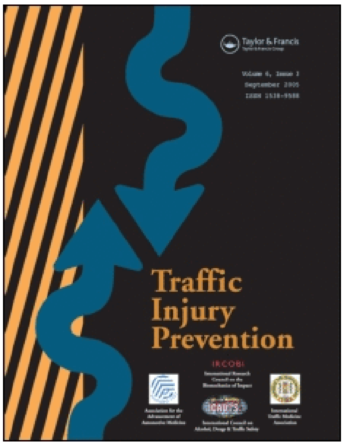

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Motorcycle Injury Severity in Barcelona: The Role of Vehicle Type and Congestion

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Objectives: *To determine factors affecting the severity of moped and motorcycle injuries in Barcelona—the city with the highest number of motorcycles per inhabitants in Europe—paying especial attention to differences across vehicle type and to the role of congestion in a city that has promoted powered two-wheelers (PTWs) to alleviate traffic density.*

Method: *Drawing on Barcelona's local police census database on casualties (2002–2008), we use a parametric estimation based on an ordered multinomial logistic regression in order to identify factors affecting injury severity. We control for demographic characteristics, environment and traffic conditions, primary causes of accidents, and regulatory measures. Regressions distinguish PTW casualties from the rest of vehicles and present results for motorcycles and mopeds separately.*

Results: *We confirm the higher vulnerability of PTW casualties—especially motorcycle casualties (OR 2.30)—and show that factors such as gender, excess speed, road width, and alcohol consumption do affect casualty severity. Regarding traffic conditions, we find that congestion diminishes the probability of suffering severe injuries, although its statistical significance only appears for motorcycle casualties (odds ratio [OR] 0.80), which are also more severe due to speed violations (OR 6.29).*

Conclusions: *We confirm the negative relationship between traffic flow (congestion) and injury severity of PTWs casualties. This is clearly identified, at least for motorcycle casualties, although moped casualties present similar impacts as well. As a result, alleviating congestion through PTWs promotion turns out to be a trade-off between congestion and safety that public officers must consider. The article also highlights the need of awareness campaigns and safety policies focused on specific groups of drivers. Attention should also be given to the enforcement of speed limits and alcohol restrictions in Barcelona.*

Keywords Injury severity; Motorcycles; Mopeds; Risk factors; Congestion

INTRODUCTION

Recent road safety trends in developed countries highlight the success of safety measures being taken by public authorities or as a result of public concern. The European Union (EU) countries, for example, have achieved significant reductions in road safety outcomes, presenting a decreasing trend in the annual number of fatalities, although the reduction in the number of injuries is not so clear (Table I). All in all, these states have recorded a significant effectiveness in combating road injury severity, which has had a direct effect on health impacts and associated socioeconomic costs (Hotz et al. 2004; Mayou and Bryant 2003; Wells et al. 2004).

Yet, this success must be treated with caution: first, because of the high number of deaths that continue to be caused by road crashes and, second, because if we disaggregate the number of road traffic deaths by vehicle type it becomes apparent that this promising outcome is not consistently supported for all vehicle types (Table I). In fact, in the United States annual motorcyclist fatalities more than doubled between 1997 and 2005 (Dee 2008); likewise, although a less substantial increase, motorcyclist fatalities increased by 22 percent between 1996 and 2005 in the EU. Moreover, this is the sole means of transport to record a rise in the annual number of fatalities and to show an increasing trend over the last decade in the EU (Table I). Powered two-wheeler (PTW) fatalities as a share of total annual fatalities have increased recently. But because moped-related fatalities have fallen by more than 40 percent for the same period, it is clear that this result is primarily attributable to motorcycle-related deaths.

At this point it is worth clarifying what we will understand by a PTW throughout. This study considers a PTW as a single-track, two-wheeled motor vehicle. Under this category we include both motorcycles and mopeds, with motorcycles those vehicles with a power over 50 cubic centimeters and mopeds those vehicles with a power of 50 cubic centimeters.

The analysis of PTW safety outcomes and their determinants is of importance in urban areas, because almost half of such fatalities occur in built-up areas (European Road Safety

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Table I Road safety trends by type of vehicle in the EU14, 1996–2005

	% Change 1996–2005
Total injury accidents	−1
Total fatalities	−25
Pedalcycle	−31
Cars and taxis[a]	−27
Lorries and heavy goods > 3.5 t[a]	−27
Lorries and heavy goods < 3.5 t[a]	−28
Bus and coaches	−28
PTW	−5
Moped	−41
Motorcycle	22
% PTW fatalities[b]	28
Motorcycle	63
Moped	−20

[a]The European Road Safety Observatory (2008) provided numbers of fatalities in cars and taxis plus all other vehicle fatalities. This means that car-related and lorry-related fatalities are overestimated.
[b]Motorcycle fatalities represented 9.5 percent of total fatalities in 1996 and 15.5 percent in 2005. Moped fatalities represented 7 percent of total fatalities in 1996 and 5.6 percent in 2005.
Source: Self-construction given data offered by the European Road Safety Observatory (2008), Community Road Accident Database (CARE).

