TÍTULO

HOW RISKY IS DRUNK DRIVING IN SPAIN AND HOW MUCH DOES IT COST?

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How risky is drunk driving in Spain and how much does it cost?

by

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Abstract

In this thesis, it is estimated the relative risk that drunk drivers pose on sober drivers, passengers and pedestrians, and quantified the external cost of drunk driving in Spain between 2004–2015. Eventually, the following conclusions are obtained. Firstly, it is found the relative risk of drunk drivers causing a crash during the night to be between 2.7–3.9 times higher than that of sober drivers. Secondly, the results point to a decline in drunk driving offences alongside an increase in its punition, mainly after the implementation of the Penalty Points System for driving licenses in Spain on July 1st 2006. It is also estimated that drunk drivers should be fined by €1250, in order to offset the external costs they caused, in terms of harmfulness. Overall, this assessment indicates a downturn in the external costs of drunk driving over the last decade in Spain.

JEL classification: R490, E320, C220

Keywords: Pigouvian fine, Road accidents, Drunk driving, Relative risk, Multinomial probability, Negative binomial, External costs.

Resumen

En este trabajo, se estima el riesgo relativo que los conductores ebrios representan para los conductores sobrios, pasajeros y peatones, y se cuantifica el coste externo de la conducción ebria en España entre 2004–2015. Se han obtenido las siguientes conclusiones. En primer lugar, el riesgo relativo de que los conductores ebrios causen un choque durante la noche es entre 2.7 y

3.9 veces mayor que el de los conductores sobrios. En segundo lugar, los resultados apuntan a una disminución en los delitos de conducir en estado de ebriedad junto con un aumento en su castigo, principalmente después de la implementación del Sistema del Carnet por Puntos para los permisos de conducción en España el 1 de julio de 2006. También se estima que los conductores ebrios deberían ser multados con 1250 € para compensar los costes externos que provocaron en términos de lesiones. En general, las estimaciones indican una disminución en los costes externos de conducir bajo los efectos del alcohol durante la última década en España.

Clasificación JEL: R490, E320, C220

Palabras clave: Multa Pigouviana, Accidentes de tráfico, Conducción ebria, Riesgo relativo, Probabilidad multinomial, Binomial negativo, Costes externos.

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1 Introduction

The aim of this work is to estimate the relative risk of drunk drivers compared with sober drivers, and to assess the external costs of drunk driving in Spain over the period 2004 – 2015. To do this, I use the methodology proposed by Levitt and Porter (2001), who exploit the multinomial structure in two-car crashes, based on a reduced number of axiomatic assumptions. This methodology allows gauging the relative risk of drunk driving, defined as the probability of a drunk driver causing a road crash with respect to that of a sober driver. The number of drunk drivers, relative to sober ones, is simultaneously identified. For that reason, this identification requires observations of road crashes where two cars have interacted. This methodology is used to explore different dimensions of drunk driving and road crashes in Spain, mainly related to the hourly intervals where these crashes are more likely to occur.

Spain is an interesting case study. At the beginning of the 90 s, the share of fatal victims in Spain was at twice the number as those of western EU countries, 9.0% versus 4.3%. As of 2015, the Spanish ratio had met those of these countries, with fatal victims now accounting for 1.8% of victims[1]. Several reasons are likely behind this downturn: technological improvements in passenger vehicles, surveillance controls, enhanced civic responsibility, or better traffic institutions. However, the basic tenet of improving road security has progressively evolved from infrastructure improvement and vehicle safety standards to the monitoring of drivers' behaviours and punishing driving offences, such as drunk driving. A causal analysis behind this downturn is beyond the scope of the current thesis, but I present useful evidence to certify the evolution of the risk of drunk driving, the relative number of drivers who drive under the effects of alcohol, and the external costs due to drunk driving in Spain.

The contribution of this work to the existing research comes from providing an assessment of the external costs of drunk driving in Spain, as well as highlighting the differences in the risk of drunk driving causing a crash across hourly intervals. Overall, the achieved results point to a decline in drunk driving offences alongside an increase in the punitive measures. I also discuss some

[1] OECD Data. (2019). *Road Accidents* (Accessed on September 2019). Organization for Economic Co-operation and Development.

limitations of Levitt and Porter's (2001) methodology and suggest techniques to overcome these shortcomings.

In this work, I use a sample of road crashes in Spain from 2004 to 2015, containing detailed information on crashes, the vehicles involved, the drivers and occupants, and the likely causes behind the accident, such as drunk driving. This sample is split into three hourly intervals: from 6:00 to 19:00, labelled as' work hours', and two nighty segments, from 20:00 to 23:00, and from 00:00 to 5:00, denoted as 'after work' and 'party time' hours, respectively.

The results suggest the following conclusions. Firstly, the estimated relative risk of drunk drivers ranges between 2.7 and 3.9 during nighttime hours, i.e. from 20:00 p.m. to 5:00 a.m. By contrast, during 'work hours', this relative risk is one, meaning that the risk of a drunk driver causing a crash cannot be distinguished from that of a sober driver. Additionally, the share of drunk drivers ranges between 1.5% and 7.5%, increasing at night. Such an increase in both the risk and the proportion of drunk driving during nighttime hours can be seen as the result of a strong complementarity between leisure time and alcohol consumption in Spain, as seen in the EDAP' 2015 survey (DGT, 2016a), the EDADES 2017 survey (MSCBS, 2019), and West and Parry (2009) who estimated this cross-price elasticity for the US, and find they are strongly complementary. These results contrast with those found by Levitt and Porter (2001) for US data over the period 1983–1993, who conclude that drunk drivers are seven times more likely than sober drivers to cause a fatal crash and that the proportion of drunk drivers declined from 0.20 to 0.15. Following on from this, there is also reported evidence that the share of drunk drivers versus sober drivers dramatically declined following the implementation of the Penalty Points System (from now on abbreviated to PPS) for driving licenses implemented as of July 1st, 2006 in Spain.

Secondly, using individual administrative data on road accidents, discrete choice and count model regressions, I confirm heterogeneous patterns of alcohol consumption on road accidents across hourly intervals. The marginal effect of drunk driving on road fatalities is positive and changes in each hourly segment, increasing during nighttime hours. I provide statistically significant elasticities of fatal crashes and victims with respect to drunk driving ranging from 0.5 to 0.7 (i.e., a drop of 1 p.p. in the number of drunk drivers leads to a drop in fatal crashes of between 0.5 and 0.7 p.p.) When estimating the decline in fatalities following the PPS that can be accounted for drunk driving, this approach does a good job in capturing the change in fatalities during all hourly intervals, except the working hours.

Finally, the assessment indicates important welfare gains from public interventions on drunk driving aimed at reducing the number of drunk drivers. The social cost caused by drunk drivers, both in terms of victims (all severities) and in monetary terms, has declined from 2004 to 2015. Relative to the Spanish GDP, this implies a fall from 0.017% in 2004 to 0.004%. in 2015. Based on this assessment, it is concluded that drunk drivers should be fined by €1250, in order to internalize the external costs they caused. It is noteworthy that this amount was below the existing fines before the enforcement of the PPS in July 2006. Afterwards, however, legal reforms of traffic laws introduced additional sanctions that may have met this amount.

The thesis is organized as follows. Section 2 contains the literature and regulation review regarding impaired driving. Section 3 summarizes the methodology proposed by Levitt and Porter (2001). Section 4 describes the database used in this work and provides summary statistics. The results are reported in Section 5, in which it is introduced the results of the logit and the count model estimates. Section 6 presents an assessment of the social cost of drunk driving, using the results obtained in Section 5. Section 7 displays robustness tests of the estimations of the previous sections. Finally, the last Section presents the conclusions reached in this work and sets forth several policy recommendations.

2 Literature and regulation review

According to the Spanish Directorate-General of Transport (from now on abbreviated to DGT) (DGT, 2018), excluding Catalonia and Basque Country, 120,333 drivers were involved in accidents with victims in Spain on 2017, in which 175 of the 955 drivers (26% of the tested) that died in a period of 30 days after the accident, had a higher Blood Alcohol Concentration (BAC) than the legal limit. The percentages of impaired drivers are much higher in urban roads than in interurban ones, being impaired 32% of tested dead drivers.

The previous numbers show the relevance of alcohol in road accidents (mortal and non-mortal) in Spain. As a matter of fact, the survey about the prevalence of consumption of alcohol and drugs among drivers of Spain, the EDAP' 15 survey, carried by the DGT and the Spanish Ministry of Interior (DGT, 2016a), remarks that while 3% of male drivers in the survey reported an air alcohol content higher than 0.05 mg. per litre, only 1.4% of female drivers reported it. Also, it is pointed out the patterns on reported air alcohol content bigger than 0.05 mg. per litre by age, finding that younger and older drivers are the ones with higher proportions of impaired observations. Furthermore, there are observed differences between the proportion of positive tests observed in urban roads and non-urban, being the proportion lower in the latter. Finally, they indicated differences in the percentage of tested drivers with air concentration level higher than 0.05 according to the hour and day of the week. Concretely, more drivers impaired drivers were observed on Saturdays, Sundays and Mondays between 0:00 a.m. to 6:59 a.m.

