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Hidden figures behind two-vehicle crashes: An assessment of the risk and external costs of drunk driving in Spain

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Abstract: This paper presents an assessment of the external cost of drunk driving in Spain between 2004-2015. Eventually we arrive at the following conclusions. Firstly, we find the relative risk of drunk drivers causing a crash during the night (20:00 p.m. to 5:00 a.m.) to be between 2.7 to 3.9 times higher than that of sober drivers. Secondly, we provide evidence that the relative number of drunk drivers versus sober drivers declined during nighttime hours after the implementation of the Penalty Points System for driving licenses in Spain on July 1st 2006. Thirdly, using logistic and count model regressions, we confirm hourly heterogeneity in the pattern of drunk driving, and estimate elasticities of fatal crashes with respect to drunk driving, which range between 0.5 and 0.7. When estimating the decline in fatalities after the Penalty Points System, our approach does a good job in capturing the change in fatalities during nighttime hours that can be accounted for by drunk driving. Finally, our assessment indicates a downturn in the external costs of drunk driving over the last decade in Spain. In addition, we estimate that the fine for drunk driving should be set at 1250€, in order to offset its external costs. Overall, our results point to a decline in drunk driving offences alongside an increase in its punition.

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1. Introduction

The aim of this paper is to assess the external cost of drunk driving in Spain over the period 20042015. To do this, we 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 us to gauge 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. We use this methodology 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 90s, 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. 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' behaviors and punishing driving offences, such as drunk driving. A causal analysis behind this downturn is beyond the scope of the current paper, but we 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.

We contribute to the existing research by providing an assessment of the external costs of drunk driving in Spain, as well as highlighting the differences in the risk of drunk driving in causing a crash across hourly intervals. Overall, our results point to a decline in drunk driving offences alongside an increase in the punitive measures.

We 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, which we label as 'work hours', and two nightly segments, from 20:00 to 23:00, and from 00:00 to 5:00, labeled as 'after work' and 'party time' hours, respectively. We reach the following conclusions. Firstly, the estimated relative risk of drunk drivers ranges between 2.7 and 3.9 during nighttime hours, i.e. from 20:00p.m. to 5:00a.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 (West and Parry, 2009, estimate this cross-price elasticity for US, and find they are strong complement). Our 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, we also report evidence that the share of drunk drivers *versus* sober drivers dramatically declined following the Penalty Points System (from now on abbreviated to PPS) for driving licenses implemented as of July 1st 2006 in Spain. Since ours is not a causal analysis, a word of caution: one should refrain from interpreting this finding as a causal effect.

Secondly, using individual administrative data on road accidents, discrete choice and count model regressions, we 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. We 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 0.7p.p.) When estimating the decline in fatalities following the PPS that can be accounted for by drunk driving, our approach does a good job in capturing the change in fatalities during all hourly intervals, except the working hours.

Finally, our 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. Using this assessment, we conclude that drunk drivers should be fined1250€. We document that this amount was below the existing fines before the Penalty Point System in July 2006. Afterwards, however, legal reforms of traffic laws introduced additional sanctions that have met this amount. Moreover, we show that this fine is equivalent to imposing a theoretical fine of 2-3 cents per kilometer driven by a drunk driver.

The paper is organized as follows. Section 2 describes the database used in this work and provides summary statistics. Section 3 summarizes the methodology proposed by Levitt and Porter (2001), and the results are reported in Section 4. Section 5 introduces 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 4, combined with the logit and count model estimates. Finally, the last Section presents the conclusions reached in this paper and sets forth several policy recommendations.

2. Summary of 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 we denote 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 interact with. Let N_i denote the number of drivers of type $i \in \{D, S\}$. The (unobservable) share of each driver is given by:

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

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

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

- *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:

$$\theta = \frac{\theta_D}{\theta_S} > 1 \qquad (3)$$

This last assumption is crucial for our purposes. A body of research papers has raised several caveats about the consequences of alcohol consumption on driving. Alcohol consumption produces retarded visual scanning (Moser et al. 1998), reduces the ability of reaction to unexpected events (Forchheimer, *et al*., 2005) and increases risk-taking behaviors (Ogden and Moskowitz, 2004; NHTSA, 2009; Phillips and Brewer, 2011; Bogstrand et al. 2015). Additionally, alcohol consumption has been shown to interact with drowsiness, causing most alcohol-related crashes to occur at night (Moskowitz and Fiorentino, 2000). Thus, drunk drivers are more likely to be involved in a fatal crash than sober drivers (Awadzi et al., 2008; Ponnaluri, 2016; Zeckey et al., 2011; Lombardi, 2017; Benhood and Mannering, 2017).

