Impact of enforcement on traffic accidents and fatalities: A multivariate multilevel analysis

George Yannis[1]	Eleonora Papadimitriou	Constantinos Antoniou
Assistant Professor	Research Assistant	Research Associate
geyannis@central.ntua.gr	nopapadi@central.ntua.gr	antoniou@central.ntua.gr

National Technical University of Athens
Department of Transportation Planning and Engineering
5, Iroon Polytechniou str., GR-15773 Athens

Abstract

In this research the effect of the intensification of police enforcement on the number of road accidents and related fatalities at national and regional level is investigated, focusing on two most important infringements: speeding and drinking-and-driving. Distributional assumptions of the Poisson family are considered for the counts of road accidents and fatalities of the various regions of Greece. A multilevel analysis technique is then applied to investigate the effect of the intensification of enforcement on the reduction of road accidents in different regions of Greece. Multivariate multilevel models are developed, in order to assess the combined effects of police enforcement in different regions and for different road safety outcomes (accidents with casualties and fatalities), and to quantify these effects. Results show a significant overall effect of enforcement on both road accidents and fatalities. As regards the regional variation of the effect, which results from different levels of intensified police enforcement per region, a significant difference between accidents and fatalities is identified. In particular, the regional variation of the effect of enforcement on accidents is highly significant, whereas no significant regional variation of the effect on fatalities is identified. The combination of the model results with additional behavioural data led to the conclusion that enforcement intensification has a direct impact on the improvement of driver behaviour and attitude and subsequently on the reduction of road accident and fatalities.

Key words: enforcement; road accidents; fatalities; multivariate multilevel modelling.

[1] Corresponding Author: Dr. George Yannis
National Technical University of Athens
School of Civil Engineering
Department of Transportation Planning and Engineering
5, Iroon Polytechniou str., 15773 Athens, Greece
Tel: +30 210 7721326
Fax: +30 210 7721454
E-mail: geyannis@central.ntua.gr

1. Introduction

In 1998, the Greek Traffic Police started the intensification of road safety enforcement, aiming at gradually increasing the number of roadside controls on speeding and drinking-and-driving. In particular, during the period 1998-2002, an increase of 250% in drinking-and-driving infringements registered and of 350% in speeding infringements registered was achieved, as a result of the increase of related controls, whilst the number of road accidents with casualties and the related fatalities presented an important decrease of around 30% and 25% respectively. Table 1 presents the yearly evolution of road safety and enforcement figures in Greece for the period 1998-2002. Although other reasons may have also led to this significant improvement of the Greek road safety figures, the intensification of enforcement (together with an increase of congestion) may be considered as a main factor.

Table 1 to be inserted here

Therefore, it is necessary to quantify the effect of this intensification of enforcement on road accidents and fatalities. Moreover, the consideration of regional effects might be particularly interesting, as the regional administrative structure of the Police may have led to different practices (i.e. different types and amounts of enforcement), which in turn may have resulted in different regional effects. According to the above, the objective of this research is the investigation of the effect of Police enforcement on the number of road accidents and fatalities, focusing on the identification of regional effects.

For that purpose, a multilevel modelling technique is applied. In particular, the multilevel modelling can reveal the magnitude and significance of the regional effect of enforcement. Moreover, the multivariate multilevel modelling can describe the dependencies among road accidents and fatalities, also in relation to the effect of enforcement. As the numbers of road accidents and fatalities are random counts of events occurring within a population, Poisson-family statistical distributions are assumed.

Previous research on enforcement assessment has indicated that only a significant increase in enforcement level may affect the number of accidents (Bjørnskau, Elvik, 2003). Additionally, very little validation of enforcement effect at national level has been available, as most evaluation attempts concern a temporary increase in local resources or concentrated enforcement efforts in a selected area (ESCAPE, 2003).

The effect of Police enforcement is often examined in the framework of longitudinal studies. For instance, Welki and Zlatoper (2007) examined several explanatory variables to describe the decrease of road accidents in Ohio, USA during the period 1973-2000 and found that the introduction of a drink-driving arrests law and the intensifications of its enforcement had a short term positive effect on accidents. A similar research in the Netherlands (Mathijssen, 2005) showed that each intensification of alcohol enforcement within the period 1970-2000 resulted in a short term drink-driving decrease.

An intensification of Police enforcement on road safety is generally considered to affect both drivers' behaviour and the road safety outcome, in terms of road accidents and fatalities. Goldenbeld and Van Schagen (2005) report a significant decrease in road accidents and a significant modification of drivers speeding behaviour, as a result of an intensification of speeding enforcement on the rural network of a large area in the Netherlands. Chen et al. (2002), as well as De Waard and Rooijers (1994), report a significant effect of speed enforcement on both drivers speeding behaviour and accidents occurrence.