These patterns on drinking and driving seem to coincide with the most recent analysis in patterns of alcohol consumption in Spain, the EDADES 2017 survey, which addresses the consumption of alcohol and drugs in Spain, carried by the Spanish Ministry of Health, Consumption and Social Welfare (MSCBS, 2019). The results of this survey remark the following patterns of alcohol consumption in Spain. Firstly, they indicate that the group with highest proportion of people coming through binge drinking are between 15 and 34 years old. Secondly, people aged between 35 and 64 years are the ones who consume more alcohol beyond weekends. Finally, men aged between 15 and 24 years are the ones who experience drunkenness more.

It is unarguable the effects that alcohol have on the capacity of drivers. A wide range of literature has been written describing the effects of alcohol on people. Alcohol consumption produces retarded visual scanning (Moser et al. 1998), reduces the ability of reaction to unexpected events (Forchheimer, et al., 2005), interacts with drowsiness (Moskowitz and Fiorentino, 2000), and increases risk-taking behaviours (Ogden and Moskowitz, 2004; NHTSA, 2009; Phillips and Brewer, 2011; Alver et al. 2014). In this way, Bogstrand et al. (2015) showed that in Norway between 2005 and 2010, alcohol consumption was the most important factor when observing speeding and no seat-belt use. In another way, Phillips and Brewer (2011) indicated that the risk of fatal accident is higher in accidents where at least one of the drivers have a BAC=0.01% than in accidents with BAC=0.00%, due to infractions from drivers who drank related to speed and unfastened seatbelt, and to the fact that BAC=0.01% drivers are much more likely to handle the striking vehicle rather than the struck one.

As a matter of fact, a vast range of literature has been written analyzing the effects of impaired driving in the likelihood of finding more severe injuries in road crashes. Benhood et al. (2014) pointed alcohol to be the key factor in severe-injury crashes on male drivers in Illinois' Cook County between 2004 and 2011. Ponnaluri (2016), using data of crashes in Florida between 2003 and 2010, also reported that the presence of DUI (Driving Under Influence) raised the risk of observing a fatal crash (an Odds Ratio -OR- equal to 2.76) and Wrong-Way-Direction (WWD) fatal crashes (OR=5.81), controlling, among other, age and gender of the drivers, hourly interval, and type of day. Benhood and Mannering (2017), using data in Cook County (Illinois) of single-vehicle crashes between 2004 and 2012, estimated that older drivers were associated with more severe injuries, no matter if affected or not by alcohol or drugs, whereas young drivers affected by alcohol were associated with more severe injuries, and unimpaired young (below 22 years old) drivers were not.

In this respect, an extensive variety of literature has been written analyzing the effects, not only of alcohol but other covariates like gender, age, type of vehicle, time of day and others in the likelihood of different grades of severity in road accidents. Laapotti et al. (2001) reported that young and male drivers were the riskiest novice drivers in Finland. Kockelman and Kweon (2002) estimated the positive effects of alcohol on severity for all type, one-vehicle and two-vehicle crashes in the US in the year 1998, finding also non-linear effects of age (younger and older drivers tend to be more involved) as well as the decrease in the likelihood of severity if the vehicle involved is a light-duty truck. Clarke et al. (2005) found that in the UK between 1994 and 1996, young drivers had between three and four times as many accidents per year as older drivers, and also that half of the midnight accidents involved alcohol. In this way, it is noted that the time of the accident is another factor that could interact with alcohol consumption. Awadzi et al. (2008), using a multinomial logit model with data of the United States in the year 2003, reported alcohol to be a factor that raised the likelihood of injury (OR=1.51) and the likelihood of fatality (OR=2.3), also denoting heterogeneity according to the time of day, gender, age, and type of vehicle, among others. Chen et al. (2012) reported that in Victoria (Canada), between 2000 and 2009, the odds for male drivers being involved in fatal intersection crashes were 32% higher than for female drivers, that drivers between 65 and more years had more risk of being involved in a severe crash than drivers between 16 and 24, and that the more risky time period of the day was the period 12:00 a.m. – 5:59 a.m., after the period 6:00 p.m. - 11:59 p.m. Kim et al. (2013) estimated a positive coefficient in a mixed logit model of impaired driving in the likelihood of all kind of injuries in crashes between 2003 and 2004 in California, finding also positive effects of being male and on weekends and heterogeneous effects depending of the hourly interval (mainly for severe injuries).

Most recent research on this topic reached the following results. Ma and Yan (2014) reported that alcohol or drugs-abuse raised the likelihood of being at-fault in a rear-end accident, through an additive logit model, using data from the National Highway Traffic Safety Administration of the United States (NHTSA) in 2011, observing being female reduced this likelihood, and younger and older drivers showed higher likelihood than middle-age drivers. Donmez and Liu (2015) estimated with data from 2003 to 2008 of the U.S. National Automotive Sampling System's General Estimates System that alcohol was related to more severe injuries (including fatalities). From a health cost assessment, Shen and Neyens (2015) observed that in South Carolina between 2005 and 2007, alcohol use is another factor that is associated with higher costs for younger or middle-aged drivers. Concretely, younger male drivers have higher care costs than female drivers and are more likely to have higher care costs in weekend crashes, and while middle-aged drivers tend to have lower health costs in weekend crashes, drivers in older groups have higher costs than younger drivers. Penmetsa and Pulugurtha (2017) found from data between 2010 and 2013 from North Carolina, that younger and older drivers have more risks than the rest of drivers to be involved in crashes, and that drunk driving has much more effect on the likelihood of suffering a severe-injury accident than a moderate-injury one. Yasmin and Eluru (2018) analyzed through a negative binomial-ordered logit fractional split model using data from the state of Florida for the year 2015 the effects of a set of exogenous variables including sociodemographic characteristics, socioeconomic characteristics, built environment, transport infrastructure and traffic characteristics in the likelihood of severities.

Additionally, assessments of the external cost of impaired drivers have also been conducted. In order to try to evaluate in the United States in the year 1986 the effectiveness of the penaltie,s in monetary terms, imposed to drunk drivers, Kenkel (1993) reported that although the expected economic sanction raised to 12.82, the expected external cost based on health costs was of $47.77.

In all of the papers mentioned above, except in Ma and Yan (2014), the assessment of the effects of impaired driving was carried on the degree of harmfulness of drivers or people involved in the accidents, not in the likelihood of causing the accident. Furthermore, Ma and Yan (2014) rely on the judgment of the police officer who filled the report indicating the guilty of the accident. In the case of Spain, this analysis would be extremely difficult, as explicit data of this type is missing in the database exploited in this thesis. In the seminar paper by Levitt and Porter (2001), they found through a maximum likelihood estimation based on a series of assumptions (mentioned in Section 3), without data of which driver was guilty of the accident, that in the United States (using data from the Fatality Analysis Reporting System) between 1983 and 1993, drivers with BAC above the limit of 0.1 were, at least, 7.51 times more likely to be the cause of two-car fatal crashes, and 7.45 times more likely to be the cause of one-car fatal crashes, with male and drivers under 25 the group with more risk, and reported heterogeneous effects according to the time of day. They also found and a Pigouvian tax of $8000 per arrest to internalize the external cost these drivers produced. To obtain these relative risks, they based their calculations on the underlying structural parameters naturally emerges from a model of fatal accidents. Along this thesis, I will explain the methodologies proposed by Levitt and Porter (2001) to obtain their relative risk results and Pigouvian tax and will apply them to the case of Spain, extending it beyond fatal crashes, and use it to analyze the effects of the Penalty Points System (PPS).

Research has also been carried out to assess the reasons for drunk driving. Hence, Krüger (2013) analyzed the socioeconomic determinants of road accident risk and impaired driving in Sweden in the period 1976 - 2007, finding through panel data models that unemployment is a factor strongly (negatively) related to deaths in road accidents, as well as the share of drivers aged between 18 and 30 years old, obtaining the same results for these variables when instead of analyzing the injuries, the dependent variable is charges for drunk driving. Kim and Lee (2017) also found that psychoticism and lie were significant when explaining DUI recurrence apart from being male and controlling BAC, drinking frequency and educational background.