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. Let R denote the following ratio:

$$R = \frac{A_{DS}^2}{A_{DD}\, A_{SS}} \qquad (4)$$

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

$$\theta = \begin{cases} (R - 2 + \sqrt{(R^2 - 4R)}/2, & for\ R \geq 4, \\ 1, & otherwise. \end{cases} \qquad (5)$$

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

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

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:

$$\lambda = \frac{Q_D/Q_S}{N} \qquad (7)$$

3. Dataset description and summary statistics

We 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). We focus 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, or whether the crash was caused by other situations (a driver's sudden illness, a vehicle's sudden breakdown, adverse weather, etc.). As reported by the DGT (2011), most common infringements are speeding, drunk 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 (see also López, 2016).

With regards to drunk driving, all drivers involved in an accident are tested for their blood alcohol concentration (henceforth, BAC) using a breathalyzer by police agents. Drivers who refuse this test are fined and sanctioned via a Penalty Points System (PPS). The BAC of demised drivers is measured and reported by forensic services.

Table 1 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 nightly interval, drivers involved in crashes are the youngest across the three-hourly intervals, accounting for a sizable fraction of drivers with blood alcohol concentration (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 1 present basic statistics for two-vehicle crashes, representing 47% of the total number of accidents. The most likely case is that of collisions where both drivers were sober. Cases with one sober driver and one drunk drivers are less likely to be observed. Cases of two-car collisions where both drivers were reported to be drunk are a minority, and are more likely during nightly hours. These last two cases are crucial to identify the risk that drunk drivers pose on other people.

[**Table 1 here**]

4. Assessing the relative number and risk of drunk drivers

Table 2 presents the estimates for N, θ and λ for all crashes on every kind of road from 2004 to 2015 using the Levit-Porter approach presented in the previous section. These estimations are reported for the three hourly intervals,[1] and by type of vehicle involved: cars, pickup trucks, and motorcycles. With

[1] Further arguments of why this hourly classification can matter can be found in Lenné et al (1997) and Awadzi et al. (2008). Lenné et al. (1997), Kim et al. (2013) or Alver et al. (2014), document that drivers' conduct changes within the hourly interval.

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 difference 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' range, respectively. This increase in both λ and θ during 'after work hours' reflects a strong complementarity between leisure time and alcohol (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.

Our 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 (ours is 2.24-2.7) and that the share of drunk drivers is 0.20 and 0.15, (ours 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. For example, 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. Recently, Ponnaluri (2016) has estimated that the relative risk of a drunk driver causing an accident by going in the wrong direction is 5.81 times as high as that of a sober driver.

Table 3 presents the estimates arranged by type of day [2] (non-weekend and weekend) and by the hourly interval. 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.

[**Tables 2 and 3 here**]

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

[2] As Clarke et al. (2005), Kim et al. (2013), and Ponnaluri (2016) observe, crash involvement rates and risk of fatal accidents could also differ by weekday.

Table 4 summarizes some common offences sanctioned by the PPS, their respective penalty points and fines, together with a reform that altered these 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 to 6 points. Overall, the *monetary* fines did not substantially change after the PPS, and across the period of study[3]. 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.

Table 5 shows the results of our estimates using data from 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 regardless of the type of vehicle, results show that the proportion of drunk drivers decreased by 25 percent during 'party time', and by 11 percent in the 'after work hours' interval, while there was no reduction during the 'work hours' interval. Again, this reflects that alcohol and leisure hours are strong complements for Spaniards (West and Parry, 2009). 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 θ after the PPS.

We now simulate 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, we 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 $(N^{post-PPS}/N^{pre-PPS})$. We 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.

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, we 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', we conclude that the PPS helped reduce the ratio $\frac{N^{post-PPS}}{N^{pre-PPS}}$ for 65 and 80 percent of cases, respectively. Viewed in another way, during the nighttime hours, 'party time' and 'after work hours' intervals, the ratio was at least 50 percent smaller after the PPS in 10 and 31 percent of simulated cases, respectively. The remaining benchmark values show a reduction in the relative number of drunk drivers after the PPS.