Only a few studies focus on the possible variations of the effect of enforcement in space. Chen et al. (2002) showed that a significant effect was obtained not only on and around the enforcement locations, but also along the entire enforcement corridor. Hauer and Ahlin (1982) report a spatial dispersion (upstream and downstream the enforcement sites). Wechsler et al. (2003) showed that the occurrence of drinking-and-driving differs significantly according to the policy environment at local and regional levels and the enforcement of those policies. At a more macroscopic level, Vanlaar (2005) analyzed the results of a drinking-and-driving survey in Belgium and reported significant differences among different survey sites are found. Moreover, Hakkert et al. (2001) evaluated the regional effect of a general road safety enforcement project in Israel and found a significantly different regional effect.

According to the above, apart from the investigation of the effect of enforcement of road safety, there is also a need to separately yet comparatively examine this effect in relation to different road safety outcomes (road accidents with casualties and fatalities), and further examine regional effects. The present analysis examines the following issues:

- Quantification of the effect of speed and alcohol enforcement on both road accidents and fatalities
- Examination whether the effect on accidents and fatalities is similar
- Investigation of the regional variation of the effect on accidents and fatalities

It is noted that no time or distance halo effect is considered in the present research, which focuses on macroscopic overall effects. In particular, previous research in Greece has shown a significant two-months time halo effect of enforcement (Agapakis, Mygiaki, 2003), which is not considered in the present research, as only annual data are used. Especially as regards the distance halo effect, this would concern the case that the effect of enforcement would cross county borders to the neighbouring counties of the same or neighbouring regions. However, given that the intensification of enforcement was not individually decided by local authorities, but was instead applied on all counties of Greece, it is considered that the cross-county effects of neighbouring counties (and regions) do not significantly affect the within-county (or region) effects.

2. Methodology

Within this research, geographical hierarchies are involved in the identification of regional effects of enforcement. Furthermore, these effects are analyzed on two different yet associated road safety outcomes. In order to examine the combined effect (by road safety outcome and by region) of enforcement on road accidents and fatalities, a multilevel modelling technique is used. Multilevel modelling allows for the analysis of complex hierarchical data structures by taking into account the related dependencies. However, a more sophisticated technique was chosen: multivariate multilevel modelling, which allows for the combined investigation of effects for more than one response by taking into account the dependencies amongst responses, as well as the hierarchical dependencies.

As far as the distributional assumptions of the examined road safety outcomes are concerned, different Poisson-family distributions (those being considered typical for accidents and fatalities) are tested, namely the Poisson, the extra-Poisson and the Negative Binomial distributions. Moreover, the analysis follows a two-level structure; univariate models are developed for the two responses before proceeding to the more complex multivariate model. The basic definitions and assumptions of the examined techniques are briefly presented in the following sections.

2.1. Poisson-family multilevel models

In case of Poisson multilevel modelling, the lower level unit is a count of events and there is a higher level classification of the counts across which the probability response is considered to vary. The multilevel model fitted to the data is based on iterative generalized least squares estimation. Assuming multivariate normality, calculations alternate between estimation of fixed and random parameter vectors until convergence is reached (Langford et al, 1998). A Poisson distributed response vector of observed cases is assumed, and therefore it is necessary to include an offset of expected numbers of cases in the model so that:

$O \sim \text{Poisson}(\pi_{ij})$

$\log(\pi_{ij}) = \log(E_{ij}) + \beta_{0j} + \beta_{1j} x_j + e_j$

$\beta_{0j} = \beta_0 + u_{0j}$
$\beta_{1j} = \beta_1 + u_{1j}$

where E_{ij} represents the expected numbers of cases for each level 1 unit (Rasbach et al., 2000).

The Poisson distribution is used to model the level 1 variance, with a logarithmic link function, and assume random parameters at higher levels as being multivariate normal. An efficient estimation procedure for this non-linear model is predictive quasi-likelihood, where estimation of random parameters, and associated residuals, is made using a Taylor series expansion around the current values of the fixed and random parts of the model (Langford et al, 1998).

It should be underlined though that no random structure can be specified at the lowest level of a Poisson multilevel model. In particular, there is nothing random to estimate as in the Poisson model the relationship between mean and variance is known, so that there is no need to separately estimate the latter. However, the opposite is true in the classical linear regression model, where the mean of the error term is assumed equal to zero but the variance is unknown and must therefore be estimated. Consequently, one would be interested in making the intercept term vary randomly at the 1st level of a normal model but not at the 1st level of a Poisson model.

The assumption of Poisson variation of the cases of counts can be further discussed. A dispersion parameter at level 1 is estimated, so that

$$var(\pi_{ij}) = \pi_{ij} = \sigma_1^2 \mu$$

If $\sigma_1^2=1$, then variation is assumed to be Poisson, if $\sigma_1^2>1$ then there is extra-Poisson variation present (overdispersion), and if $\sigma_1^2 <1$ the model is underdispersed as can happen when many of the counts are zero. However, quite often there are theoretical reasons to assume that extra-Poisson variation may be present in the data (Dean, 1992). For instance, if the counts examined come from significantly heterogeneous populations, the expected values may vary significantly. In order to handle the overdispersion, one option is to consider an additional parameter α, resulting to an extra - Poisson or quasi - Poisson distribution, so that:

$$var(\pi_{ij}) = \alpha \pi_{ij} = \alpha \sigma_1^2 \mu$$

This situation may be further described by stating that the counts in each level 1 unit are being modelled as Poisson conditional on the distribution of rates between units. These rates may be assumed to follow a gamma distribution, and hence the mixture of these two distributions can be expressed as a negative binomial distribution of counts, so that:

$$O \sim \text{Negative Binomial } (\mu)$$

$$\log(\pi_{ij}) = \beta_{0j} + \beta_{1j} x_j + e_j$$

$$\beta_{0j} = \beta_0 + u_{0j}$$
$$\beta_{1j} = \beta_1 + u_{1j}$$

where the variance is a quadratic function of π_{ij}:

$$var(\pi_{ij})= \pi_{ij} + \pi_{ij}^2 / v = \sigma_1^2 \mu + \sigma_2^2 \mu^2$$

It should be noted that, ignoring extra-Poisson variation would not significantly affect parameter estimates; however the related significances may be slightly affected (Dean, 1992).

2.2. Multivariate multilevel models

In order to build a multivariate Poisson model, the individual component is treated as a level 2 unit and the "within-component" measurements (e.g. the different responses) as level 1 units. Each level 1 entry has a response, which is one of the multiple responses. In the simplest case of a bivariate model, each level 1 entry would be a response indicating one of the two response variables for each unit, the basic explanatory variables would be a set of binary variables indicating which of the two responses is present and further explanatory variables would correspond to unit level variables (Rasbash et al. 2000, Yang et al. 2001). This structure is illustrated in Table 2.

Table 2 to be inserted here

The statistical formula for the two level basic bivariate Poisson model, is written as follows:

Response1 ~ Poisson (π_{1j})
Response2 ~ Poisson (π_{2j})

$$\log(\pi_{ij}) = \log(E_{1j}) + \log(E_{2j}) + \beta_0 z_{1j} + \beta_1 z_{2j} + \beta_2 z_{1j} x_{ij} + \beta_3 z_{2j} x_{ij}$$

Where $z_{1j} = \begin{cases} 0 & \text{if response 1} \\ 1 & \text{if response 2} \end{cases}$, $z_{2j} = 1 - z_{1j}$

$$\operatorname{cov}\begin{bmatrix} z_{1j} \\ z_{2j} \end{bmatrix} = \begin{bmatrix} \pi_{1j} & \\ \rho(\pi_{1j}\pi_{2j})^{0.5} & \pi_{2j} \end{bmatrix}$$

There are several interesting features in this model. There is no level 1 variation specified, as level 1 exists solely to define the multivariate structure. The level 2 variances and covariance are the (residual) between-responses variances. The estimates are statistically efficient even where some responses are missing (Rasbash et al, 2000).

It should be noted though that the estimates obtained are not necessarily the same as the estimates that would be obtained by fitting two separate univariate models. If there is a tendency, for instance, to report/measure only one of the responses, or if the occurrence rate of one response is different from the occurrence rate of the other response, the omitted values of the other response are not missing completely at random. In the univariate analysis there is no way to correct for this bias, as it is considered that any absent values are missing completely at random (MCAR). The multivariate model contains the covariance between the responses, assuming that the absent values are missing at random (MAR), which is a weaker assumption (Hox, 2002). Thus, the formulation as a 2-level model allows for the efficient estimation of a covariance matrix with missing responses, where the missingness is at random.

Accordingly, a third level can be incorporated and this is specified by inserting a third subscript k as follows:

Response1 ~ Poisson (π_{1jk})
Response2 ~ Poisson (π_{2jk})

$$\log(\pi_{ij}) = \log(E_{1jk}) + \log(E_{2jk}) + b_{0k}z_{1jk} + b_{1k}z_{2jk} + b_2 z_{1jk}x_{ijk} + b_{3k}z_{2jk}x_{ijk} + v_{0k}z_{1jk} + v_{1k}z_{2jk} + v_{2jk}z_{1jk} + v_{3jk}z_{2jk}$$

Where $z_{1jk} = \begin{Bmatrix} 1 & \text{if response 1} \\ 0 & \text{if response 2} \end{Bmatrix}$, $z_{2jk} = 1 - z_{1jk}$,

$$\begin{bmatrix} v_{0k} \\ v_{1k} \\ v_{2k} \\ v_{3k} \end{bmatrix} \sim N(0, \Omega_v) \qquad \Omega_v = \begin{matrix} \sigma^2_{v0} & & & \\ \sigma_{v01} & \sigma^2_{v1} & & \\ \sigma_{v02} & \sigma_{v12} & \sigma^2_{v2} & \\ \sigma_{v03} & \sigma_{v13} & \sigma_{v23} & \sigma^2_{v3} \end{matrix}$$

$$\text{cov}\begin{bmatrix} z_{1jk} \\ z_{2jk} \end{bmatrix} = \begin{bmatrix} \pi_{1jk} & \\ \rho(\pi_{1jk}\pi_{2jk})^{0.5} & \pi_{2jk} \end{bmatrix}$$

This model could be extended further, by adding more explanatory variables to the model and allowing them to vary on level 3 for each response. It should be noted that, multiplying each explanatory variable with all the dummy variables, each regression coefficient in the model is different for each response. All the assumptions of Poisson multilevel models described above also apply in the case of multivariate models.