Observatory 2008). Similarly, motorcyclist fatalities represented 68 percent of urban PTW deaths (Table I).

PTWs are usually seen by the public and local authorities alike in Spain as a type of vehicle that can alleviate congestion and facilitate both mobility and parking in busy city centers. In fact, the Spanish government enacted a regulatory measure in 2004 to promote PTW use in order to fight congestion costs. The new regulation on licenses permitted car license holders with more than 3 years' driving experience to ride PTWs up to 125 cc. This measure was introduced in an attempt at improving traffic flow and at reducing the number of automobiles with just one occupant. The result of this measure in Barcelona has been an increase in the ownership of motorcycles and in the absolute number of motorcycle-related victims (Table II), giving rise to the growing concern of public authorities and road users for PTW road safety. On the other hand, our dataset shows that the number of PTW injuries maintained a steady trend at over 8500 victims between 2002 and 2004. However, an increase was recorded since 2005, which continued until 2007.

Indeed, PTWs are the most vulnerable of powered transport modes because of their lack of safety devices and the absence of a protecting chassis for drivers and passengers, which means that PTW riders are more likely to suffer fatalities than car occupants when involved in similar accidents (Aare and Van Holst 2003; Lin and Kraus 2008; Wells et al. 2004).

However, recent literature (Aarts and Van Shagen 2006; Broughton et al. 2009; Fuller et al. 2008) has shown how reducing speed could reduce injury severity. Therefore, it is easy to support that congestion, despite being a negative externality that increases travel time and reduces accessibility, could also act as a safety factor in road accidents because it reduces injury severity by limiting speed.

For all these reasons the first objective of this study is to examine the main causes of the different degrees of PTW injury severity suffered, distinguishing PTWs between motorcycles and mopeds to identify significant differences that can help in understanding the problems related to motorcycle safety. The second objective is in line with the fact that when policy makers are concerned with developing strategies to alleviate congestion, it is relevant to examine whether these policies could be associated to higher casualty severity as an unexpected result. If these policies imply the promotion of PTWs, it is also necessary to check how congestion affects injury severity of PTW casualties. In this study we are going to pay special attention to the role played by congestion on injury severity determination.

METHODS

Data

This study draws on the database created by the local police of Barcelona, the second largest city in Spain. Barcelona represents a relevant case for study because it is one of the cities with the highest absolute number of registered PTWs in Europe—second only to Rome (Italy)—and the city with the most PTW vehicles per inhabitant.

The local police census is a rich source of data on road injuries that occurred between 2002 and 2008, providing information about casualties, main cause of collision, crash location, injury severity, and traffic characteristics at the time of the crash. The dataset also provides certain details regarding alcohol tests administered and infrastructure quality.

The dataset stores 175,037 observations about road casualties, of which 57,488 were PTW casualties. However, it should be mentioned that the number of observations finally used in each estimation presented in this article differs from these figures somewhat. The first reason is that observations are missing regarding some of the relevant variables in each model used in the analysis. Second, depending on the vehicle involved in the

Table II Registered vehicles in the city of Barcelona 2003–2007

Registered vehicles in Barcelona	2003	2004	2005	2006	2007	% Change 2003–2007
Total	931,258	942,232	965,172	978,448	991,151	6
Passenger cars	603,343	607,791	617,291	616,814	617,022	2
Motorcycles	144,584	149,363	160,392	173,190	184,888	28
Mopeds	89,579	90,730	91,650	93,067	93,783	5
Others	93,752	94,348	95,839	95,377	95,458	2
Bicycling (bike renting)	—	4216	4552	7696	14,696	249

Source: Department of Statistics, City Council of Barcelona.

Table III Number of total victims and fatalities in Barcelona by mode 2002–2007

	2002	2003	2004	2005	2006	2007	% Change 2003–2007
Number of victims							
PTW	8850	8681	8532	9230	9500	9652	9
Rest of vehicles	24,184	25,363	24,505	25,932	24,986	25,234	4
Number of fatalities							
PTW	22	27	28	28	39	33	50
Rest of vehicles	44	48	44	48	55	46	4

Source: Self-construction given data from the Barcelona local police database (City of Barcelona 2008).

accident, a different number of observations as well as a different number of missing observations was found. Table III shows the growth of road safety victims by vehicle type in Barcelona (2002–2007).