[**Tables 4, 5, 6 and Figure 1 about here**]

[3] The penal code introduced by Law 10/1995, enforced in May 1996, punished drunk driving with a prison sentence of between 8 and 12 weeks *and* a fine, together with the deprivation of the driving license for a period of 1 to 4 years. Several reforms are worth noting. Firstly, there was a change in the possible jail time or fine by Law 15/2003, enforced in October 2004, which raised the prison sentence from 3 to 6 months, increased the fine, and forced offenders to provide community service for between 31 and 90 days.

5. Heterogeneous effects of drunk driving across hourly intervals

Results in Section 4 indicate a heterogeneous pattern 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 we now make use of a regression analysis. More concretely, we study the influence of drunk driving on the probability of fatal accidents. We use logistic regression to gauge how the probability of a fatal accident is affected by drunk drivers. In a second regression, we use negative-binomial regressions to explore how the number of fatal victims per accident changes with drunk driving. We limit our estimation to crashes occurring on urban roads because the effects of drunk driving are more easily isolated from other infringements, such as speeding. 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 non-urban road accidents occur, speeding cases tend to occur coincidently. This pattern is common across hourly intervals. Therefore, the effects of drunk driving on the likelihood of fatal victims can be more easily identified on urban roads.

In both regressions, the covariates encompassed 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 and dummy variables which indicates changes in laws related to road infractions, especially drunk driving, such as the reform of the penal code, or reforms to the Traffic Laws. Of course, a dummy variable for drunk driving is also incorporated.

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 ratios range between 1.70 and 1.98, which means that the probability of observing a fatal crash is 70 to 98% higher when the driver is drunk. These results are consistent, albeit lower, with those found in the related literature for other countries.[4] 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 found for θ and λ in Table 2. 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 p.p. to 0.13, 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 fatal crashes between 0.53 and 0.68 p.p.

Table 9 displays the results for the negative binomial regressions, where the dependent variable is the number of fatal victims. Similarly in Table 8, in view of the marginal effects, we 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 helps reduce fatalities by 0.5 to 0.7 p.p. in crashes where at least one of the drivers is observed to be drunk.

[**Tables 7, 8 and 9 here**]

[4] For instance, Awadzi *et al*. (2008) found odd ratios near to 2.3 in fatal crashes in the U.S.A. in 2003, and Penmentsa and Pulugurtha (2017) found an odd ratio of 4.6 in crashes involving severe injuries in the State of North Carolina in the period 2010-2013.

6. Assessing the external costs of drunk driving

In this Section, we estimate the external cost imposed by drunk drivers in terms of victims (fatal and non-fatal), and propose a monetary evaluation of it. This 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 our 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, we are not accounting for them here.

The assessment proceeds as follows. Firstly, we use a wide definition of four-wheel vehicles: passenger cars and light trucks, and take the relative risk, θ and λ, estimated in Tables 2, 3 and 5. Secondly, in two-car crashes with one drunk driver and one sober driver, drunk drivers can be made responsible for a fraction of (θ-1)/(θ+1) of crashes. For instance, if we take 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, we assign the blame for half of all victims to drunk driving assuming that only one of the drivers caused the crash, regardless of the hourly interval. Analogously, for one-vehicle crashes, we consider a fraction (λ-1)/λ of victims that can be considered as external. Finally, we borrow the cost of injuries estimated 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 summarizes these results from 2004 to 2015 (mild victims and severe victims are not reported for simplicity). We find that the number of fatal victims due to drunk driving has declined over this period, especially in the ‘party time’: the number of fatalities due to drunk driving in 2015 were 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, for an average of 14 thousand kilometers driven per vehicle and year, and for the percentage of drunk drivers - calculated by N/(1+N) from Table 2 - drunk drivers should pay 2 Euro-cents per kilometer driven.[5]

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 our evaluation, the external cost of drunk driving was about 840 million Euros over this period. This implies that drunk drivers should be fined by 1250 Euros, on average, to internalize the external costs. Table 4 indicates that the fine on drunk drives has ranged between 300 and 600€ with few changes. This is considerably lower than the estimated fine.[6] However, since the PPS, drunk driving has been sanctioned with a loss of points, from

[5] For this assessment, we consider the stock of vehicles in Spain (DGT) and the kilometers driven (Spanish National Institute of Statistics, 2008, *Encuesta de Hogares y Medio Ambiente*). Kilometers driven decays with the age of the car: brand new cars are used more intensively than old cars.

