Journal of Safety Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

The effect of fatigue driving on injury severity considering the endogeneity

Yanyan Li, [a,*] Toshiyuki Yamamoto, [b] Guangnan Zhang [c,d]

[a] Department of Civil Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
[b] Institute of Materials and Systems for Sustainability, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
[c] Institute of Guangdong, Hong Kong and Macao Development Studies, Sun Yat-Sen University, Xingang Xi Road, Guangzhou, China
[d] Center for Studies of Hong Kong, Macao and Pearl River Delta, Sun Yat-Sen University, Xingang Xi Road, Guangzhou, China

ARTICLE INFO

Article history:
Received 15 May 2017
Received in revised form 4 October 2017
Accepted 5 December 2017
Available online xxxx

Keywords:
Fatigue driving
Endogeneity
Injury severity
Commercial vehicle driver

ABSTRACT

Introduction: Fatigue driving is one of the most risky driving-related behaviors and represented a significant social and economic cost to the community. Several studies have already examined the relationship between fatigue driving behavior and traffic injury severity from different aspects. However, fatigue driving and injury severity in traffic crash may share some common influential factors. Ignoring the impact of these common factors will lead to endogeneity problem and result in biased parameter estimation. *Method:* Based on 38,564 crash records during 2006–2011 in Guangdong province, China, we apply a bivariate endogenous binary-ordered probit model to examine the relationship between fatigue driving and injury severity considering endogeneity of fatigue driving. We also explore the difference of influential factors between commercial and non-commercial vehicle drivers. *Results:* This study identifies several common observed influential factors of fatigue driving propensity and fatal injury propensity and reveals a substantial and significant negative correlation of unobserved factors between them. *Conclusions:* The influence of fatigue driving on injury severity is significantly underestimated if the endogeneity of fatigue driving on fatal injury propensity is ignored. Factors such as vehicle insurance and road types not only affect fatal injury propensity, but also fatigue driving propensity. *Practical applications:* The findings in this study can help better understand how those factors affect fatigue driving and injury severity, and contributes to more efficient policy for preventing the harmfulness of fatigue-related crashes.

1. Introduction

Road safety has already become a great threat to human beings all around the world. According to *Global Status Report on Road Safety 2015* by the World Health Organization (WHO, 2015), more than 1.2 million people die each year on the road, with millions more sustaining serious injuries and living with long-term adverse health consequences. In low- and middle-income countries, traffic injuries have become one of the leading causes of death and cost approximately 3% of their GDP (WHO, 2015).

Fatigue driving was identified as one of the four most risky driving-related behaviors, especially in fatal traffic crashes (Fernandes, Hatfield, & Job, 2010) and represented a significant social and economic cost to the community. Approximately 20% of fatal crashes in Canada involved driver fatigue, eliminating the influence of alcohol, speeding, and unsafe passing (Canadian Council of Motor Transport Administrator, [CCMTA], 2010). In Australia, 20%–30% of all fatal traffic crashes were found to be due to fatigue driving (Australian Transport Council, 2011). However, this situation could be worse in developing countries since those countries include most of the traffic crashes worldwide (WHO, 2015). A questionnaire-based research among commercial bus drivers in Malaysia found that the prevalence of fatigue among commercial bus drivers was 37.7% (Fadhli, Mohamed, Othman, Sarani, & Voon, 2008). Statistics from China also showed that 1271 (0.83% of total number of crashes due to any cause) crashes were caused by fatigue driving in 2013, with 677 (1.16% of total number of people killed in the crashes due to any cause) people killed, 1600 (0.75% of total number of people injured in crashes due to any cause) people injured, and over RMB 37 million in property losses (Traffic Management Bureau, Ministry of Public Security, PRC, 2013). China seems to have a lower fatal fatigue-related crash rate than Canada and Australia. The reason for this contrast may be related to their criterion for calculating the "crash rate." The fatigue crash rate in the statistics of Canada and Australia is calculated using the number of crash that "fatigue is one of the contributing factors." However, the fatigue-related crash rate for China is calculated by the number of crashes that "fatigue is the major cause of crash." In this case, China is applying a much narrower concept in calculating fatigue-related crash rate than Canada and Australia. Applying the