Spanish authorities considered vital to modify the regulation regarding drinking and driving. In this way, the most recent changes in regulation in Spain regarding alcohol consumption and driving were the following. As early as in 1973, Law R.D. 1890 regulated and limited the BAC to 0.80 mg. per litre of blood. Law RD 1333/1994 updated the regulation to use of the breathalyzer by police agents (or blood alcohol content test, in some cases) and limited the BAC to 0.50 mg. per litre of blood. By Law RD 2282/1998, alcohol content was limited to 0.50 mg. per litre of blood or up to 0.25 mg. per litre of air. These latter are the current effective limits. However, another vital policy on this topic must be taken into account: The implementation of the Penalty Points System in July 2006. It was established by Law 17/2005 and enforced on July 1st 2006. The procedure of the PPS is simple. Drivers are endowed with 12 points. Experienced drivers without road infringements over the following three years are awarded 2 additional points, with a maximum of 15 points. The complete loss of points implies deprivation of the driving license. Drivers may redeem their points only if they do not commit any other fault within the 6 months after deprivation, and they take a road civility course.

Table 1. Infringements, penalty points and evolution of fines in Spain.

Infringements	**Penalty points [a]**	**Fines[b]**	**Fines[c]**	**Fines[d]**
Driving under the effects of alcohol:				
More than 0,50 mg per liter of blood alcohol content (for novice and professional drivers 0,30 mg/L)	6	[€301, €600]	€500	€ 500 / 1000
Between 0,25 and 0,50 mg. per liter of blood alcohol content (for novice and professional drivers [0.15, 0.30] mg/L)	4	[€301, €600]	€500	€500
Driving under the effects of drugs	6	[€301, €600]	€500	€1,000
Refusing to be tested for blood alcohol/drug level analysis by police agent	6	[€301, €600]	€500	€1,000
Speeding [d]	6	[€301, €600]	[€100, €600]	[€100, €600]
Reckless driving, wrong way, illegal races, and other similar behaviours	6	[€301, €600]	€500	€500
Driving without using seatbelt, kid seats, helmet, and other compulsory safety devices	3	[€91, €300]	€200	€200
Driving while using cell phones, programming the GPS, using earphones, or using any other device that may reduce drivers' attention	3	[€91, €300]	€200	€200

Notes: [a] Penalty points are compiled in Annex II, Law 17/2005 (Ley de permiso y la licencia de conducción por puntos). Law 17/2005 was reformed by Law 18/2009, and previous Law of Traffic (R.D. Legislativo 339/1990, Ley sobre Tráfico, Circulación de Vehículos a Motor y Seguridad Vial).

[b] These fines are specified in Pesetas in art. 67, Law 339/1990 (R.D. Legislativo 339/1990). The conversion to Euros was carried out using € 1 = Ptas 166,386. Following the reform of art. 67 of Law 339/1990 introduced by Law 17/2005, these fines were converted into Euros holding approximately these amounts.

c. These fines are given in art. 67, Law 18/2009, enforced on May 24th 2010.

d. After Law 6/2014, enforced on April 8th 2014, if the driver has been sanctioned for drunk driving during the last year or his/her BAC is twice the over the legal limit, he/she will be fined €1000. The rest of the fines have also changed.

Table 1 summarizes some common offences sanctioned by the PPS, their respective penalty points and the evolution of their respective fines (for a summary of infringements and arrests, see DGT, 2011, and López, 2016). Offences related to driving under the influence of drugs or alcohol, speeding over the legal limit and reckless driving are penalized the most, between 3–6 points. Overall, the monetary fines did not substantially change after the PPS, and across the period of study. However, the PPS did introduce a new way to fine road infringements, through the possibility of losing or imposing limitations on the use of one's driving license. Additionally, the reform of the penal code of 2007, implemented on December 2nd by Law 15/2007, tightened sanctions related to drunk driving[2].

Several papers have been written in order to assess the effects of policies regarding impaired driving. McCartt et al. (2010), using a Poisson model found that laws related to driving licenses in the USA that were considered good were associated with a reduction of traffic accident. Green et al. (2014), through Differences-in-Differences methods, found that the liberalization of bar hours reduced traffic accidents in England and Wales. However, a considerable proportion of the literature is focused on the effects of the Minimum Legal Drinking Age (MLDA) (Carpenter and Dobkin, 2011; Callaghan et al., 2014; Callaghan et al., 2016; Hansen and Waddell., 2018). In spite of that, some papers assess the impacts of alcohol concentration limits and the implementation of the PPS. Related to the effectiveness of alcohol concentration limits, Hansen (2015) analyzed the effects of having a Blood Alcohol Content (BAC) higher than the legal limit in the legal state of Washington, finding a reduction in recidivism. Also, Albalete (2006) assessed the impact of lowering the BAC limit to 0.5 mg/l in Europe between 1991 and 2003 on traffic fatality rates, finding positive impacts, though a lag on the effectiveness around 2 years. Furthermore, regarding the evaluation of effects of the PPS, De Paola, et al. (2013), using a Regression Discontinuity Approach, found negative effects of the PPS on the number of victims and offenders in Italy during the period 2001 - 2005, by type of driving offence, including drunk driving, for which found a reduction of near 10% of offences.

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[2] Concretely, when there is an observed risk for other drivers due to impaired driving, the possible prison sentence increases from the previous one, who ranged between 1 and 4 years to the range between 2 and 5. It is also modified the possible fine, from ranging between 6 and 12 months to ranging between 12 and 24. Additionally, another vital difference is that with this reform it is also considered a possible crime driving with alcohol concentration of 0.6 mg. per air litre or 1.2 mg. per blood litre

3 Methodology

Levitt and Porter (2001) show that the probability of a type-*i* driver causing a crash, relative to that of a type-*j* driver, can be identified using fatal two-vehicle accidents. In a nutshell, they need the following set of axiomatic assumptions:

- *First*, there are only two types of drivers which are denoted by sub-index $i \in \{D, S\}$, D for drunk drivers, and S for sober drivers.

- *Second*, the number of times a driver interacts with other vehicles is independent of the driver's type, and a driver's type does not affect the composition of the driver types which he/she interacts with. Let N_i denote the number of drivers of type $i \in \{D, S\}$. The (unobservable) share of each driver is given by:

$$\Pr(i \mid I = 1) = \frac{N_i}{N_D + N_S}, \quad i \in \{D, S\} \tag{1}$$

  Where I is an indicator that takes value one when two cars interact and zero, otherwise. The relative probability of being a driver of type-*i* is equal to the relative number of drivers of type-*i*.

- *Third*, the joint probability is given by:

$$\Pr(i, j \mid I = 1) = \Pr(i \mid I = 1) \times \Pr(j \mid I = 1); \quad i, j \in \{D, S\} \tag{2}$$

- *Fourth*, a crash results from a single driver's error. A type-*i* driver causes a crash with probability θ_i, where $i \in \{D, S\}$.

- *Fifth*, the composition of driver types in two-vehicle and one-vehicle crashes is independent of the composition of drivers in any other fatal crash.

- *Finally*, the risk of a drunk driver type-*i* causing a crash is higher than that of a sober driver: $\theta_D \geq \theta_S$. As Levitt and Porter (2001) argue, although *absolute* probabilities, θ_D and θ_S, cannot be identified, the *relative* probability, denoted as θ, can be calculated based on the following assumption:

$$\theta = \frac{\theta_D}{\theta_S} > 1 \tag{3}$$

This last assumption is crucial for the purpose of this work. A body of research papers has corroborated for the serious negative consequences of alcohol consumption on driving skills. Alcohol consumption produces retarded visual scanning (Moser et al. 1998), reduces the ability of reaction to unexpected events (Forchheimer, et al. 2005), increases risk-taking behaviors (Ogden and Moskowitz, 2004; NHTSA, 2009; Phillips and Brewer, 2011; Alver et al. 2014; Bogstrand et al. 2015) and interacts with drowsiness, causing most alcohol-related crashes to occur at night (Moskowitz and Fiorentino, 2000).

Let A_{ij} denote the share of two-vehicle crashes with one of the drivers belonging to type-*i* and the other to type-*j*, where i and j can coincide or differ. Note that $\{A_{i,j} \backslash\, i, j = S, D\}$ follows a multinomial structure, so that $A_{SD} + A_{DD} + A_{SS} = 1$, and can be estimated through maximum likelihood estimation. Let R denote the following ratio:

$$R = \frac{A_{DS}^2}{A_{DD}\, A_{SS}} \tag{4}$$

Having this ratio R, the *relative risk* θ can be calculated as:

$$\theta = \begin{cases} \dfrac{R - 2 + \sqrt{(R^2 - 4R}}{2}, for\ R \geq 4, \\ 1, \quad otherwise. \end{cases} \tag{5}$$

Let N denote the relative share N_D/N_S, which can be calculated according to:

$$N = \frac{N_D}{N_S} = \frac{1}{\theta} \frac{\left(A_{DS} \dfrac{\theta}{1+\theta} + A_{DD}\right)}{\left(A_{DS} \dfrac{1}{1+\theta} + A_{DD}\right)} \tag{6}$$

Additionally, using this estimated relative number, N, the relative risk can be estimated from observations in *one-vehicle* accidents. Let λ denote this alternative measure of the relative risk using observations of *one-vehicle* crashes. Denoting Q_D and Q_S the shares of drunk drivers and sober drivers in one-vehicle crashes, respectively, the relative probability λ can be estimated as:

$$\lambda = \frac{Q_D / Q_S}{N} \tag{7}$$

Although Levitt and Porter (2001) applied this methodology on the analysis of fatal crashes, the assumptions, and therefore the methodology, are perfectly suitable for accidents with and without fatal victims. In this thesis, the methodology used by Levitt and Porter (2001) will be applied in Spain between 2004 and 2015.