Empirical Strategy

We use an ordered multinomial logistic model to estimate the associated severity of PTW injuries, given a group of casualty and environment-related characteristics, by using the local police road injuries census during the period 2002–2008. The ordered logit model is based on a continuous latent variable specified as a linear equation:

$$y_i^* = \beta' x_i + \varepsilon_i, \ -\infty < y_i^* < \infty. \tag{1}$$

where y_i^* (unobserved) measures the injury severity of the casualty; x_i is the set of factors explaining y_i^*, with associated parameters β; and the error term ε indicates the effect of all unobserved factors on y_i^*. Assuming that y_i is the observed discrete variable that reflects the different severity levels for individual i, the relationship between the latent variable and the observed variable is obtained according to the next model:

$$y_i^* = 1 \text{ if } -\infty \le y_{\text{i}}^* < \mu_1 \quad i = 1, \ldots, n.$$

$$y_i^* = 2 \text{ if } -\infty \le y_{\text{i}}^* < \mu_2 \quad i = 1, \ldots, n.$$

$$y_i^* = 3 \text{ if } -\infty \le y_{\text{i}}^* < \mu_3 \quad i = 1, \ldots, n.$$

$$\ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots$$

$$y_i^* = J \text{ if } \mu_{\text{J}-1} \le y_{\text{i}}^* < \infty \quad i = 1, \ldots, n. \tag{2}$$

The μs are the estimated thresholds where the discrete observed responses are defined. This model estimates the probability that an individual $\underline{i}$ sustains an injury of severity j or lower (j-1, ..., 1). Therefore, the model specification is as follows:

$$\log\left[\frac{\gamma_j(x_i)}{1-\gamma_j(x_i)}\right] = \mu_j - [\beta_1 x_{1i} + \beta_2 x_{2i} + \ldots + \beta_K x_{Ki}],$$

$$j = 1, \ldots, n \tag{3}$$

where γ_j is the cumulative probability, $\underline{\beta}$ is the vector of parameters ($\beta_1, \beta_2, \ldots, \beta_K$), and x_i is the vector of regressors. Parameter estimates are obtained by maximum likelihood.

Variables

Degrees of injury severity resulting from a crash are included in the local police database for Barcelona, thereby enabling us to construct a categorical variable that captures different ranks of severity. Once an ordered dependent variable has been obtained, we can then use it to estimate the determinants of differences in the degree of accident severity. Thus, the dependent variable *severity* contains 3 increasing degrees of severity according to police reports following the crash: nonsevere, severe, and fatal. We can then apply the ordered multinomial logistic regression using a number of potential determinants as explanatory variables of injury severity. Table II offers descriptive statistics of these independent variables as well as variable definitions.

Next we present and briefly motivate the use of these potential determinants in our estimations below:

Vehicle type: motorcycles vs. mopeds. One of the assumptions underlying this study is that PTW casualties are more vulnerable in a crash than other vehicle casualties. To compare their relative vulnerability we include 2 variables identifying casualties as having been involved in either motorcycle or moped crashes to test this assumed vulnerability in the case of Barcelona..

Traffic characteristics: congestion and number of vehicles involved. We are interested in paying special attention to the role played by congestion as a safety factor in urban transportation. For this reason, we control by traffic density. The congestion variable is recorded by the officer for the accident, who states whether the accident occurred in a congested traffic flow. We include congestion to test the hypothesis that it reduces severity due to lower vehicle speeds and less space in a large city like Barcelona. This variable is of special interest in the case of Barcelona because PTW promotion is based on the objective of alleviating congestion by favoring a modal change with more PTWs and less congestion.

A similar factor we consider is the number of vehicles involved in the collision. We expect to find different severity patterns resulting from crashes involving one vehicle and those involving 2 or more.

Demographic casualty profiles. The database includes data on the age and gender of each casualty. We have a categorized *age* variable—by age intervals—that serves to identify heterogeneous severity patterns. In the analysis, the base category is the group of youngest victims; that is, those under the age of 20. Therefore, the odds ratios (ORs) associated with all the other age groups are compared with this youngest group.