3. Data

The dataset that is used in the framework of this analysis concerns regional data from 49 counties of Greece (245 observations in total), nested within 12 regions in the period 1998-2002. The response variables are the number of road accidents with casualties and the related fatalities, and possible explanatory variables are the number of alcohol controls, the number of speed infringements (no data on the number of speed controls are available), as well as socioeconomic parameters such as vehicle ownership and road network type. The population of each county is used as offset term, to express the expected number of accidents. The dataset variables are summarized in Table 3.

Table 3 to be inserted here

It should be noted that the Athens and Thessaloniki metropolitan areas, where a disproportionally high number of accidents and police controls are observed, were not included in the dataset. In particular, these are two very large agglomerations, with different traffic conditions (e.g. more congestion) and consequently different travel patterns and driving behaviours, making the linking between road safety and enforcement figures much more complex.

4. Results

4.1. Univariate analysis

The first stage of the analysis concerns a univariate multilevel modelling of the number of road accidents with casualties in 49 counties of Greece under Poisson assumptions. We first consider a two-level model with a random intercept term only, in order to examine the variation due to the regional effects. The results presented in Table 4 indicate a significant random variance among regions

Table 4 to be inserted here

The next step in model fitting with this dataset is to add explanatory (predictor) variables into the multilevel model. Firstly, the effect of alcohol controls on the number of accidents is examined, allowing it to randomly vary between regions. A multilevel model with a random intercept and a random slope is therefore fitted (Model 2) and the results are also presented in Table 4.

It is noticed that all fixed and random effects are significant. However, the variance of alcohol controls is less significant than the variance of the intercept, suggesting that the regional variation of accidents itself (in geographical terms) is a stronger determinant of the number of accidents than the effect of enforcement. It is also noted that there is a significant covariance among intercept and slope, indicating that, the higher the number of accidents of a region, the higher the effect of alcohol enforcement (reduction of accidents). Additionally, Model 2 presents a significantly improved fit, as the related deviance reduction is equal to (7,038.97 - 4,624.30) = 2,414.67, which is highly significant compared to a Chi-square distribution with 12 degrees of freedom. It should be noted though that likelihood statistics for discrete response models are very approximate, as quasilikelihood estimation is used. Therefore, likelihood statistics are only examined as a rough assessment of models fit (Rasbash et al., 2000).

Accordingly, the effect of speed enforcement on the number of accidents is separately examined, by removing the number of alcohol controls from the model and adding the number of speed infringements, also allowing it to randomly vary between regions. Another multilevel model with a random intercept and a random slope is therefore fitted (Model 3). All the results are quite similar to those of Model 2 on alcohol controls. The resulting residual deviance in this case is equal to 2372.94, and the corresponding reduction is also significant for 12 degrees of freedom, however somewhat less improving the model fit compared to the number of alcohol controls.

The next step concerns the incorporation of both speed and alcohol enforcement effects in the model, in order to examine the related combined effect. A two-level model is therefore fitted (Model 4), allowing both explanatory variables to vary among regions. In this case, all fixed effects are highly significant. However, the Level-2 variances and covariances related to the number of speed infringements are non significant. This is quite surprising, when considering that both effects were significant when examined separately. Moreover, the respective parameter estimates for each region were examined and it was shown that several slopes presented an inversed counter-intuitive effect, not directly attributable to regional characteristics. Additionally, the fact that the overall fit of the model was at the same time improved indicates some bias in the estimates.

This is probably due to the fact that both variables may be seen practically as measurements of one parameter (i.e. police enforcement). The correlation between speed infringements and alcohol controls was examined, resulting to a positive correlation of 0,729. In this case (multicollinearity), a redundancy of variables is exposed, causing both logical and statistical problems and weakening the analysis through reduction of degrees of freedom error (Washinghton et al. 2003). As far as multilevel models are concerned, the results of a recent study show that, with multicollinearity presented at Level 1 of a two-level mixed-effects linear model, the fixed-effect parameter estimates produce relatively unbiased values; however, the variance and covariance estimates produce downwardly biased values (Shieh, Fouladi, 2003).

Another issue that should be examined in case of Poisson multilevel models is overdispersion (Dean, Lawless, 1989). A procedure to investigate and possibly account for this overdispersion can be used as explained above, by not restricting the variance-mean relationship to be equal to one. It should be noted that this assumption would not significantly affect parameter estimates; however the related significances may be slightly affected (Dean, 1992). In the framework of the present research, the regional effect of alcohol controls on the number of accidents was examined assuming extra-Poisson variation.

Table 5 to be inserted here

In particular, in Table 5, parameter estimates are presented for an intercept only model (Model 5) and a model examining the variation of the effect of alcohol over regions (Model 6). It is noticed that fixed parameter estimates are not significantly different from the ones obtained with Poisson assumptions. However, the regional variation as well as the covariance of intercept and slope are somewhat reduced. Moreover, a significant estimate of the variance/mean ratio is obtained, indicating that the variance-mean equality assumed in the previous examples was not adequate, as overdispersion was present in the data and is sufficiently handled in this model.