4 Data description and summary statistics

In this thesis, I use a dataset of road accidents with victims occurring on Spanish roads from 2004 to 2015, recorded by the Spanish Directorate-General of Transport (DGT). In this work, the focus is placed on those accidents in which there were one and two vehicles involved. This amounts to 508,696 crashes of all severities. Each crash is initially recorded by the police in the place of occurrence, and other information is later completed by other agents: medical services, forensic analyses, and the district attorney office (Fiscalía). The dataset collects information about the characteristics of the individuals, the vehicles involved in a crash, the kind of road where the crash occurred, and the type of infraction (if any) committed by drivers or pedestrians, and whether the crash was caused by other situations (a driver's sudden illness, a vehicle's sudden breakdown, adverse weather, etc.). As reported by DGT (2011), most common infringements are speeding, impaired driving, driving without mandatory passive security items (no helmet, unfastened security belt, no child seats), or driving while using a cell phone, which has increased significantly over the last few years (López, 2016).

Regarding alcohol content measurement, all drivers involved in an accident are tested for their alcohol content using a breathalyzer device (or blood alcohol content test, in some cases) by police agents. Drivers who refuse this test are fined and sanctioned via the Penalty Points System (PPS).

Table 2. Summary statistics for drivers' profile by hourly intervals, Spain 2004 – 2015.

	0:00 a.m. - 23:00 p.m.		Party time: 0:00 a.m. - 5:00 a.m.		Work hours: 6:00 a.m. - 19:00 p.m.		After work hours: 20:00 p.m. - 23:00 p.m.	
Variable	**All crashes**	**Fatal crashes**	**All crashes**	**Fatal crashes**	**All crashes**	**Fatal crashes**	**All crashes**	**Fatal crashes**
Women drivers (%)	20.7	11.5	15.5	8.2	21.7	12.3	19.0	11.1
Age of drivers involved in a crash (years):								
Mean	38.2	39.8	33.2	33.2	38.8	41.4	35.8	37.6
Mode	30.0	30.0	22.0	22.0	30.0	30.0	25.0	21.0
Median	35.0	36.0	30.0	30.0	36.0	38.0	33.0	35.0
Drivers involved in a crash by age (%):								
Between 18 and 25 years old	18.6	19.3	28.5	30.3	16.6	16.5	22.6	21.7
Between 26 and 30 years old	13.2	13.2	15.8	17.3	12.8	12.5	14.1	12.8
Between 31 and 40 years old	22.9	21.7	22.0	22.0	23.2	21.4	22.0	22.6
Between 41 and 50 years old	15.8	15.7	12.7	12.9	16.3	15.8	14.5	17.3
Older than 50 years	29.5	30.1	20.9	17.5	31.0	33.8	26.9	25.6
Drivers with reported blood alcohol content (BAC) above legal limits (%)	3.3	3.8	11.5	8.6	2.3	2.7	4.1	4.4
Cars, SUV	3.9	4.7	12.2	9.4	2.8	3.4	4.7	5.7
Pickup trucks	3.6	3.2	14.8	8.8	2.3	2.1	5.7	3.9
Motorcycles	1.4	1.4	7.2	5.9	1.0	1.0	1.9	0.8
Two-vehicle crashes with:								
Two sober drivers	95.9	93.6	85.6	86.9	97.0	95.7	94.0	90.8
One sober and one drunk driver	4.0	6.2	13.9	13.1	2.8	4.1	5.8	9.0
Two drunk drivers	0.1	0.2	0.6	0.6	0.1	0.2	0.1	0.1

Table 2 compiles summary statistics on vehicle crashes in Spain from 2004 through to 2015 in three hourly intervals, classified from 0:00 a.m. to 5:00 a.m. ('party time'), 6:00 a.m. – 19:00 p.m. ('work hours'), and 20:00 p.m. – 23:00 p.m. ('after work hours'). In view of this classification, there are apparently different patterns in the composition of drivers' profiles, especially for the 'party time'. For this nighty interval, drivers involved in crashes are the youngest across the three hourly intervals, accounting for a sizable fraction of drivers with BAC over the limit (11.5% in all crashes and 8.6% in fatal crashes). In the 'after work hours' interval, drivers' ages slightly increase, the ratio of drunk drivers falls, as well as the percentage of male drivers. The 'work hours' segment is different: drivers' age is older, there is a significant reduction in the number of drunk drivers, and there are more female drivers.

The final three rows of Table 2 present basic statistics for two-vehicle crashes, representing 47% of the total number of accidents. The most likely case of collisions is where both drivers were sober. Cases with one sober driver and one drunk driver are less likely to be observed. Cases of two-vehicle collisions where both drivers were reported to be drunk are a minority but more likely during nighty hours. These last two cases are crucial to identify the risk that drunk drivers pose on other people.

5 Results

5.1 Assessing the relative number and risk of drunk drivers

Table 3. Drunk vs. sober drivers by type of vehicle and hourly interval, Spain 2004 – 2015.

		Hourly Interval					
Variable	**Vehicle**	**Party time: 0:00 a.m. - 5:00 a.m.**		**Work hours: 6:00 a.m. - 19:00 p.m.**		**After work hours: 20:00 p.m. - 23:00 p.m.**	
$\theta = \theta_D / \theta_S$	**Cars**	2.24	(0.65)	1.00	(0)	3.78	(1.01)
	Cars and pickup trucks	2.69	(0.60)	1.00	(0)	3.94	(0.92)
	Cars, pickup trucks and motorcycles	1.00	(0.22)	1.00	(0)	1.00	(0.23)
$N = N_D / N_S$	**Cars**	0.07	(0.01)	0.02	(3.10E-04)	0.02	(4.26E-03)
	Cars and pickup trucks	0.06	(0.01)	0.02	(2.62E-04)	0.02	(3.67E-03)
	Cars, pickup trucks and motorcycles	0.08	(6.53E-03)	0.02	(1.54E-04)	0.03	(2.31E-03)
$\lambda = \lambda_D / \lambda_S$	**Cars**	3.11	(0.61)	2.30	(0.08)	3.93	(0.90)
	Cars and pickup trucks	3.59	(0.64)	2.32	(0.07)	4.10	(0.82)
	Cars, pickup trucks and motorcycles	2.39	(0.30)	3.00	(0.08)	2.34	(0.32)

Notes: This table presents different estimates for parameters N, θ and λ for different types of vehicles involved in the crash and by different time intervals. These estimations were made following Levitt and Porter (2001). Figures in parentheses denote standard errors.

Table 3 presents the estimates for N, θ and λ for all crashes on every kind of road from 2004 to 2015 using the Levitt-Porter approach presented in the previous section. Following Clarke et al. (2005), Chen et al. (2012), Kim et al. (2013), Benhood (2014), and Ponnaluri (2016), an analysis of heterogeneity based on hourly intervals is included. So, these estimations are reported for the three hourly intervals, and by type of vehicle involved: cars, pickup trucks, and motorcycles (representing 90% of the sample). With respect to car drivers, and for the first hourly interval ('party time', 0:00 a.m. - 5:00 a.m.), the relative risk of a drunk driver causing a crash, θ, is 2.24

times as high as that of a sober driver. For ‘work hours’ (from 6:00 a.m. to 19:00 p.m.), the relative risk of a drunk driver, θ, is one, implying no differences in the risk of causing an accident by a drunk driver compared to a sober one. For the ‘after work hours’ interval (20:00 p.m. – 23:00 p.m.), θ is 3.78. These estimates are very similar when pickup trucks are incorporated. However, they change when motorcycles and mopeds are also considered, being equal to one. This suggests that (sober) drivers of motorcycles possess an additional risk of causing a road accident.

Interestingly, the estimated proportion of drunk drivers per sober drivers, N, is higher in the ‘party time’ interval (0:00 a.m. – 5:00 a.m.), than in the ‘after work hours’ (20:00 p.m. – 23:00 p.m.), being 0.07 and 0.02, respectively. These results are similar when pickup trucks and motorcycles are included, with N reaching 0.08 in the ‘party time’. The ‘work hours’ range (06:00 a.m. – 19:00 p.m.), presents a similar N to the ‘after work hours’ interval, 0.02 and 0.03, respectively. This shows signs of alcohol consumption patterns.