Table IV Descriptive statistics of independent variables

Variable	Description	Mean	Std. Deviation
Age			
20–30	If casualty is between 20 and 30 years old = 1; 0 otherwise	0.28	0.45
30–40	If casualty is between 30 and 40 years old = 1; 0 otherwise	0.39	0.48
40–50	If casualty is between 40 and 50 years old = 1; 0 otherwise	0.14	0.34
50–60	If casualty is between 50 and 60 years old = 1; 0 otherwise	0.09	0.29
>60	If casualty is older than 60 years old = 1; 0 otherwise	0.17	0.01
Males	If casualty is male = 1; 0 otherwise	0.73	0.44
Congestion	If traffic was congested at the moment of crash = 1; 0 otherwise.	0.15	0.36
No. of vehicles (>1)	If there are more than one vehicle involved in a crash = 1; 0 otherwise	0.44	0.49
No. of lanes (>2)	If there is more than 2 lanes in the street where crash happened = 1; 0 otherwise	0.80	0.39
Primary causes			
Alcohol	If primary cause of crash was alcohol consumption = 1; 0 otherwise	0.06	0.23
Speed	If primary cause of crash was excess speed = 1; 0 otherwise	0.03	0.18
Road surface	If primary cause of crash was road surface condition = 1; 0 otherwise	0.01	0.08
Rainy weather	If it was raining at the moment of crash = 1; otherwise	0.07	0.26
Ring roads	If the crash occurred in the city ring roads (interurban roads) = 1; 0 otherwise	0.07	0.25
Vehicles			
Motorcycle	If motorcycle casualties = 1; 0 otherwise	0.17	0.37
Moped	If moped casualties = 1; 0 otherwise	0.15	0.36
Helmet/seat belt	If casualty was wearing a helmet/seat belt = 1; otherwise	0.03	0.16
Regulation 2004	If crash happened after the enactment of regulation promoting PTWs = 1; 0 otherwise	0.67	0.46

In addition, we identified the gender of the victims using the variable *male*.

Infrastructure features and environtment-related determinants. We also take into consideration the number of traffic lanes at the site of the crash, because we expect road width and lane choice to be significant factors of safety outcomes. Another related factor that we include here are the city's ring roads, which serve as interurban or access roads. We expect urban and interurban mobility to differ and, for this reason, we also expect road accident severity to be different. Finally, we include a weather-related variable to capture the effect of rain on injury severity.

Primary causes of accidents. Following a traffic crash, the local police unit reports its main cause. The most common causes included in the database are those related to alcohol consumption, speed violations, and poor road surface. The first two have been well defined and are widely discussed in the literature (see Albalate 2008; Dee and Sela 2003; Kasantikul et al. 2005). Therefore, we included these 3 categories and then compared them with other potential causes.

Safety devices and regulatory measures. Most drivers can rely on various safety devices to reduce the effects of an accident—helmets in the case of motorcycle and moped riders and seat belts for the users of non-PTW vehicles. Because we would expect to find lower degrees of injury severity in casualties using these devices (Cohen and Einav 2003; Dee 2008; Houston and Richardson 2008; Loeb 2001), we introduce a binary variable identifying the use of such a device by the victim.

Finally, to reflect the change in the regulation allowing car drivers with more than 3 years of experience to use a certain class of motorcycle up to 125 cc, we introduced a dummy variable with a value of 1 to indicate the years following this change and 0 for the years preceding it. This variable was labeled *Regulation_2004* and aimed to capture the effect of the increase in the number of motorcycles in the city of Barcelona. The description and statistics of variables employed is displayed in Table IV.

RESULTS

First of all, we present an aggregated model (specification 1) with all casualties in the database to check the vulnerability of PTW. An inspection of Table V shows that for all victims involved in motorcycle or moped accidents the risk of suffering an injury with a high degree of severity is statistically significant and greater than that of casualties involved in other types of accident (Table V, specification 1). Thus, the risk of a motorcycle crash casualty suffering a severe injury is 2.3 times greater than the risk associated with other vehicle types, and the risk for a moped injury is 1.83 times higher, according to the respective odds ratio and the 95 percent confidence intervals.

Moreover, this research deals with measuring the effect of congestion and vehicle type on casualty severity. Specification 1 includes a binary variable accounting for congestion and its odds ratio appears to be 0.79—then reducing probabilities of severe injuries—and statistically significant at 95 percent, which confirms the trade-off between congestion and lack of road safety when no distinction is made for vehicle type.