* Corresponding author.
E-mail addresses: lyy901207@gmail.com (Y. Li), yamamoto@civil.nagoya-u.ac.jp (T. Yamamoto).

https://doi.org/10.1016/j.jsr.2017.12.007
0022-4375/

similar criteria, UK estimated the fatigue-related crash rate should be around 2% of all crashes in 2015 (Department for Transport, UK, 2016), which the fatigue-related rate is much closer to China. Although the reported fatigue-related crash rate of China is not so high, we can still speculate that the crash rate for "fatigue is one of the contributors of crash" would be much higher.

Despite an extensive body of research addressing the harmfulness of fatigue driving on road safety, it has not attracted enough attention. Drivers were less concerned about fatigued driving than other traffic safety issues (Vanlaar, Simpson, Mayhew, & Robertson, 2008). Studies from different countries showed that many people still drove when they felt fatigue (Beirness, Simpson, & Desmond, 2005; Nordbakke & Sagberg, 2007; Tefft, 2010). Besides drivers, the public are also not fully aware of the potential risk of fatigue driving because it is difficult to evaluate its effect accurately. For example, fatigue could be resolved after a period of rest (Karrer, Vöhringer-Kuhnt, Baumgarten, & Briest, 2004), this feature made it hard to detect and identify after crashes occurred. When other risky driving behaviors are involved, it is even harder to tell what the major contributor is and may lead to misclassification of the cause of crash (Armstrong, Smith, Steinhardt, & Haworth, 2008; Horne & Reyner, 1995; Philip et al., 2005). In addition, police also tended to assign the cause of crash to current interest (Ogden & Moskowitz, 2004).

Several studies have examined the relationship between fatigue driving and traffic injury severity from different aspects. However, fatigue driving and injury severity in traffic crashes may share some observed common influential factors (e.g., road types). There are also some unobserved factors between fatigue driving and injury severity. The connection between sleep disorder, fatigue, and traffic injury severity were discussed by many researchers (Akerstedt & Kecklund, 2001; Horne & Reyner, 2001; Philip et al., 2003; Stutts, Wilkins, Osberg, & Vaughn, 2003). Ignoring the impact of these common factors will lead to endogeneity problem and incorrect conclusion. This study contributes toward current fatigue driving research by applying a bivariate endogenous binary-ordered probit model framework to examine the relationship between fatigue driving propensity and fatal injury propensity in a crash considering the potential endogeneity of fatigue driving. Considering the potential systematic differences between commercial and non-commercial vehicle drivers, this model also identifies the observed common factors of fatigue driving and injury severity for two groups of drivers and makes a comparison. This result may help better understand how those factors affect fatigue driving propensity and injury severity, and contributes to more efficient policy for preventing the harmfulness of fatigue-related crashes. The analysis includes several types of factors, including driver characteristics, vehicle characteristics, road characteristics, environmental characteristics, and collision characteristics.

The rest of this paper is arranged as follows: In Section 2, we review related literature of factors affecting fatigue driving propensity and injury severity in a crash. We present the methodology in Section 3, and data source and sample descriptive statistics in Section 4. Empirical analysis and discussion of estimation results are presented in Section 5. Conclusions and practical applications are provided in Section 6.

2. Literature review

Fatigue is a gradual and cumulative process closely related to deterioration of performance efficiency like driving performance (Haworth, 1998; Philip et al., 2005; Rajaratnam & Arendt, 2001), and could be induced by repetitive and monotonous activities like driving long distances (Stutts, Wilkins, & Vaugh, 1999). Research pointed out that fatigue was not a strictly monotone decreased progress (Karrer et al., 2004), but an interaction between deactivation and compensation processes, resulting in variability of performance (Dinges & Kribbs, 1991).