As for the relative risk estimated for one-vehicle crashes, λ, results show a similar hourly pattern. The relative risk, λ, is 3.11, 2.3, and 3.92, in the ‘party hours’, the ‘work hours’, and in the ‘after work hours’ ranges, respectively. This increase in both λ and θ during ‘after work hours’ reflects a strong complementarity between leisure time and alcohol, as seen in the EDAP’ 15 survey (DGT, 2016a) and the EDADES 2017 survey (MSCBS, 2019) - for an estimate of this cross-price elasticity for US consumers, see West and Parry, 2009 -. When pickup trucks and motorcycles are included, the difference between λ and θ is reduced.

The results differ in magnitude from those of Levitt and Porter (2001). They find that the risk of drunk drivers is 7.51 times as high as that of a sober driver (mine is 2.24-2.7) and that the share of drunk drivers is 0.20 and 0.15, (mine is 3-7% for Spain, depending on the interval). These differences may be due to the period under consideration, 1983–1993, or habits of alcohol consumption. Indeed, this is a common finding in other US studies. Awadzi et al. (2008) found that the relative risk of a drunk driver causing a non-fatal accident was 1.51 times as high as that of a sober driver. For fatal crashes and for the hourly interval 9:00 p.m. – 7:00 a.m., these authors found that the relative risk is 2.3 times higher. Chen et al. (2012) found higher risk for the likelihood of severity in the interval 00:00 a.m. – 06:00 a.m. (ORs below 1 of different hourly intervals, with respect to the interval 00:00 a.m. – 06:00 a.m.). Kim et al. (2013) observed that alcohol had different effects on the likelihood of a crash of determined severity (they obtained elasticities valued 73%, 32% and 31% for fatal, severe and visible injury single-vehicle crashes, respectively) and that observing the accident between 6:00 a.m. and 9:59 a.m. increased by 22% the likelihood of severe injuries. Benhood (2014) also found an increase in the likelihood of minor injury in nighty hours as well as severe injury when alcohol-impairment is observed for male drivers. Ma and Yan (2014) estimated that alcohol or drug abuse was key for being found guilty for a rear-end accident (OR=3, proximately). Donmez and Liu (2015) obtained too that alcohol is a very important factor that raises the likelihood of injuries (OR=2.23). Recently, Ponnaluri (2016) has estimated that the relative risk of a drunk driver causing a fatal accident by going in the wrong direction is 5.81 times as high as that of a sober driver, apart from finding a significant raise in the likelihood of observing a fatal WWD accident in the time interval 00:00 – 06:00 a.m. (OR=4.17). Penmetsa and Pulgurutha (2017) also found that the probability of observing moderate or severe injuries for drivers raises significantly with the presence of alcohol (OR=1.948 and 14.850, respectively) in the accident.

Table 4. Drunk vs sober drivers by hourly interval and weekday, Spain 2004 - 2015.

	Party time: 0:00 a.m. - 5:00 a.m.			**Work hours: 6:00 a.m. - 19:00 p.m.**			**After work hours: 20:00 p.m. - 23:00 p.m.**		
Week day	***N***	***Θ***	***λ***	***N***	***θ***	***λ***	***N***	***θ***	***λ***
Monday - Sunday	0.07	2.24	3.11	0.02	1.00	2.30	0.02	3.78	3.92
	(0.01)	(0.64)	(0.60)	(0.02)	(0.74)	(0.68)	(4.29E-03)	(1.00)	(0.81)
Monday - Friday	0.05	3.04	4.01	0.02	1.00	2.22	0.02	3.99	4.13
	(0.01)	(1.25)	(1.20)	(2.89E-04)	(1.81E-03)	(0.05)	(0.01)	(1.55)	(1.27)
Saturday - Sunday	0.08	1.99	2.85	0.05	1.00	2.25	0.03	4.22	4.21
	(3.08E-04)	(0)	(0.03)	(9.66E-04)	(0.02)	(0.05)	(0.01)	(1.61)	(1.28)

Notes: This table presents estimates for parameters N, θ and λ for crashes with cars and pickup-trucks involved. Estimates are arranged by different hourly gaps in different days of the week. These estimations were made following Levitt and Porter (2001). Figures in parentheses denote standard errors.

Table 4 presents the estimates arranged by type of day (non-weekend and weekend) and the defined hourly intervals for crashes involving cars and pickup-trucks (motorcycles were not included as sober drivers of motorcycles seem to possess an additional risk of producing an accident). No important differences are found in the relative risk, θ and λ, during weekends with respect to the rest of the week. However, regardless of the hourly interval, N takes lower values from Monday to Friday and increases at the weekend, which is in line with alcohol consumption habits. Comparing these results with the EDAP' 2015 study (DGT, 2016) it is checked that the proportion of drivers with air alcohol concentration >0.05 mg. per litre in the interval (00:00 a.m. – 06:59 a.m.) on weekends is higher than on the rest of the week.

Kim et al. (2013) found positive in the likelihood of fatal injury when it happened on weekends (elasticities with values of 21 and 26% for fatal and severe injuries, respectively); Ponnaluri (2016) also found a raise in the risk of observing a fatal WWD accident in Saturdays and Sundays (OR=1.57) than on the rest of the week.

5.2 Effects of the Penalty Points System on drinking drivers

As a follow-up exercise, I recalculate (N, θ, λ) for observations before and after the Penalty Points System (PPS).

Table 5. PPS effects over relative risk drunk vs. sober drivers, Spain 2004 – 2008.

	Relative number			Relative risk: Two-car crashes			Relative risk: One-car crashes		
January 2004 to June 2006	$N_{pre\text{-}PPS} = N_D/N_S$			$\theta_{pre\text{-}PPS} = \theta_D/\theta_S$			$\lambda_{pre\text{-}PPS} = \lambda_D / \lambda_S$		
Hourly Interval:	**Cars**	**Cars and pickup trucks**	**Cars, pickup trucks and motorcycles**	**Cars**	**Cars and pickup trucks**	**Cars, pickup trucks and motorcycles**	**Cars**	**Cars and pickup trucks**	**Cars, pickup trucks and motorcycles**
0:00 a.m. – 5:00 a.m.	0.08	0.09	0.09	2.26	1.85	1.00	2.23	1.97	1.74
6:00 a.m. – 19:00 p.m.	0.02	0.02	0.01	1.00	1.00	1.00	1.81	1.81	2.42
20:00 p.m. – 23:00 p.m.	0.02	0.03	0.03	4.14	3.13	1.00	2.90	2.33	1.75
July 2006 to December 2008	$N_{pre\text{-}PPS} = N_D/N_S$			$\theta_{pre\text{-}PPS} = \theta_D/\theta_S$			$\lambda_{pre\text{-}PPS} = \lambda_D / \lambda_S$		
Hourly Interval:	**Cars**	**Cars and pickup trucks**	**Cars, pickup trucks and motorcycles**	**Cars**	**Cars and pickup trucks**	**Cars, pickup trucks and motorcycles**	**Cars**	**Cars and pickup trucks**	**Cars, pickup trucks and motorcycles**
0:00 a.m. – 5:00 a.m.	0.06	0.05	0.07	2.40	3.37	1.25	3.80	4.85	3.03
6:00 a.m. – 19:00 p.m.	0.02	0.02	0.02	1.00	1.00	1.00	2.44	2.46	3.14
20:00 p.m. – 23:00 p.m.	0.02	0.02	0.03	3.68	4.46	1.00	4.34	5.06	2.54
	$N_{pre\text{-}PPS} = N_D/N_S$			$\theta_{pre\text{-}PPS} = \theta_D/\theta_S$			$\lambda_{pre\text{-}PPS} = \lambda_D / \lambda_S$		
Relative change:	**Cars**	**Cars and pickup trucks**	**Cars, pickup trucks and motorcycles**	**Cars**	**Cars and pickup trucks**	**Cars, pickup trucks and motorcycles**	**Cars**	**Cars and pickup trucks**	**Cars, pickup trucks and motorcycles**
0:00 a.m. – 5:00 a.m.	0.73	0.52	0.72	1.07	1.82	1.25	1.70	2.47	1.74
6:00 a.m. – 19:00 p.m.	0.98	0.97	1.01	1.00	1.00	1.00	1.35	1.36	1.30
20:00 p.m. – 23:00 p.m.	0.91	0.62	0.89	0.89	1.43	1.00	1.50	2.17	1.46

Notes: This table presents estimates for parameters N, θ and λ by different hourly gaps in two time periods, one ranging January 2004 – June 2006 (pre-PPS) and the other between July 2006 – December 2008 (post-PPS). It also presents the relative change in the parameters after PPS implementation (post-PPS) with respect to before PPS implementation (pre-PPS). These estimations were made following Levitt and Porter (2001).