In this regard, it is worth considering alternative modeling to allow for heterogeneity in the parameter associated with congestion across vehicle type to capture heterogeneous impacts. In fact, we allow the possibility that the influence of congestion on severity may vary across vehicle type due to unobservable factors such as differences in driving behavior. Specification 2 uses a different specification in which we include 3 interacted variables for each vehicle type that denote congestion and belonging

Table V Aggregate estimates on the determinants of road accident severity in Barcelona 2002–2008

Explanatory variables	Aggregated OR (95% CI) (1)	P > |z|	Aggregated OR (95% CI) (2)	P > |z|
Age				
20–30	0.89 (0.81–0.98)	0.025	0.89 (0.81–0.98)	0.025
30–40	1.08 (0.78–1.48)	0.628	1.08 (0.78–1.48)	0.628
40–50	1.05 (0.77–1.41)	0.760	1.05 (0.77–1.41)	0.760
50–60	1.30 (0.92–1.85)	0.139	1.30 (0.92–1.85)	0.139
>60	2.58 (1.83–3.63)	0.000	2.58 (1.83–3.63)	0.000
Males	1.39 (1.27–1.52)	0.000	1.39 (1.27–1.52)	0.000
Congestion	0.79 (0.70–0.89)	0.000	–	—
Congestion * Motorcycles	—	—	0.81 (0.68–0.98)	0.026
Congestion * Mopeds	—	—	0.90 (0.72–1.14)	0.402
Congestion * Other	—	—	0.65 (0.52–0.83)	0.000
No. of vehicles (>1)	0.58 (0.52–0.63)	0.000	0.58 (0.52–0.63)	0.000
No. of lanes (>2)	0.76 (0.68–0.85)	0.000	0.76 (0.68–0.85)	0.000
Primary causes				
Alcohol	1.47 (1.21–1.80)	0.000	1.47 (1.21–1.80)	0.000
Speed	4.95 (4.28–5.73)	0.000	4.95 (4.28–5.73)	0.000
Road surface	0.42 (0.26–0.68)	0.000	0.42 (0.26–0.68)	0.000
Rainy weather	0.96 (0.82–1.13)	0.661	0.96 (0.82–1.13)	0.661
Ring roads	1.09 (0.92–1.28)	0.291	1.09 (0.92–1.28)	0.291
Vehicles				
Motorcycle	2.30 (2.08–2.54)	0.000	2.30 (2.08–2.54)	0.000
Moped	1.83 (1.64–2.05)	0.000	1.83 (1.64–2.05)	0.000
Helmet/seat belt	0.63 (0.55–0.72)	0.000	0.63 (0.55–0.72)	0.000
Regulation 2004	0.50 (0.45–0.55)	0.000	0.50 (0.45–0.55)	0.000
N	64,486		64,486	
LR χ^2	696.81	0.000	701.56	0.000
Log-likelihood at convergence	−11,765		−11,765	
/cut1	3.09 (2.95–3.24)	0.000	3.09 (2.95–3.24)	
/cut2	5.43 (5.25–5.62)	0.000	5.43 (5.25–5.62)	

to one of these 3 groups of casualties. There is indeed a heterogeneous impact, because contrarily to motorcycles and other vehicles we realize that congestion is not statistically significant for moped casualties, although the odds ratio is certaintly in line with that of motorcycles.

Given our interest in overcoming the aggregate model it is common to evaluate the statistical significance of separating the sample by casualty characteristics (see Haque et al. 2009). Because we are interested in differences across vehicle type, we evaluate the statistical significance of separating crashes by motorcycle, moped, and other vehicle casualties. This is evaluated by using the likelihood ratio test, which is formally presented in Eq. (4):

$$\chi^2 = -2[\mathrm{LL}(\beta_{\mathrm{A}}) - \mathrm{LL}(\beta_{\mathrm{MT}}) - \mathrm{LL}(\beta_{\mathrm{MP}}) - \mathrm{LL}(\beta_{\mathrm{OT}})] \quad (4)$$

where $\mathrm{LL}(\beta_{\mathrm{A}})$ denotes the log-likelihood at convergence of the aggregate model, and $\mathrm{LL}(\beta_{\mathrm{MT}})$, $\mathrm{LL}(\beta_{\mathrm{MP}})$, and $\mathrm{LL}(\beta_{\mathrm{OT}})$ are the log-likelihood at convergence using only motorcycle, moped, and other vehicle casualties data, respectively. Once the likelihood ratio test is conducted, we can check whether separating the sample by vehicle type is better than a model with the whole sample. On the one hand, the log-likelihood values at convergence for the vehicle-specific models are found to be −3236 (df 18) for motorcycles, −4577 (df 18) for mopeds, and −3866 (df 18) for the rest of vehicles. On the other hand, the corresponding value for the aggregate model is −11,765 (df 20). The resulting χ^2 statistic of 170.74 (P-value < 0.001)supports our strategy of separating the sample by vehicle type because the vehicle specific models are statistically better.

Once this separation is confirmed, we proceed to test our different groups of determinants for each vehicle type and their impact on injury severity. Table VI displays our results. Specification 3 replicates the estimation for motorcycle casualties only and specification 4 does the same for moped casualties.