As explained previously, another option for overdispersed counts data is to assume a Negative Binomial distribution, allowing for a more flexible variance structure. The results for the examined dataset are presented in Table 6. It is noted that the Negative Binomial models are very similar to the Extra-Poisson models, in terms of both fixed and random parameter estimates and models fit. It is therefore shown that both Extra-Poisson and Negative Binomial distributional assumptions can efficiently overcome overdispersion in count data. The results of the above analysis models indicate that Models 6 and 8 are the best Models for the purposes of the present analysis.

Table 6 to be inserted here

Summarizing, the multilevel modelling revealed a significant decrease of road accidents due to enforcement within the examined period. Moreover, a significant regional variation of the effect of enforcement was obtained. It is noted that none of the other available variables were found to add explanatory effect in the reduction of road accidents in Greece. This was not surprising, as no other parameter (e.g. vehicle ownership, road network length etc.) presented a significant variation, comparable to the increase of enforcement, in the examined period. Consequently, the intensification of enforcement is considered to be the main cause of the improvement of road safety in Greece; however, the models developed above are not considered to fully describe this trend. Additional explanatory variables might be required; however not among those for which data were available. However, they are considered as efficient to describe the regional variation of this trend and the relative regional effect of the main causal factor.

As far as the regional effect is concerned, the results confirmed the initial suspicion of a significant regional variation of the effect of enforcement. It would be reasonable to assume that the regional variation of the effect is mainly the result of different practices (e.g. different presence on the road network) in the implementation of enforcement, as the Greek Police is organized according to an administrative structure in full accordance with the examined geographical structure. The next question to be investigated concerns the respective effect on fatalities, both in terms of regional variation and on correlation with the effect on road accidents.

4.2. Multivariate analysis

The interest of this multivariate analysis lies on the fact that road accident severity (number of casualties) may or may not be fully related to accident frequency (number of accidents). In particular, an improved road environment or an increase in traffic may be the causes of fewer casualties within the same number of accidents. Accordingly, the intensification of police enforcement may or may not have the same effect on the number of accidents as on the number of related casualties, and each effect may or may not have the same regional variation for the two outcomes. Only the number of alcohol controls is examined as explanatory variable in this case, since it was proved previously that alcohol and speed enforcement are significantly correlated and therefore they should not be examined jointly. Moreover, a lack of data on the number of speed controls does not allow the examination of the sum of speed and alcohol controls.

The initial stage of the analysis concerns a two-level model, which is specified in order to define the bivariate response variable. In particular, level 1 is defined as a dummy variable indicating the presence of each response and level 2 is defined as the respective value of each response. Therefore, a response variable of 98 units (counties) is created; 49 units corresponding to the 1st response (number of accidents) and 49 units corresponding to the 2nd response (number of persons killed).

The natural logarithm of the population is used as an offset in both responses. It should be also noted that, following the results of the univariate analysis, extra-Poisson distributional assumptions are considered for both responses, in order to allow for more flexibility in the estimations. The modelling results for the simple examination of variability between responses (Model 9, two-level model with fixed intercept) are presented in Table 7.

The intercept terms of the two responses are both highly significant. Additionally, a significant between-response covariance indicates that the two responses follow similar overall trends. When proceeding in adding a fixed slope for alcohol controls (Model 10), the results indicate that the overall effect of alcohol enforcement is highly significant for both the number of accidents and the number of persons killed.

Table 7 to be inserted here

At the next stage, the significance of the regional effects on the responses are examined, by adding a 3rd level to the model (which would correspond to the 2nd level of the respective univariate model) and introducing a random intercept.

Table 8 to be inserted here

The results are presented in Table 8. A significant regional variation of both road accidents and road accident fatalities is shown (the variation of fatalities is marginally significant), as well as a significant covariance between the two intercepts (Model 11). Additionally, the regional variability of the intercept is higher for the number of accidents, as indicated by the values of the related mean variances. However, one can notice that the covariance between responses and its significance is reduced. It can be deduced that some of the covariance between accidents and killed is situated at the regional level.

When adding the randomly varying explanatory variable to the model (Model 12), it can be seen that the regional variation of the number of fatalities is now non significant. Moreover, the mean (fixed) effect of enforcement on the number of accidents is significant, while the related fixed effect on persons killed is very marginally significant. The regional variation of the effect of alcohol enforcement effects is only (and marginally) significant as far as the number of accidents is concerned. It is noted that, for practical reasons i.e. convergence problems, only variances (diagonal matrix) are examined at the highest level for Model 12.

At this stage, there is enough evidence that road accidents and road accident casualties present a significantly different regional variation, which is higher for accidents than for persons killed. Additionally, the increase of alcohol controls causes a different reduction on accidents and persons killed at national level, which is more important for accidents than for persons killed.