[6] After April 8th 2014, the fine for drunk driving was risen to 1000 € if a driver’s BAC was twice above the upper limit, or if the driver had been already sanctioned for drunk driving in the last year.

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 Dollars per arrested driver and 16 cents per mile driven by each drunk driver. Regardless of the exchange rate Dollar/Euro considered, this widely surpasses our estimates for Spain. In this case, differences can be due to the period they use, or the monetary value of statistical life (3 million dollars per fatal US victim).

As an extension, we finally study whether the observed reduction in fatal crashes and fatal victims after the PPS can be predicted given the elasticities in Tables 8 and 9, and 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 we use a wide definition of vehicles, including light trucks and mopeds). From Tables 8 and 9, the elasticities of fatal crashes and fatalities are 0.53 and 0.49, respectively, which would have produced 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), we conclude that our estimates provide an accurate prediction for this hourly interval (note that observed changes are contained within the 90% confidence band). For the two other hourly intervals, predicted changes are calculated analogously. Unsurprisingly, for the 'work hours' interval, our estimate does fail to predict changes in road fatalities: during these hours, habits of alcohol consumption are for different reasons than that of complementing leisure time. For the two nightly intervals, however, we predicted the changes accurately.

[**Tables 10 and 11 here**]

7. Conclusions and policy implications

This paper has presented an assessment of the external costs of drunk driving in Spain over the period 2004-2015. We have also 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.

We reached the following conclusions. Firstly, we estimated a relative risk of drunk drivers that 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 drunk drivers tended to increase during nighttime hours. Unsurprisingly, the relative number was also higher on weekends, regardless of the hourly interval. These results reveal a 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 (West and Parry, 2009). When comparing our results with those of Levitt and Porter (2001) for US roads, we produced 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.

Secondly, we 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. We 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.

Thirdly, our 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 less infringements and safer vehicles, although this last reason is beyond the scope intended for the current paper. Having this external cost, we 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 introduced additional punitions (deprivation of credit points), whose cumulative effect now approaches the equivalent of our proposed fine.

Finally, using logistic and negative-binomial regressions, we also found differences in the hourly marginal effects of drunk driving, which were higher in the 'party time'. These differences are also found in the elasticities of fatal victims with respect to drunk driving, which were estimated and ranged between 0.5 and 0.7. Taking these values, our 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 drunk driving is less likely to happen. This provides robustness to our count model regressions and the estimated reduction of drunk drivers after the PPS.

We contributed to the existing research by highlighting differences in the risk of causing a crash between hourly intervals, revealing alcohol consumption patterns that correspond to leisure time. As a second contribution, we presented an assessment of the external costs of drunk driving in Spain. Overall, our results pointed to a decline in drunk driving offences alongside an increase in the punition of these infringements since 2006. As we show, 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 motivating improvements in the safety devices of vehicles. Whether the adoption of these measures is behind the downturn of drunk driving in Spain requires a causal analysis, which lies beyond the scope of this paper, but is an ongoing piece of work currently in progress.

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Appendix: Figures and Tables

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.