One of the main determinants of severe injuries is speed violations. This result is confirmed by both aggregate and restricted estimations based on different subsets of vehicle-type casualties. Thus, victims of crashes attributable to speed violations seem more likely to suffer a severe outcome. In the case of motorcycle-related injuries (specification 3), this odds ratio is even greater (6.29 OR). Alcohol consumption was also found to be statistically significant at the 95 percent confidence interval, increasing the severity of PTW injuries (specifications 3 and 4), with OR between 1.62 and 1.66, whereas poor road surfaces had the opposite effect (OR 0.29 and 0.60), suggesting that these crashes are not as dangerous as those attributable to excess speed or alcohol. The rationale behind this last result could emerge from the fact that speed tends to decrease when driving on a poor quality surface.

The demographic variables also confirm what is commonly assumed and regularly found: there is evidence that the age and gender profile plays an important role in PTW injuries. On the one hand, the coefficient associated with the oldest age group was statistically significant, indicating that this group

Table VI Estimates on the determinants of road accident severity in Barcelona by vehicle type (PTWs) 2002–2008

Explanatory variables	Motorbikes OR (95% CI) (3)	P > |z|	Mopeds OR (95% CI) (4)	P > |z|
Age				
20–30	0.94 (0.81–1.10)	0.462	0.92 (0.78–1.09)	0.343
30–40	1.21 (0.80–1.85)	0.358	1.43 (0.60–3.43)	0.420
40–50	1.01 (0.68–1.52)	0.939	0.85 (0.37–1.95)	0.706
50–60	1.26 (0.79–2.03)	0.331	1.14 (0.43–2.99)	0.780
>60	1.88 (1.16–3.06)	0.011	2.49 (0.99–6.28)	0.053
Males	1.47 (1.25–1.71)	0.000	1.37 (1.17–1.62)	0.000
Congestion	0.80 (0.67–0.95)	0.000	0.88 (0.70–1.11)	0.284
No. of vehicles (>1)	0.65 (0.57–0.76)	0.000	1.01 (0.85–1.19)	0.897
No. of lanes (>2)	0.72 (0.60–0.88)	0.000	0.75 (0.61–0.92)	0.005
Primary causes				
Alcohol	1.66 (1.17–2.35)	0.000	1.62 (1.10–2.40)	0.114
Speed	6.29 (4.87–8.13)	0.000	4.73 (3.26–6.86)	0.000
Road surface	0.29 (0.14–0.62)	0.001	0.60 (0.30–1.23)	0.165
Rainy weather	0.97 (0.73–1.29)	0.822	0.84 (0.60–1.16)	0.298
Ring roads	1.40 (1.11–1.76)	0.005	1.77 (1.24–2.52)	0.002
Vehicles				
Motorcycle	—	—	—	—
Moped	—	—	—	—
Helmet/seat belt	0.65 (0.52–0.81)	0.000	0.86 (0.69–1.07)	0.191
Regulation 2004	0.50 (0.43–0.59)	0.000	0.55 (0.000)	0.000
N	20,412		17,425	
LR χ^2	234.09	0.000	422.68	0.000
Log-likelihood at convergence	−3236		−4577	
/cut1	2.76 (2.51–3.00)	0.000	2.34 (2.10–2.58)	0.000
/cut2	5.31 (4.98–5.66)	0.000	4.67 (4.39–4.96	0.000

is more likely to suffer more severe injuries than their younger counterparts—younger than 20 (ORs 1.88 and 2.89)—presumably due to a greater vulnerability because of their age. On the other hand, in the case of gender, males are associated with higher severity (1.38 OR), though no significant differences were found across disaggregated estimates.

Traffic and environment-related factors also play an important role in the determination of injury severity. As shown in Table VI, congestion is associated with lower degrees of injury severity of PTW casualties in Barcelona (ORs 0.80 and 0.88). This result is important and clearly estimated in the case of motorcycles, whereas for mopeds no statistical significance was reported. Therefore, we must point out that the odds ratio associated with mopeds does not differ from that associated with motorcycles.

Similarly, interesting results can be drawn from the number of vehicles involved in the collision. Crashes involving more than one vehicle are associated with lower degrees of severity compared to those in which just one vehicle is involved, with the exception of moped-related casualties. Similarly, suffering a crash on a road with more than 2 lanes favors safety outcomes by reducing injury severity in all vehicle-type casualties. By contrast, rainy weather does not seem to increase the degree of severity even when bad weather conditions are expected to affect road safety.

The impact of ring roads as a location factor of traffic injuries emerges as a key element for justifying disaggregated estimates by vehicle type. According to specification 1, which takes into account the whole sample of casualties, these interurban routes do not have any consequences in terms of injury severity. However, when our models are applied to disaggregated groups of victims, it becomes apparent that PTW casualties tend to suffer more severe injuries on this type of road than on urban routes due to speed, whereas non-PTW accident victims seem to suffer less severe injuries on ring roads.