Table 5 shows the results of the estimates using data of one and two-vehicle crashes on every kind of road for two periods. To make sure that the results are not biased due to the sample selection, data is split within time intervals of equal length. The first begins in January 2004 and finishes on June 30th, 2006. The second period begins on July 1st, the date of PPS implementation, and finishes on December 31st, 2008. Following the PPS and taking into account all the vehicles considered in this thesis, results show that the proportion of drunk drivers decreased by 25% during ‘party time’, and by 11% in the ‘after work hours’ interval, while there was no significant reduction during the ‘work hours’ interval, regardless of the type of vehicle. These results seem to coincide with the obtained by De Paola et al. (2013), who found a reduction in the number of offences related to impaired driving around 10%. Again, this reflects that alcohol and leisure hours are strong complements for Spaniards, as seen in the EDAP' 2015 survey (DGT, 2016a) and EDADES 2017 survey (MSCBS, 2019). The relative risk of drunk drivers, θ, predictably increased within the 'party time' and the 'after work hours' intervals, while for the 'work hours' remained stable. It is documented that there was an unequal downturn in all types of road offences after the PPS, mainly in speeding infringements (DGT, 2011; and López, 2006). Since the commission of these road offences has unequally declined, given that they can be committed by a sober or a drunk driver, it is not surprising that there is an increase in the relative risk after the PPS.

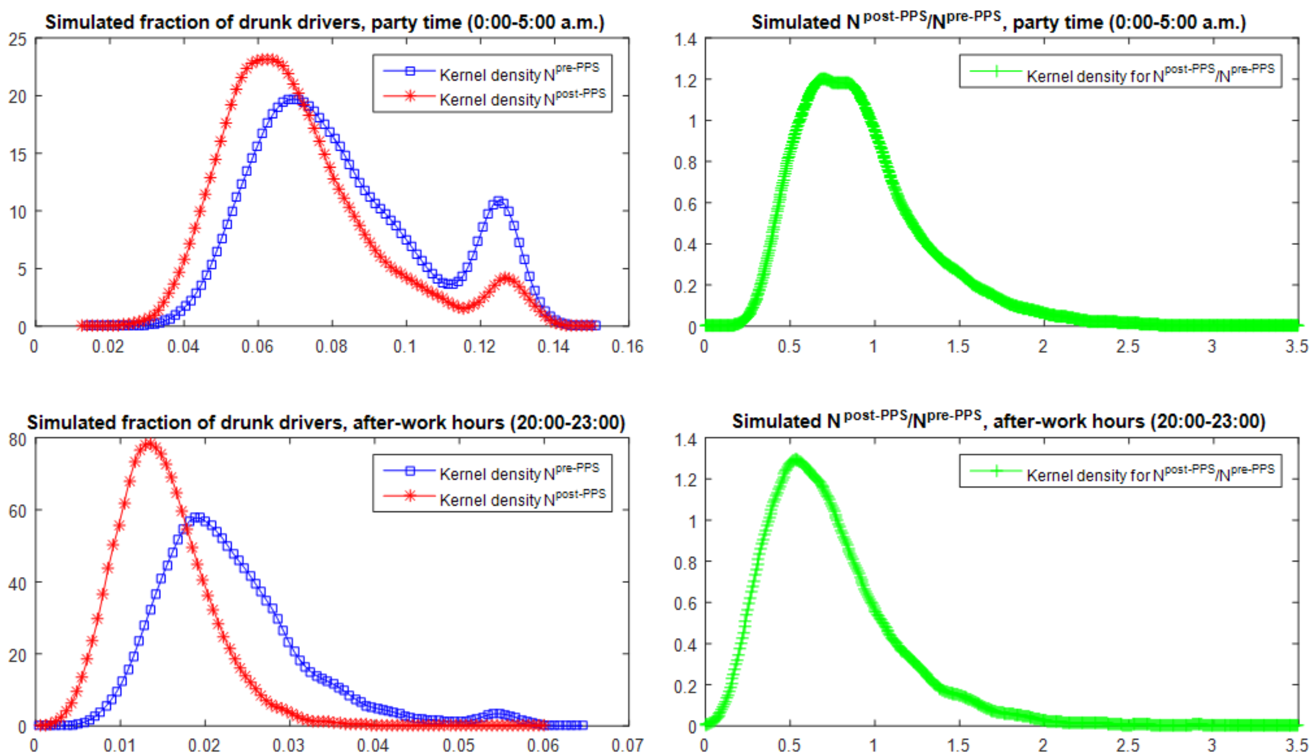

Figure 1. Kernel density simulations of the relative number of drunk drivers in the 'party time' and the 'after work hours' before and after the Penalty Points System implementation. Spain, 2004 – 2008.

It is now simulated the multinomial distribution $A = (A_{DS}, A_{DD}, A_{SS})$ estimated for these two samples. For each random realization n = 1,…10^5, denoted A_n, I compute the implied relative risk, θ, and relative fraction, N. Let $(N_n^{pre-PPS}, N_n^{post-PPS})$ denote the *n-th* realization of the relative fraction, according to the distributions before and after the PPS, for n = 1,…10^5. Figure 1 represents the kernel densities for $(N^{pre-PPS}, N^{post-PPS})$, and the kernel density for the ratio $(N^{post-PPS}/N^{pre-PPS})$. I focus on the 'party time' and the 'after work hours' intervals, which are the intervals in which the associated risk of drunk driving is observed. Overall, after the implementation of the PPS in both intervals, results show that the kernel densities of N shifted to the left and the dispersion decreased.

Table 6. Percentage of reduction in drunk driving after PPS, Spain 2004 – 2008.

Bound	Party time: 0:00 a.m. – 5:00 a.m.	After work hours: 20:00 p.m. – 23:00 p.m.
1.00	65.45%	79.93%
0.90	55.35%	73.35%
0.75	38.02%	59.86%
0.60	20.38%	43.62%
0.50	10.16%	30.75%
0.40	3.47%	18.10%
0.25	0.19%	4.72%
0.10	0.00%	0.32%

Notes: Last two columns represent the cumulative probability that ratio $N^{post-PPS}/N^{pre-PPS}$ is contained between 0 and the bound in crashes between vehicles that occurred in the 'party time' and 'after work hours'.

The right-hand column of the kernel densities in Figure 1 shows that the ratio $\frac{N^{post-PPS}}{N^{pre-PPS}}$ softened after the PPS. Using a value-ratio of 1 as a benchmark to evaluate whether the current situation is at least as good as the previous one, I conclude that in most of the cases, the ratio levelled out considerably during these two hourly intervals. More precisely, Table 6 introduces different cumulative values for these simulated ratios for a range of values from 0 to 1. For the 'party time' and the 'after work hours', I conclude that the PPS helped reduce the ratio $\frac{N^{post-PPS}}{N^{pre-PPS}}$ for 65% and 80% of cases, respectively. Viewed in another way, during the nighttime hours, 'party time' and 'after work hours' intervals, the ratio was at least 50% smaller after the PPS in 10% and 31% of simulated cases, respectively. The remaining benchmark values show a reduction in the relative number of drunk drivers after the PPS.

5.3 Robustness of the heterogeneous effects of drunk driving across hourly interval through econometric estimations

Results in Sections 5.1 and 5.2 indicate heterogeneous patterns in drivers' alcohol consumption across hourly intervals, according to the statistical method proposed by Levitt and Porter (2001). To confirm the robustness of these results I make use of different regression analysis. More concretely, I study the influence of DUI on the probability of fatal accidents by using a logistic regression to gauge how the probability of a fatal accident is affected by impaired drivers, and in a second approach, I use negative binomial regressions to explore how the number of fatal victims per accident changes with impaired driving. The focus is placed on crashes occurring on urban roads because the effects of DUI are more easily isolated from other infringements, such as speeding.

Table 7. Differences in drunk driving between urban roads and non-urban roads, by hourly interval, Spain 2004 – 2015.

	Urban roads		**Non-urban roads**	
Hourly interval	**Drunk driving crashes**	**Drunk driving crashes without further infractions**	**Drunk driving crashes**	**Drunk driving crashes without further infractions**
0:00 a.m. – 5:00 a.m.	7.6%	5.1%	10.1%	3.4%
6:00 a.m. – 19:00 p.m.	1.3%	0.9%	2.2%	0.9%
20:00 p.m. – 23:00 p.m.	2.5%	1.6%	5.2%	1.9%

Notes: This table compares the percentage of crashes in which drunk driving was observed in urban and non-urban roads with the percentage of crashes in which only drunk driving was observed, i.e. omitting interactions with other infractions like speeding, etc. These percentages were made by hourly interval and in urban roads and non-urban roads.

In this respect, Table 7 compiles some descriptive statistics clarifying this strategy. The share of crashes with drunk drivers is higher on non-urban roads. However, when these nonurban road accidents occur, speeding cases tend to occur coincidently. This pattern is common across hourly intervals. Therefore, the isolated effects of drunk driving on the likelihood of fatal victims can be more easily identified on urban roads. In both regressions, the covariates encompassed, following approaches observed in the literature, are as follows: accident characteristics (hour, day of the week, province, and date), features about the vehicles involved (type of vehicle, i.e car, industrial vehicle, moped etc., number of passengers with unfastened seatbelt or with helmet incorrectly adjusted), characteristics about the drivers (age and sex), variables denoting the economic period (Krüger, 2013; Kim et al., 2017). Also, in order to capture more correctly the effect of drunk driving, several dummy variables indicate changes in laws related to road infractions, especially on impaired driving, such as the reform of the penal code of December 2007 or reforms of the traffic laws mentioned in the regulation review. Of course, a dummy variable for drunk driving is also incorporated.