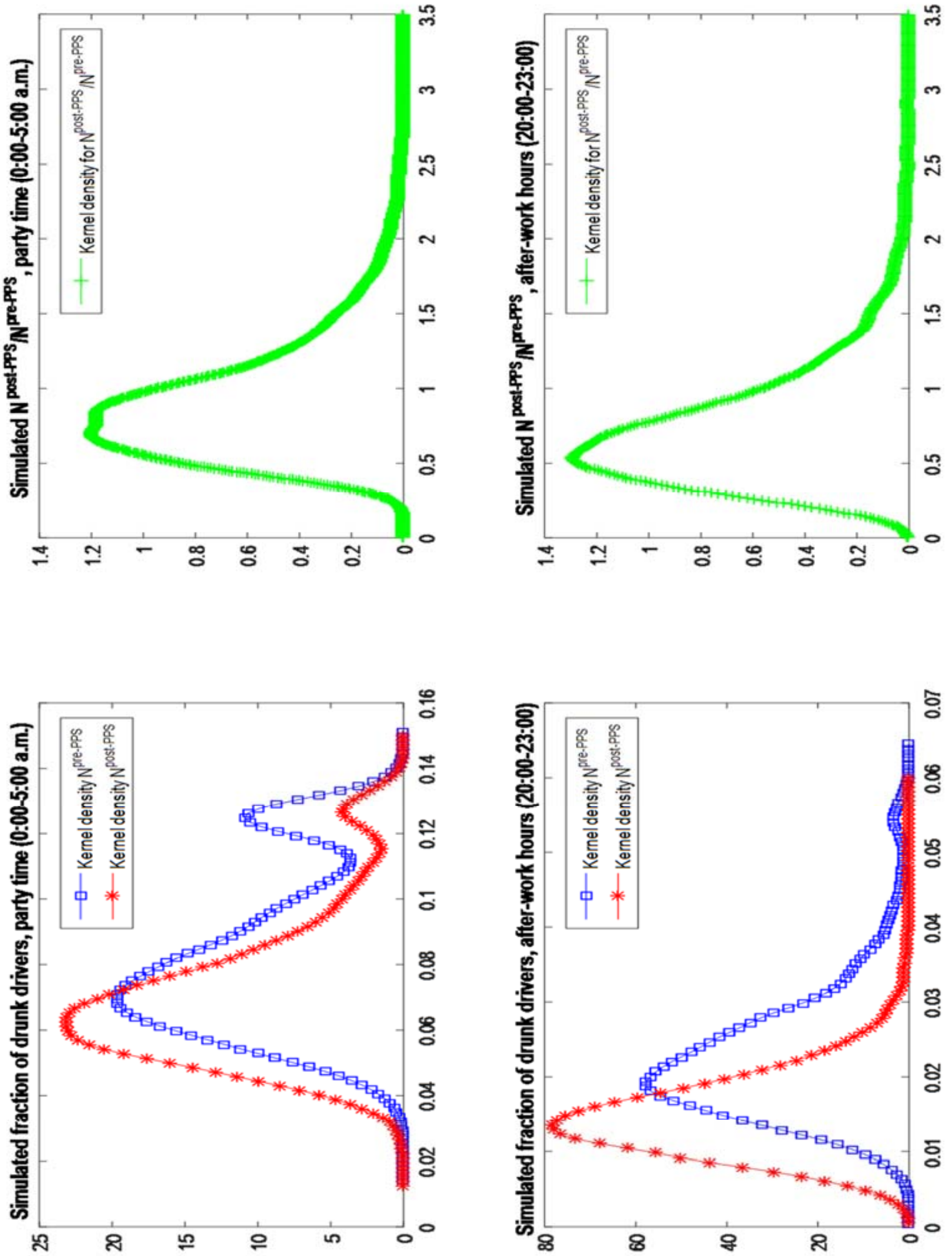

Table 1: Summary statistics for drivers profile by hourly intervals (Spain, 2004–2015)

Variable	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.	
	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-car crashes with:								
Two sober drivers	95.9	93.6	92.5	96.9	98.5	99.0	97.0	98.0
One sober and one drunk driver	4.0	6.2	3.7	1.7	0.7	0.6	1.5	0.7
Two drunk drivers	0.1	0.2	3.8	1.5	0.8	0.5	1.5	1.3

Table 2: Drunk vs. sober drivers, Spain 2004-2015

Variable	Vehicle	Hourly interval: 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 θ, N 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: Relative risk for drunk drivers of cars, Spain 2004-2015

Week day	Party time: 0:00 a.m. - 5:00 a.m. N	θ	λ	Work hours: 6:00 a.m. - 19:00 p.m. N	θ	λ	After work hours: 20:00 p.m. - 23:00 p.m. 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 θ, N and λ for crashes with only cars 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: Infringements, penalty points and fines