The last 2 variables to be tested were those related to safety devices and the regulatory license change. Coefficients were statistically significant for the determination of motorcycle casualties, though no statistical significance was found in the case of mopeds. Casualties wearing a helmet or a seat belt suffered less severe injuries than those suffered without these devices in the first 2 cases, whereas no differences were found for moped-related casualties probably due to the high percentage of safety device usage.

Finally, our estimated odds ratio associated with the regulatory variable suggests that the measure—relaxing licence policy—did not increase aggregate injury severity in the city of Barcelona.

DISCUSSION

This study has sought to further our understanding of the factors accounting for the degree of severity of PTW road injuries by drawing on data from Barcelona, the city with the highest number of registered PTW vehicles per capita in Europe. The confirmed higher vulnerability of PTW casualties—consistent with several previous studies; for example, Broughton and Walker (2009)—provides the need for local authorities to pay particular attention to PTWs. Their particular characteristics must lead to appropriate policy responses, and this study contributes by providing useful information regarding how demographic, behavioral, infrastructure, and traffic characteristics affect PTW injury severity in urban areas.

Our findings, especially regarding the effect of congestion on injury severity, connect to previous literature. On the one hand, the relationship between speed and both crash rates and injury severity has been already deeply studied by previous articles, finding an increasing (positive) association among them (see Aarts and Van Shagen 2006; Fuller et al. 2008; Kloeden et al. 2001; O'Donnel and Connor 1996; Shankar and Mannering 1996; Shefer and Rietveld 1997; among others). On the other hand, some authors have dealt with the relationship between traffic flow and crash rates (Dickerson et al. 2000; Martin 2002; Newberry 1988; Vitalino and Held 1991), discussing the existence of either a linear or a nonlinear relationship between both variables. Unlike these articles, this research empirically addresses the role of traffic flow, particulary congestion, on injury severity in a built-up area. Therefore, our results must be compared with the studies by Noland et al. (2008) and Noland and Quddus (2004 and 2005), who reported the positive impact of congestion on road safety outcomes. In their article on London, Noland and Quddus (2005) found little support for the safety effects of urban congestion, but they recognized the weakness of proxies used for congestion as a possible cause of their result. They concluded that their results are inconclusive and suspected that the role of congestion as a mitigator of crash severity is less likely to be present in urban conditions than it is on motorways. Generally, we confirm the safety effect of congestion in a big urban area.

Furthermore, this analysis is focused on the most vulnerable vehicles, PTWs, neglected by earlier works focused on traffic flow. This is particulary appropriate, according to Fuller et al. (2008), because PTW riders tend to drive at inappropriately high speeds for conditions.

Because congestion is highly correlated with crash speed, our results are consistent with those of previous works finding a positive relationship between crash speed and severity. For instance, this study is in line with O'Donnell and Connor (1996) and Shankar and Mannering (1996), although their works are not focused on PTW or test traffic flow, and with Lin et al. (2003a, 2003b) and National Highway Traffic Safety Administration (NHTSA 2007), where motorcycles appear as an important concern.

The safety effect produced by congestion was already highlighted by Peirson et al. (1998). Although more cars on a road may increase crash risk (see Elvik et al. 2004), higher levels of traffic promote a slowdown in the average speed, lowering probabilities of fatal accidents (Shefer and Rietveld 1997). This is what led Noland and Quddus (2004) to claim that increasing speeds by fighting congestion may have adverse safety consequences.

The statistical insignificance of congestion on mopeds may be a power issue, because it is certainly in line with the results for motorcycles and other road users. Nonetheless, we could justify a rationale for a lack of a clearer impact on severity considering differences in engine size/vehicle weight and differences in riding behavior (Shankar and Mannering 1996). Indeed, Langley et al. (2000), who estimated the relationship between the cubic capacity of motorcycle engines and the risk of accidents, found that the risk of an injury crash increases with increasing engine capacity of the motorcycle. Moreover, it could also be explained by the larger ability of mopeds to filter in congested traffic due to their smaller size and weight.

Moreover, Shefe and Rietveld (1997) argued that concern must be focused on speed variance (speed differences) rather than in its average. The same result was already shown by Lassarre (1986), where the evolution of the mean of speeds does not affect the severity of accidents, but it does the evolution of the scatter of the speeds by reducing significantly the number of deaths. This characteristic was also confirmed in Garber and Gadiraju (1989) and Taylor et al. (2000). We should consider that mopeds enjoy a limited speed in comparison with motorcycles in light traffic. This makes the speed variance less important for mopeds and produces lower differences between the congestion speed and light traffic speed, especially due to its higher ability to filter.