Table 8. Logit estimation on fatal crashes per hourly interval in urban roads in Spain. 2004 – 2015.

Hourly interval	Coefficient	Marginal effect	Elasticity	Log-likelihood	Sample Size
Party time: 0:00 a.m. – 5:00 a.m.	0.531** (0.237)	0.00471** (0.00213)	0.526** (0.235)	-741.4	15,670
Work hours: 6:00 a.m. – 19:00 p.m.	0.681*** (0.168)	0.00290*** (0.000721)	0.678*** (0.167)	-5481	214,390
After work hours: 20:00 p.m. – 23:00 p.m.	0.649*** (0.244)	0.00314*** (0.00120)	0.646*** (0.243)	-1520	54,740

Notes: This table reports logit estimates. The dependent variable is a dummy denoting if there were any fatalities in the crash. Covariates included are classified into accident characteristics, economic cycle, driver and vehicle characteristics, and regulation changes. *** p<0.01, ** p<0.05, * p<0.1. Figures in parenthesis denote standard errors.

The results of the logistic regressions are displayed in Table 8. The effect of alcohol consumption on fatal crashes is always positive and significant for all intervals, ranging from 0.53 to 0.68. The implied odds are 1.7, 1.98, and 1.91 for the ‘party time’, ‘work hours’, and ‘after work hours’ intervals, respectively, which means that the probability of observing a fatal crash is between 70% and 98% higher when at least one of the drivers is drunk, depending on the hourly interval. The marginal effect of drunk driving on the probability of a fatal crash is higher during nighttime hours relative to ‘work hours’, consistent with the results displayed in Table 3. Therefore, the probability of a fatal crash when at least one driver is observed to have consumed alcohol above the legal limit varies from 0.11 to 0.13 p.p., depending on the hourly interval. The implied elasticities range between 0.53 to 0.68; a 1 p.p. reduction in drunk drivers produces a decrease in the likelihood of observing fatal crashes between 0.53 and 0.68 p.p.

The obtained results seem to match the obtained in the literature. Kockelman and Kweon (2002) estimated that the presence of alcohol raised the likelihood of severity. When DUI is observed, Awadzi et al. (2008) found increases in the likelihood of finding a fatal accident (OR=2.3,), Kim et al. (2013) also reported a raise in the probability of finding fatal victims when drunk driving was observed (OR=2.75), Donmez and Liu (2015) found that the presence of alcohol increases the likelihood of more severe injuries (including fatalities), Ponnaluri (2016) reported as well, an increase in the likelihood of fatality (OR=1.06), Penmetsa and Pulugurtha (2017) found an OR of 4.6 in crashes involving severe injuries in the State of North Carolina in the period 2010-2013.

Table 9. Negative binomial estimation on fatal victims per hourly interval in urban roads in Spain. 2004 – 2015.

Hourly interval	Coefficient	Marginal effect	Elasticity	Log-likelihood	Sample Size
Party time: 0:00 a.m. – 5:00 a.m.	0.490* (0.250)	0.00466* (0.00245)	0.490* (0.250)	-797.8	17,213
Work hours: 6:00 a.m. – 19:00 p.m.	0.636*** (0.179)	0.00292*** (0.000830)	0.636*** (0.179)	-5710	214,942
After work hours: 20:00 p.m. – 23:00 p.m.	0.699*** (0.259)	0.00373*** (0.00142)	0.699*** (0.259)	-1602	56,236

Notes: This table reports negative binomial estimates. The dependent variable is the number of fatal victims in each crash. Covariates included are classified into accident characteristics, economic cycle, driver and vehicle characteristics, and regulation changes. *** p<0.01, ** p<0.05, * p<0.1. Figures in parenthesis denote standard errors.

Table 9 displays the results for the negative binomial regressions, where the dependent variable is the number of fatal victims. Analogously to the results displayed in Table 8, in view of the marginal effects, I also find heterogeneity of drunk driving over fatal victims depending on the hourly intervals, being higher in the 'party time' than in the rest of the intervals. Thereby, the likelihood of finding a fatal victim increases by between 0.15 and 0.25 p.p. when at least one driver is reported to be drunk. The implied elasticities suggest that a 1 p.p. reduction in the number of drunk drivers reduces fatalities by 0.5 to 0.7 p.p. in crashes where at least one of the drivers is observed to be drunk.

6 Assessing the external costs of drunk driving

In this Section, the external cost imposed by drunk drivers in terms of (fatal and non-fatal) victims is estimated, and it is proposed a monetary evaluation of it. This assessment has been calculated from the risk that drunk drivers pose to others, θ and λ, treating damage to occupants in vehicles driven by the drunk driver as internal. It is worth noting that this assessment represents a lower bound cost. Although other costs are also external, such as property damage and police surveillance costs, which are assimilated by both insurance companies and the government, they are not taken into account in this work.

The assessment proceeds as follows. Firstly, I use a wide definition of four-wheel vehicles: passenger cars and light trucks, and take the relative risks, θ and λ, estimated in Tables 2, 3 and 5.

Secondly, according to Levitt and Porter (2001), in two-car crashes with one drunk driver and one sober driver, drunk drivers can be made responsible for a fraction of $\frac{(\theta-1)}{(\theta+1)}$ of crashes. For instance, having a relative risk of θ = 3,94 during the 'after work hours', drunk drivers should be made responsible for 59,5% (i.e., 2.94/4.94) of injured occupants in two-car crashes with one sober driver and one drunk driver. For those two-vehicle crashes where both drivers are reported to exceed the legal limit of BAC, following Levitt and Porter (2001) and Parry et al. (2014), it is assigned the blame for half of all victims caused by impaired driving assuming that only one of the drivers caused the crash, regardless of the hourly interval. Analogously, for one-vehicle crashes, I consider a fraction $\frac{(\lambda-1)}{\lambda}$ of victims that can be considered as external. Finally, this cost of injuries are borrowed from the estimations in the Handbook on External Costs of Transport (Korzhenevych et al., 2014), which proposes Values of Statistical Life of €1.91 million per dead victim, €0.24 million per severely injured victim, and €0.02 million per mildly injured victim (expressed in Euros of 2010, including the monetary value per victim and an estimate of other direct and indirect costs). Using the GDP deflator (base year 2010), these estimates are updated for all years in the sample, from 2004 to 2015.

Table 10. External cost of drunk driving in Spain. 2004 – 2015.

Year	Number of fatalities due to drunk driving			Cost of victims of all severity wrt GDP
	Party time 0:00 a.m. – 5:00 a.m.	**Work hours** 6:00 a.m. – 19:00 p.m.	**After work hours** 20:00 p.m. – 23:00 p.m.	
2004	50	57	18	0.017%
2005	43	37	21	0.013%
2006	30	50	27	0.013%
2007	35	35	21	0.012%
2008	21	29	17	0.009%
2009	20	23	21	0.010%
2010	23	33	21	0.010%
2011	14	28	14	0.006%
62012	10	40	5	0.006%
2013	4	32	4	0.004%
2014	7	15	10	0.004%
2015	10	20	5	0.004%

Notes: This table presents the number of fatalities and the cost of victims of all severity (fatal, severe and mild) caused by drunk driving with respect to GDP by year and hourly interval. The estimate of the number of fatalities was made using the implied risk from Levitt and Porter's (2001) methodology (Tables 2, 3 and 5). The monetary cost per victim of all severity is borrowed from the estimate given in the *Handbook of External Cost of Transport* (Korzhenevych et al., 2014).

Table 10 summarizes these results from 2004 to 2015 (the number of mild victims and severe victims are not reported for simplicity but included in the costs assessment). It is found that the number of fatal victims due to drunk driving has declined over this period, especially in the 'party time', where the number of fatalities due to drunk driving in 2015 was five times as low as in 2004. This is reflected in the monetary cost of all victims due to drunk driving, expressed in terms of the GDP, evolving as a downward sloping trend, from 0,017% to 0,004%, i.e. four times smaller. Overall, both in absolute terms (number of fatalities and other victims) and in relative terms (monetary external cost relative to the nominal GDP, as an indicator of the economic size of the Spanish economy).

Equivalently, obtaining an average of 14 thousand kilometres driven per vehicle and year from the Spanish National Statistics Office (INE, 2008), and for the percentage of drunk drivers - calculated by $\frac{N}{(1+N)}$ from Table 3 - drunk drivers should pay 2 Euro-cents per kilometre driven.