As for the influential factors related to fatigue driving, prior studies basically focused on four categories: driver characteristics, road characteristics, environmental characteristics, and vehicle characteristics. Considering driver characteristics, male drivers were at high risk of fatigue driving for the reason that males were more likely to drive for a longer time (Armstrong, Obst, Livingstone, & Haworth, 2011; Fernandes et al., 2010). In Armstrong et al.'s (2008) study, it was found that drivers aged 17–24 years were more likely to be involved in a fatigue-related crash. However, the influence of age is much more complicated and there exist different behavior patterns between young drivers and older drivers. Young drivers frequently committed their fatigue-related offenses during early morning and night-time hours (Horne & Reyner, 1995, 2001; Maycock, 1996; Pack et al., 1995) while older drivers mostly in the afternoon (Summala & Mikkola, 1994). In addition, the motivation for driving while fatigued for young drivers might be their overestimation of capabilities (Gregersen & Bjurulf, 1996) and miscalculation of the cost of consequence (Fernandes et al., 2010).

For road characteristics and environmental characteristics, driving on different types of roads can lead to similar consequence. Both high-demand and low-demand road condition could induce driver fatigue (Oron-Gilad, Ronen, & Shinar, 2008; Zhao & Rong, 2013). Dyani (2007) divided driver fatigue into two groups: passive fatigue and active fatigue. Passive fatigue was defined closely related to underload, which has been confirmed by simulated driving studies in monotonous condition (Desmond & Hancock, 2001; Thiffault & Bergeron, 2003). Active fatigue was defined related to overload of driver. For example, poor road condition (Arnold et al., 1997), complex traffic conditions, and road environments (Pilcher & Huffcutt, 1996) required more attention and could easily induce physical and mental fatigue. Time of day was mentioned by several fatigue-related studies. Folkard (1997) has reviewed research that studied the relationship between road safety and time of day. It was widely believed that time of day was closely related to human rhythms, which was identified as an important factor affecting driver fatigue (Haworth, 1998; Philip et al., 2005). Horne and Reyner (2001) found that 2 a.m.–6 a.m. and 2 p.m.–4 p.m. are the time periods associated with higher probability of fatigue. Haworth (1998) also pointed out that nighttime is a significant contributor of fatigue-related crashes. Light level (Sullivan & Flannagan, 2002) and season were also identified to play important roles (Radun & Radun, 2009).

Nevertheless, fatigue-related crashes are severe among commercial vehicle drivers. Statistics from Europe pointed out that approximately 20% of commercial vehicle crashes were related to driver fatigue (European Transport Safety Council [ETSC], 2001). The causes of fatigue varied since fatigue could be developed while on the job with regular sleep patterns or arrived at work already fatigued with irregular sleep patterns (Young & Hashemi, 1996). Commercial vehicle drivers suffered from sleep restriction (Hanowski, Hickman, Fumero, Olson, & Dingus, 2007) and were under great work pressure, which made them vulnerable to fatigue-related crashes. Specifically, drivers in developing countries are more likely to drive while fatigued for financial reasons (Mock, Amegashie, & Darteh, 1999; Nantulya & Muli-Musiime, 2001). Surveys conducted among truck and taxi drivers in Beijing, China, showed that driver fatigue was prevalent and the most important reason was prolonged driving time (Meng et al., 2015).

Even though it is not in agreement, fatigue driving and injury severity in the crash may share some common influential factors, including observed and unobserved factors. Radun and Radun (2009) claimed that there was no connection between crash severity and whether the driver was judged to have been fatigued. However, more studies believed there existed some kind of connection (Haworth, 1998; Zhang, Yau, Zhang, & Li, 2016). Fatigue-related crashes were often severe that drivers could not take evasive action under fatigue (Haworth, 1998). Some factors related to fatigue driving may impair driver performance, then affect injury severity. For example, some unobserved factors related to the driver's internal state and circadian cycle can also affect both

Please cite this article as: Li, Y., et al., The effect of fatigue driving on injury severity considering the endogeneity, *Journal of Safety Research* (2017), https://doi.org/10.1016/j.jsr.2017.12.007