Traffic congestion diminishes injury severity, suggesting that measures designed to fight congestion, such as road-charging or the promotion of PTWs, should also take into consideration their impact on the undesired safety outcomes. In the words of Noland and Quddus (2005, p. 738) "external costs associated with congestion may be off-set by external benefits associated with fewer traffic fatalities due to congestion," and this poses a potential policy dillema.

In addition to our findings on congestion, our study highlights the need for undertaking awareness campaigns to target male drivers. Likewise, particular attention should be given to older age groups, whose members are likely to suffer severe accidents the most. It would therefore appear logical to design special safety devices for older persons and to restrict conditions of their PTW use. As the literature confirms, driver profile does affect road safety because it affects road driving behavior (McCartt et al. 2009; Turner and McClure 2003; Zambon and Hasselberg 2006).

Similarly, restricting and enforcing speed limits is essential, though perhaps not in itself sufficient, given our results. Policymakers must to persevere in speed control campaigns while seeking law-abiding, high-risk drivers. Similar arguments can be made in the cases of alcohol consumption and the effectiveness of wearing of protective helmets. Regarding the latter, we do not find statistically significant effects from wearing helmets, probably due to the enforcement in Barcelona. Two studies had, in fact, confirmed the effectiveness of the implementation of the compulsory use of helmets in the city (Ballart and Riba 1995; Ferrando et al. 2000). Similarly, weather conditions do not appear to be a significant determinant of injury severity. Road users change their modal choice when it rains, especially 2-wheel users. This countereffect, as well as the fact that speed is reduced because of wet conditions, can offset the expected severity damage.

Infrastructure characteristics also affect for injury severity determination. Our results show that the number of lanes (street width) is not neutral, perhaps because when it is scarce it limits the space to execute safety movements. The role of capacity was already treated in Noland and Oh (2004) and Milton and Mannering (1998), who found that increasing the number of lanes is associated with increased fatalities and accidents in the case of motorways and other interurban roads. Our results suggest that this is not the case in urban areas.

Contrary to what Segui-Gómez and Lopez-Valdes (2007) pointed out regarding the responsibility of the 2004 regulation for the increase of the number of fatal motorcycle-related crashes, our estimated odds ratio associated with the regulatory variable suggests that the measure—relaxing license policy—did not increase aggregate injury severity in the city of Barcelona. However, it was probably responsible for a higher number of PTW collisions. Also, Paulozzi (2005) described a positive relationship between motorcycle sales and mortality rates in the United States, but our results seem to be more in line with Magazzù et al. (2006), who in contrast, stressed that drivers with a motorcycle license tend to be less responsible for motorcycle–car crashes than drivers who do not hold one. In fact, we found that crashes occurring after policy implementation tended to be less severe for all types of vehicle-related casualties.

LIMITATIONS

The reader must be aware that some limitations apply to this research. First, as in any empirical analysis, the main limitation is imposed by data constraints and unavailability. As an example, it would have been helpful to further disaggregate PTW casualties by engine size, especially in order to evaluate the impact of some variables such as the 2004 regulation promoting a certain type of PTW on each type of victim. Unfortunately, we are limited to the kind of variables stored by the local police administration. As a consequence, some limitations appear; for instance, the lack of information regarding time of the day, day of the week, location, or street's posted speed limit—usual information in most road safety databases—and the inability to control for individual-level variables like risk-taking or protective clothing, which can have an important influence on riding behavior and therefore on crash rates and injury severity. Another limitation associated with the congestion variable is the lack of a continuous variable able to capture different degrees of congestion by considering average daily traffic. In this regard, we must use the only available information, which is whether traffic was congested or not according to what policy agents observed. A final point to be made is that we are using a census in which information about the accidents is recorded by the officer at the location, which usually suffers from underreporting, especially of crashes with no injuries, in which police do not attend, and therefore a certain degree of underreporting should be discounted in our case as well.

CONCLUDING REMARKS

Beyond the limitations above, this article confirms the negative relationship between traffic flow (congestion) and injury severity of PTW casualties as well as improves our understanding of how driver profiles, law violations, and infrastructure and traffic conditions affect PTW injury severity in a large, built-up area. Our findings have important public policy implications. First, alleviating congestion through PTW promotion turns out to be a trade-off between congestion and safety that public officers must consider. Second, the article also highlights the need for awareness campaigns and safety policies focused on specific groups of drivers. Also, attention should be given to the enforcement of speed limits and alcohol restrictions in Barcelona.

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