Infringements	Penalty points [a]	Fines[b]	Fines[c]	Fines[d]
Driving under the effects of alcohol:				
More than 0,50 mg per litter 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 litter 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 ag	6	[301€,600€]	500 €	1,000 €
Speeding [d]	6	[301€,600€]	[100€,600€]	[100€,600€]
Reckless driving, wrong way, illegal races, and other similar behaviors	6	[301€,600€]	500 €	500 €
Driving without seat belt, kid seats, helmet, and other compulsory safety devices	3	[91€,300€]	200 €	200 €
Driving while using cell phones, programing the GPS, using earphones, or using any other device that may reduce driver's 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. The amounts of these fines are specified in Pesetas in art. 67, Law 339/1990 (*R.D. Legislativo 339/1990*). We converted to Euros using 1€ = 166,386 Ptas. 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. The amount of these fines are given in art. 67, Law 18/2009, enfoced in May 24th 2010.

d. After Law 6/2014, enforced in 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 5: PPS effects over relative risk drunk vs. sober drivers

	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.	0.079	0.089	0.095	2.26	1.85	1.00	2.23	1.97	1.74
6:00 a.m. - 19:00 p.m.	0.024	0.023	0.015	1.00	1.00	1.00	1.81	1.81	2.42
20:00 p.m. - 23:00 p.m.	0.022	0.028	0.034	4.14	3.13	1.00	2.90	2.33	1.75
July 2006 to December 2008	$N_{post\text{-}PPS} = N_D/N_S$			$\theta_{post\text{-}PPS} = \theta_D/\theta_S$			$\lambda_{post\text{-}PPS} = \lambda_D / \lambda_S$		
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.	0.057	0.046	0.068	2.40	3.37	1.25	3.80	4.85	3.03
6:00 a.m. - 19:00 p.m.	0.024	0.023	0.015	1.00	1.00	1.00	2.44	2.46	3.14
20:00 p.m. - 23:00 p.m.	0.020	0.017	0.030	3.68	4.46	1.00	4.34	5.06	2.54
	$N_{post\text{-}PPS}/N_{pre\text{-}PPS}$			$\theta_{post\text{-}PPS}/\theta_{pre\text{-}PPS}$			$\lambda_{pre\text{-}PPS}/\lambda_{post\text{-}PPS}$		
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 displays estimates for parameters θ, N and λ for crashes with only cars involved 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 6: Percentage reduction of drunk driving after PPS

Bound	Party time: 0:00 a.m. - 5:00 a.m.	After work hours: 20:00 p.m. - 23:00
1.00	65%	80%
0.90	55%	73%
0.75	38%	60%
0.60	20%	44%
0.50	10%	31%
0.40	3%	18%
0.25	0%	5%
0.10	0%	0%

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

Table 7: Differences in drunk driving between urban roads and non-urban roads

	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.

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:	0.531**	0.00471**	0.526**	-741.4	15670
0:00 a.m. - 5:00 a.m.	(0.237)	(0.00213)	(0.235)		
Work hours:	0.681***	0.00290***	0.678***	-5481	214390
6:00 a.m. - 19:00 p.m.	(0.168)	(0.000721)	(0.167)		
After work hours:	0.649***	0.00314***	0.646***	-1520	54740
20:00 p.m. - 23:00 p.m.	(0.244)	(0.00120)	(0.243)		

Notes: This table reports logit estimates. The unit of observation is each accident. 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, vehicle and regulation changes. *** p<0.01, ** p<0.05, * p<0.1. Figures in parentheses denote standard errors.

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:	0.490*	0.00466*	0.490*	-797.8	17213
0:00 a.m. - 5:00 a.m.	(0.250)	(0.00245)	(0.250)		
Work hours:	0.636***	0.00292***	0.636***	-5710	214942
6:00 a.m. - 19:00 p.m.	(0.179)	(0.000830)	(0.179)		
After work hours:	0.699***	0.00373***	0.699***	-1602	56236
20:00 p.m. - 23:00 p.m.	(0.259)	(0.00142)	(0.259)		

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

Table 10: External costs of drunk driving in Spain

Year	No. of fatalities due to drunk driving 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.	Cost of victims of all severity wrt GDP
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%
2012	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 11: Observed and estimated change in fatal crashes and victims, January 2004 to June 2006 versus July 2006 - December 2008.

Hourly Interval		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	-16 (-12.5%)	-28 (-18.9%)
	Related to drunk driving	-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	-31 (-19.1%)	-44 (-21.9%)
	Related to drunk driving	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	-4 (-5.6%)	-6 (-7.3%)
	Related to drunk driving	-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 relative number *N* reported in Table 5.