Using the number of registered drivers of the Spanish Drivers Census in 2015 (DGT, 2016b), and using the cumulated external cost from 2004 to 2005, it is estimated that impaired driving between those years cost €1.83 per driver (drunk driver or not). Also, the DGT reports that 9% of offending drivers were sanctioned due to reported BAC above the legal limits, during the first ten years of the PPS, from July 2006 to July 2016 (López, 2016). This represents 670 thousand drivers arrested due to driving drunk. According to this evaluation, the external cost of impaired driving was about €840 million (of 2010) over this period. This implies that drunk drivers should be fined by €1250, on average, to internalize the external costs. Table 1 indicates that the fine on drunk drives has ranged between €300 and €600 with few changes. This is considerably lower than the estimated Pigouvian fine. However, since the implementation of the PPS, impaired driving has been sanctioned with a loss of points, from 3 to 6, in addition to the fine, that may lead to the deprivation of the driving license. Therefore, considering the costs of higher car insurance premia, a possible prison sentence, a possible sentence of community service, and the deprivation of driving for 1 to 4 years (if all points are exhausted), the PPS has introduced a punitive measure that has likely approached a burden on drivers equal to the actual external costs.

Using data for 1993 and 1994, Levitt and Porter (2001) estimated a fine of around $8000 per arrested driver and 16 cents per mile driven by each drunk driver. Regardless of the exchange rate

Dollar/Euro considered, this widely surpasses my estimates for Spain. In this case, differences can be due to the period they use, the monetary value of statistical life (3 million dollars per fatal US victim), the possible differences in security devices between the periods considered in Levitt and Porter (2001) and the ones in this work, as well as differences in the characteristics of road accidents in the US and Spain.

7 Robustness Test

Table 11. Observed and estimated change in fatal crashes and victims, January 2004 – June 2006 versus July 2006 – December 2008.

Hourly Interval	Type	Fatal crashes	Fatal victims
Party time: 0:00 a.m. - 5:00 a.m.	All (observed)	-396 (-31%)	-493 (-33.5%)
	Related to drunk driving (observed)	-16 (-12.5%)	-28 (-18.9%)
	Related to drunk driving (predicted)	-19 (-14.7%)	-20 (-13.7%)
	90% Confidence Interval	-25.6%	-25.3%
		-3.9%	-2.2%
Work hours: 6:00 a.m. - 19:00 p.m.	All (observed)	-943 (-17.6%)	-1185 (-19.3%)
	Related to drunk driving (observed)	-31 (-19.1%)	-44 (-21.9%)
	Related to drunk driving (predicted)	1 (0.8%)	2 (0.8%)
	90% Confidence Interval	0.5%	0.4%
		1.2%	1.1%
After work: 20:00 p.m. - 23:00 p.m.	All (observed)	-364 (-24.2%)	-384 (-23.1%)
	Related to drunk driving (observed)	-4 (-5.6%)	-6 (-7.3%)
	Related to drunk driving (predicted)	-5 (-7.1%)	-6 (-7.7%)
	90% Confidence Interval	-11.5%	-12.3%
		-2.7%	-3.0%

Notes: This table displays the observed and predicted changes between the periods January 2004 - June 2006 and July 2006 - December 2008 for fatal crashes and fatal victims. Predicted changes in crashes/victims caused by drunk driving were assessed using the elasticities reported in the logistic and negative binomial regressions, Tables 8 and 9, and the change in the relative number *N* associated with the PPS, reported in Table 5.

As an extension, I finally study whether the observed reduction in fatal crashes and fatal victims after the PPS can be predicted combining the elasticities in Tables 8 and 9, and the change in the relative number of drunk drivers in Table 5. More precisely, according to Table 5, there was a 28% fall in the relative number of drunk drivers for the 'party time' interval (note I use a wide definition of vehicles, including light trucks and mopeds). Combining this data with the elasticities of fatal crashes and fatalities from Tables 8 and 9 (0.53 and 0.49, respectively) it is estimated a fall of 14.7% in fatal crashes, and of 13.7% in fatal victims, as shown in Table 11. Comparing this with the observed changes, 12.5% and 18.9%, respectively (also in Table 11), It can be concluded that my estimates provide an accurate prediction for this hourly interval (note that observed changes are contained within the 90% confidence interval). For the two other hourly intervals, predicted changes are calculated analogously. Unsurprisingly, for the ‘work hours’ interval, my estimate does fail to predict changes in road fatalities: during these hours, habits of alcohol consumption are described by different reasons than that of complementing leisure time. For the two nighty intervals, however, the changes were predicted accurately.

8 Conclusions, policy implications and avenues for further research

This thesis has presented an assessment of the external costs of impaired driving in Spain over the period 2004–2015. It has also been reported evidence on the risk of drunk drivers causing a crash, relative to that of sober drivers, following the methodology proposed by Levitt and Porter (2001), by exploiting information inherent to two-vehicle crashes. Also, it has been estimated possible effects of the Penalty Points System on the proportion of drunk drivers in Spain.

The following conclusions can be reported. Firstly, it is estimated that the relative risk of drunk drivers ranged between 2.7 and 3.9 during nighttime hours (i.e. 20:00 p.m. – 5:00 a.m.). During ‘work time’ hours (6:00 a.m. – 19:00 p.m.), this relative risk was one, so that the probability of a drunk driver causing a road accident was indistinguishable from that of a sober one. Moreover, the relative number of impaired drivers tended to increase during nighttime hours. Unsurprisingly, the relative number was also higher on weekends, regardless of the hourly interval. These results reveal heterogeneity in the pattern of alcohol consumption across hours of the day, mainly associated with young male drivers, due to the complementarity between leisure and alcohol, as seen in the EDAP’ 2015 survey (DGT, 2016a), the EDADES 2017 survey (MSCBS, 2019), and in the analysis by West and Parry (2009). When comparing these results with those of Levitt and Porter (2001) for US roads, the results showed in this work implied lower values for the relative risk, for the relative number of drunk drivers, and for the external cost. This disparity could be due to a number of aspects, such as different habits in alcohol consumption or the yearly periods that were under analysis. The findings regarding heterogeneity on hourly interval and weekday match with a considerable proportion of the literature.

Secondly, I presented evidence that the proportion of drunk drivers declined after the implementation of the Penalty Points System for driving licenses in Spain on July 1st, 2006. I found reductions in this proportion of between 10% and 30% during nighttime hours. In terms of the likelihood of road accidents, this fact has produced more peaceful nights. Importantly, during work hours, the distribution did not change. This reduction in the number of impaired drivers is also observed in the literature assessing the impact of the PPS in the number of impaired driving infractions (De Paola et al., 2013).

Thirdly, this assessment indicated a downturn in the external costs due to drunk driving over the period 2004–2015. The decline can be explained on several grounds, such as fewer infringements and safer vehicles, although this last reason is beyond the scope intended for this thesis. Having this external cost, it is proposed that drunk drivers should be fined around €1250. Before and after the onset of the PPS in July 2006, this amount was more than twice as high as the existing fine, which had an upper bound of €600. However, the PPS (along with the reinforcements of punishments by changes in traffic laws and in the penal code) introduced additional punishment (deprivation of points), whose cumulative effect now approaches the equivalent of my proposed fine.

Finally, using logistic and negative binomial regressions, I also found differences in the hourly marginal effects of impaired driving, which were higher in the ‘party time’. These differences are also observed in the elasticities of fatal victims with respect to impaired driving, which were estimated and ranged between 0.5 and 0.7. Combining the elasticities of the logit and negative binomial models, and the estimated reduction in the proportion of drunk drivers after the PPS, my approach does a good job in capturing the change in fatalities after enforcement of the PPS during nighttime hours, but not for work hours, where impaired driving is less likely to happen. This provides robustness to the logit and negative binomial regressions, and the estimated reduction of drunk drivers after the PPS conducted in this thesis.

Throughout this thesis, I have exploited the methodology proposed by Levitt and Porter (2001) to identify the relative number of drunk drivers, based on the information hidden behind two-car collisions. Although this methodology is simple to apply, it faces two important limitations. First, it requires big data sets to guarantee adequate variability to estimate the parameters of interest N, θ and λ especially if the sample is conditioned on factors such as the hour interval, the province, or the economic activity. Second, the results from this approach are not adequate to trace an exact causation. For example, these results pointed to a decline in drunk driving offences alongside an increase in the punishments of these infringements since the PPS on July 1^{st}, 2006. This, however, cannot eventually be seen as a causal effect from the PPS. In an ongoing piece of work currently in progress, regression discontinuity design techniques are being applied.

I contributed to the existing research by highlighting differences in the relative risk of causing a crash that drunk drivers pose on sober drivers, by hourly intervals and type of day, revealing alcohol consumption patterns that correspond to leisure time. As a second contribution, it is presented an assessment of the external costs of drunk driving in Spain. As it is shown, the strong (within each day) heterogeneity in the patterns of alcohol consumption should not be neglected when road safety policies are designed and enforced. Further reductions in road victims might be achieved by active policy interventions affecting drivers' incentives, such as surveillance controls, education as well as promoting improvements in the safety devices of vehicles.

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