Furthermore, the less complex univariate model, which was successfully fitted in the accidents data, had indicated a somewhat higher regional variation of the effect of enforcement than the one obtained in the present bivariate analysis, which takes into account the dependency among accidents and fatalities. It should be underlined that, for validation purposes, a univariate model for the number of persons killed was also fitted to the data and the non-significant regional variation of the effect of enforcement was confirmed. However, the full three-level structure appears to contribute a degree of unnecessary complexity, which may also affect the efficiency of the calculations, compromising some estimates that were significant in the less complex structure. This is the case for the fatalities branch; on the other hand, the accidents branch has a satisfactory performance in a three-level structure.

According to the above, a final model presented in Table 9 is selected for the combined analysis of the effect of enforcement on accidents and fatalities and its regional variation. This Model 13 can be seen as a hybrid multivariate multilevel model, as the branch concerning fatalities has a two level structure (only fixed effects), while the branch concerning accidents has a full three-level structure (fixed and random effects). This parsimonious model also allows for a better interpretation of results. According to this final model, the intensification of enforcement has a significant effect on accidents and fatalities at national level. Moreover, this effect has a significant regional variation as far as accidents are concerned.

Table 9 to be inserted here

According to Model 13, the consecutive yearly increases of alcohol controls in the 49 Greek counties (not including Athens and Thessaloniki) within the examined period (a total increase of 664%, from 97,488 controls on 1998 to 744,869 controls on 2002), was statistically associated with a total accidents reduction of 25% (from 10,498 on 1998 to 7,814 on 2002), and a total fatalities reduction of 4% (from 1,442 on 1998 to 1,332 on 2002).

5. Discussion

This research investigates the regional effect of Police enforcement on two separate yet correlated road safety outcomes; the number of road accidents with casualties and the related number of persons killed. Consequently, those two road safety outcomes were initially considered as partially (yet not fully) interdependent. Within this framework, the impact of the intensification of enforcement in Greece was analyzed at national and regional level, using a multivariate multilevel modelling technique, which allows for the identification and quantification of all related dependencies among the examined parameters, including natural dependencies among outcomes and spatial dependencies among effects.

First of all, the preliminary univariate analyses revealed a significant regional variation of road accidents and a different (marginally) significant regional variation of the related fatalities. Moreover, a significant overall impact of the effect of enforcement on both road accidents and fatalities was identified; however, the regional variation of this effect was found to be significant only for road accidents. More specifically, a higher effect is observed in the regions with higher number of accidents in the first place. These separate results indicate a different (regional) effect of enforcement on the different road safety outcomes. The multivariate analysis, which takes into account the degree of dependency between the two responses, allows for further investigation of these findings.

Both two-level and three-level multivariate models were fit. While in the two-level model all (fixed) parameters were significant, in the three-level model only the variation of the effects for accidents were found significant. Instead of choosing one of the two models however, a hybrid model was developed, which has three levels for accidents but only two levels for killed. All parameters of this hybrid model were found significant and therefore this model was selected as the best model for describing the examined effects.
In particular, the multivariate structure provided slightly different results as far as the magnitude of the examined effects is concerned. It was shown that the number of persons killed in accidents is strongly proportional to the number of accidents, and part of this dependency is situated at the regional level. Moreover, a significant effect of enforcement on both parameters is identified at national level; however a regional variation of the effect of enforcement only concerns the number of accidents, i.e. a given increase of Police controls results to a significantly different decrease of accidents in different regions, but to a uniform decrease of fatalities in all regions, although the two responses still present an important overall covariance.

These results may be simply due to the relatively low number of fatalities per county (and a high degree of random variation in accident counts). Nevertheless, it may also be the case that the nationwide intensification of enforcement had an important overall effect on all accidents, but mainly on severe (fatal) accidents; these accidents result from more risk-taking behaviours, namely speeding. In particular, it is possible that an overall increase of the presence of the Police was perceived by drivers, who adapted their overall behaviour accordingly, adopted a more compliant and less reckless driving, which in turn resulted in a significant decrease of fatal accidents at national level, and a related decrease on fatalities.

However, fatal accidents are only a small proportion of all accidents with casualties. The effect of enforcement on more conventional (less risk-taking) behaviours, which are associated with less severe (non fatal) accidents, varies significantly among regions, and appears to be more dependent on the regional / local presence of the Police on the road network. In fact, the regional / local Police departments often have different enforcement practices (different enforcement distribution in space and time), in terms of frequency, density and duration of controls. Consequently, a locally more intensive enforcement has a more important effect on non fatal accidents, especially in regions with increased total number of accidents in the first place. On the other hand, accidents with fatalities appear to be affected by the overall national intensification of enforcement.

The change of behaviour of the Greek drivers can be observed on the data of Table 1; it is observed that during the early years of the intensification of enforcement, the number of infringements increased, as the number of police controls increased. However, a further increase of alcohol controls on 2002 corresponds for the first time to a decrease of alcohol related infringements. This change of behaviour can be also illustrated by the results of the SARTRE-2 and -3 surveys, which took place in Greece on 1996 and 2002 respectively. Figure 1 shows the proportion of drink-driving in Greece, as reported by the Greek drivers on the two SARTRE surveys. Both figures may include a self-reporting downward bias; however the overall trend indicates a significant reduction from 12.5% to 6.2% (i.e. around 50% reduction) in drink-driving between 1996 and 2002. At the same time an increase of 10.2% of positive attitudes towards further increase of the legal alcohol consumption limit was observed (SARTRE, 2004).

