safety laws to influence driving behaviors, such as impaired driving and distracted driving. The enacted highway safety laws are intended to enhance traffic safety and reduce traffic crashes and deaths, injuries, and related outcomes and costs. Currently, there are 11 types of highway safety laws by issues in the US (Governors Highway Safety Association), as shown in Table 1. However, no state has enacted all of those 11 key highway safety laws (Advocates for Highway & Auto Safety, 2016) and there are still far too many people being killed and injured in motor vehicle crashes. The latest fatality and injury data from the federal government show that 35,092 people were killed and 2.443 million people were injured in traffic crashes in 2015, a 7.17% and 4.49% increase from 2014 (National Highway Traffic Safety Administration, 2016).

To save more lives and reduce the outcomes of motor vehicle crashes, the effects of the key highway safety laws on traffic safety have to be better understood. Results from analyses and modeling of the relationship between highway safety laws and crash counts across severities could be used by decision makers, policy makers, and lawmakers to refine/amend existing laws and develop new legislation. For example, the implementation of the seat belt laws is estimated to save more than 10,000 lives annually (Advocates for Highway & Auto Safety,

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Table 1
Summary of the investigated state highway safety laws and related research.

Highway safety laws	Brief description/explanation	# states have passed laws*	# states have no laws*	Relevant research
Aggressive driving	Passed laws specifically defining aggressive driving actions	11	39	Dula and Geller (2003), Nesbit et al. (2007), Shinar and Compton (2004), Jovanović et al. (2011) and Constantinou et al. (2011)
Child passenger safety	Booster seats or other appropriate devices for children who have outgrown their child safety seats but are still too small to use an adult seat belt safely	48	2	Arbogast et al. (2004), Elliott et al. (2006), Nakanara et al. (2015) and Winston et al. (2007)
	Children younger than two years of age to be in a rear-facing child seat	4	46	
	Seat belt requirements for school buses	5	45	
Distracted driving	Hand-held cell phone ban (for all drivers)	14	36	Jacobson et al. (2012), Goodwin et al., 2012, Welki and Zlatoper (2014) and Kwon et al. (2014)
	Text Messaging Ban (for all drivers)	46	4	Atchley et al. (2011), Hallett et al., 2012, Harrison (2011) and Ehsani et al. (2014)
Graduated driver licensing	Learner stage (16 years old)	8	42	Ferguson et al. (1996), Hedlund et al. (2006) and Williams (2009)
	Full privilege stage (18 years old)	8	42	
	Intermediate stage (Nighttime Driving Restriction)	48	2	
	Intermediate stage (Passenger Restriction)	46	4	
Helmets	Motorcycle Helmets (Universal helmet law)	19	31	Weiss et al. (2010), McCartt et al. (2011), Passmore et al. (2010) and Brown et al. (2009)
	Bicycle helmets	21	29	
Impaired driving	Drugs (Zero tolerance)	16	34	Elder et al. (2011), Mercer et al. (2010) and McCartt et al (2015)
	Drugs (*Per se*)	6	44	
	Marijuana drug-impaired Driving laws (Zero tolerance or non-zero *per se* laws for marijuana)	18	32	
	Alcohol (Administrative license suspension on the first offense)	42	8	
	Alcohol (Mandatory or highly incentivized ignition interlock law)	22	28	
	Sobriety checkpoints	38	12	
Mature drivers	Special provisions for mature drivers	33	17	Siren and Meng (2012), Hakamies-Blomqvist (2006), Fitten (2003) and Langford et al. (2004a,b)
Seat belts	For front seat occupants	49	1	Nichols et al. (2012), Strine et al. (2010), Conner et al. (2010), Cohen and Einav (2003) and Shults and Beck (2012)
	Seat belt use for all rear seat passengers	28	22	
Speed limits	Different speed limits for cars and trucks	7	43	Welki and Zlatoper (2007), Welki and Zlatoper (2009) and Dong et al. (2016a,b)
	Highest speed limits higher than 70 mph	14	36	
Automated enforcement laws	Speed cameras	13[a] + 9[b]	28	Montella et al. (2012), Shin et al. (2009) and Tay, 2010
	Speed cameras implementation	12	38	
	Red light cameras	10[c] + 21[d]	19	McCartt and Hu (2014), Hu et al. (2011), Retting and Kyrychenko (2002) and Hallmark et al. (2010)
	Red light cameras implementation	24	26	
Work zones	Double the fine for committing traffic violations	33	17	Lin et al. (2004) and Ullman et al., 1997
	Workers to be present	24	26	
	Signs must be posted	42	8	

Note: *The data are based as of the year 2015.
[a] Prohibit (with very narrow exceptions) the use of speed cameras.
[b] Permit or limit the use of speed cameras.
[c] Prohibit the use of red light cameras.
[d] Permit the use of red light cameras.

2016). Some states have enacted it as a secondary law, which allows law enforcement officers to issue a citation for unbelted occupants when the driver commits a separate offense. In addition, some states require seat belt use only for front seat occupants, without requiring other occupants to wear seat belts. A better understanding of the relative effectiveness of enacted primary and secondary seat belt laws on crash counts across severities could help states develop better laws and even more lives could be saved. Furthermore, it is possible that a particular highway safety law that enacted to reduce one specific type of crash might increase the number and severity of other crashes. For example, automated red-light camera enforcement laws have been shown to be effective in reducing the incidences of red-light running and the number of red-light running crashes. However, several studies (Llau et al., 2015; Hallmark et al., 2010; Shin and Washington, 2007) showed that the implementation of red-light cameras increases the number of rear-end collisions. Modeling the counts of specific types of crashes (as opposed to total crashes) can reveal new insights that would support the law making. To analyze the effects of state highway safety laws on crashes across severities, multivariate regression models are needed, since the crash counts are interdependent. In this research, we proposed a multivariate dynamic Tobit (MVDT) model to analyze the crash data. The proposed models have two merits. The proposed models can address the issues of differential censoring in crash counts across crash types, while account for the possible contemporaneous error correlation resulting from unobserved heterogeneity in the samples. The proposed models can also address potential temporal correlation issues in the interdependent crash counts.

2. Literature review

Several studies have examined the effectiveness of enacted highway safety laws. Voas et al. (2000) analyzed the relationship between three