Figure 1 to be inserted here

It is noted that no other parameters, including socio-economic and transport features, were found to add explanatory power to the models examined, indicating that the increase of enforcement was the main factor for the overall improvement of road safety in Greece in the examined period. This is not surprising, when considering that the variation of those parameters was much less important in relation to the intensification of enforcement.

In terms of analysis techniques, several practical aspects of multilevel models were tackled in this research. First, the Poisson-family distributions were assessed for the modelling of highly overdispersed road safety outcomes. Second, the effect of multicollinearity in multilevel models was briefly demonstrated. Finally, the structure and properties of multivariate multilevel models were exploited and were proved very useful for the investigation of multiple dependencies, including those among the two road safety outcomes themselves, the examined explanatory effects and their variation in space.

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Table 1. Basic trends of road safety and enforcement in Greece (1998 - 2002)

Year	injury road accidents	persons killed	vehicles (x1000)	speed infringements	drink & drive infringements	drink & drive controls
1998	24,819	2,182	4,323	92,122	13,996	202,161
1999	24,231	2,116	4,69	97,947	17,665	246,611
2000	23,127	2,088	5,061	175,075	30,507	365,388
2001	19,71	1,895	5,39	316,451	49,464	710,998
2002	16,852	1,654	5,741	418,421	48,947	1,034,502
Total change	-32%	-24%	33%	354%	250%	412%

Table 2. Data structure for the simple bivariate multilevel model

Individual	Response	Constant		Explanatory variable (x)	
		Response 1	Response 2	X.R1	X.R2
1	Response 1	0	1	0*x	1*x
1	Response 2	1	0	1*x	0*x
2	Response 1	0	1	0*x	1*x
2	Response 2	1	0	1*x	0*x
3	Response 1	0	1	0*x	1*x
3	Response 2	1	0	1*x	0*x

Table 3. Variables and values considered

Region	The regions of Greece (1-12)
County	The counties of Greece (1-49)
Accs	The number of accidents of each county
alcontrol (1000)	The number of alcohol controls of each county
speedinf (1000)	The number of speed infringements of each county
logepop (offset)	The natural logarithm of the population of each county
Vehown	The number of vehicles per 100 inhabitants of each county
Natoroad	The percentage of National roads of the network of each county
Cons	The constant term

Table 4. Poisson multilevel models for the regional effect of enforcement on road accidents

	Model 1 (constant term)	Model 2 (Effect of alcohol controls)	Model 3 (Effect of speed controls)	Model 4 (Effect of speed and alcohol controls)
Fixed effects				
Constant	-6.488 (0.076)	-6.672 (0.108)	-6.691 (0.115)	-6.654 (0.101)
Alcontrols		-0.059 (0.014)		-0.036 (0.010)
Speedinf			-0.131 (0.043)	-0.058 (0.023)
Random effects				
Level 2 (regional effects)				
σ_{u0}^2 (constant)	0.070 (0.029)	0.140 (0.057)	0.157 (0.065)	0.119 (0.050)
σ_{u1}^2 (alcontrols)		0.0025 (0.0010)		0.0011 (0.0005)
σ_{u2}^2 (speedinf)			0.022 (0.009)	0.0066 (0.0029)
σ_{u01}^2 (covariance)		0.013 (0.006)		0.0084 (0.0044)
σ_{u02}^2 (covariance)			0.051 (0.023)	0.015 (0.0010)
σ_{u12}^2 (covariance)				0.00045 (0.00086)
Variance/mean	1.000	1.000	1.000	1.000
Degrees of freedom	233	221	221	209
-2*loglikelihood	7038.97	4624.30	4666.03	4360.68

Note: Numbers in parenthesis are standard errors of the estimated parameters

Table 5. Extra - Poisson multilevel models for the regional effect of enforcement on road accidents

	Model 5 (Constant term)	Model 6 (effect of alcohol)
Fixed effects		
constant	-6.486 (0.073)	-6.587 (0.092)
alcontrols		-0.047 (0.010)
Random effects		
Level 2 (regional effects)		
σ_{u0}^2 (constant)	0.064 (0.029)	0.094 (0.042)
σ_{u1}^2 (alcontrols)		0.00108 (0.00051)
σ_{u01}^2 (covariance)		0.0059 (0.0039)
Variance/mean	22.622 (2.096)	12.892 (1.226)
Degrees of freedom	233	221
-2*loglikelihood	2729.07	2621.82

Note: Numbers in parenthesis are standard errors of the estimated parameters

Table 6. Negative Binomial multilevel models for the regional effect of enforcement on road accidents

	Model 7 (Constant term)	Model 8 (effect of alcohol)
Fixed effects		
constant	-6.477 (0.075)	-6.599 (0.098)
alcontrols		-0.052 (0.013)
Random effects		
Level 2 (regional effect)		
σ_{u0}^2 (constant)	0.064 (0.029)	0.099 (0.0439)
σ_{u1}^2 (alcontrols)		0.0013 (0.0006)
σ_{u01}^2 (covariance)		0.0071 (0.0043)
Degrees of freedom	233	221
-2*loglikelihood	2,742.27	2,632.19

Note: Numbers in parenthesis are standard errors of the estimated parameters

Table 7. Extra - Poisson multivariate multilevel models for overall effect of enforcement on accidents and fatalities (two-level model)

	Model 9		Model 10	
Level 1	Accidents	Killed	Accidents	Killed
Level 2				
Fixed effects				
Constant	-6.471 (0.025)	-8.380 (0.023)	-6.455 (0.023)	-8.372 (0.023)
Alcontrols			-0.019 (0.003)	-0.0059 (0.0021)
Cov (accs/killed)	4.691 (0.042)		4.139 (0.657)	

Note: Numbers in parenthesis are standard errors of the estimated parameters

Table 8. Extra - Poisson multivariate multilevel models for the regional effect of enforcement on accidents and fatalities (three-level model)

	Model 11		Model 12	
Level 1	Accidents	Killed	Accidents	Killed
Level 2				
Fixed effects				
constant	-6.453 (0.044)	-8.382 (0.028)	-6.475 (0.038)	-8.381 (0.026)
alcontrols			-0.025 (0.004)	-0.0041 (0.0024)
Level 3 (regional effect)				
Random effects				
σ_{u0}^2 (constant)	0.092 (0.021)	0.0163 (0.0085)	0.053 (0.014)	0.0104 (0.0072)
σ_{u1}^2 (alcontrols)			0.00038 (0.00021)	0.000006 (0.00002)
σ_{u01}^2 (covariance)	0.025(0.010)		-	-
Cov (accs/killed)	2.898 (0.556)		3.313 (0.556)	

Note: Numbers in parenthesis are standard errors of the estimated parameters

Table 9. Final Extra - Poisson multivariate multilevel model for the regional effect of enforcement on accidents and fatalities (hybrid model)

	Model 13	
Level 1	Accidents	Killed
Level 2		
Fixed effects		
constant	-6.457 (0.036)	-8.372 (0.022)
alcontrols	-0.0210 (0.0036)	-0.0056 (0.0021)
Level 3 (regional effect)		
Random effects		
σ_{u0}^2 (constant)	0.0548 (0.013)	
σ_{u1}^2 (alcontrols)	0.00015 (0.00009)	
σ_{u01}^2 (covariance)	0.020 (0.009)	
Cov (accs/killed)	3.993 (0.573)	

Note: Numbers in parenthesis are standard errors of the estimated parameters

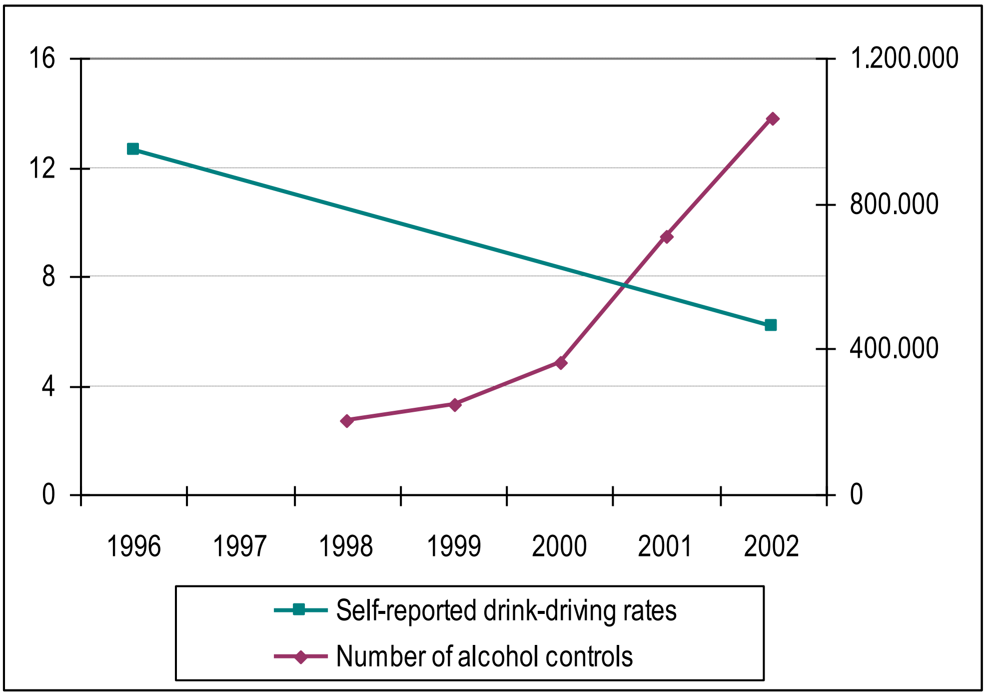

Figure 1. Self-reported drink-driving rates and number of alcohol controls in Greece 1996-2002.