When may road fatalities start to decrease?

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Abstract

The comparative analysis of macroscopic trends in road safety has been a popular research topic. The objective of this research is to propose a simple and, at the same time, reliable multiple regime model framework for international road safety comparisons, allowing to identify slope changes of personal risk curves and respective break-points. The trends of road traffic fatalities in several EU countries have been examined through the temporal evolution of elementary socioeconomic indicators, namely motorized vehicle fleet and population, at the country level. Piece-wise linear regression models have been fitted, using a methodology that allows the simultaneous estimation of all slopes and breakpoints. The number and location of breakpoints, as well as the slope of the connecting trends, vary among countries, thus indicating different road safety evolution patterns. Lessons from the analysis of the past road safety patterns of developed countries provide some insight into the underlying process that relates motorization levels with personal risk and can be proved beneficial for predicting the road safety evolution of developing countries that may have not yet reached the same breakpoints. Furthermore, the presented framework may serve as a basis to build more elaborate models, including more reliable exposure indicators (such as vehicle-km driven).

Keywords: road safety, macroscopic trends, personal risk, motorization rate

1. Introduction

The comparative analysis of macroscopic trends in road-safety-related issues among countries and regions has attracted the attention of researchers for several decades. A critical review of a number of approaches for modelling road safety trends can be found in Hakim et al. (1991) and Oppe (1989). Al-Haji (2007) provides a review of these concerns, as well as several alternative approaches for the development of road safety models. Other useful reviews are provided by the COST329 group (2004) and Broughton (1991), where a detailed analysis of the debate surrounding Smeed's formulas and analysis (Smeed, 1968) is available.

In recent years, some most interesting approaches have been presented on the topic. Lassarre (2001) presented an analysis of ten European countries' progress in road safety by means of a structural (local linear trend) model, yielding two adjusted trends, one deterministic and one stochastic. This was achieved through incorporation of intervention functions related to the major road safety measures introduced. An indicator of the rate of progress given risk exposure trends (vehicle-km travelled) was defined. It was deduced that all major EU countries exhibit rate of progress above a minimum threshold of 4.5% annually. The average of 6% is equivalent to the statement that the road transport system in Europe "is capable of absorbing a 6% increase in traffic at a constant number of fatalities".

Page (2001) presented an exponential formula that yields fatalities as the product of all explanatory variables' influence. This function is easily transformed to a simple algebraic form (first order polynomial with an intercept) by taking the logarithm of both sides. The objective of the respective research lays on safety level comparison among selected OECD countries during the period 1980-1994. Taken that fatality rates are not sufficient to perform international comparisons, a statistical multiple regression tool was set up. The model assumes that each variable's effect is independent of its original level, implying constant elasticity. Interestingly, the negative intercept represents a positive mean effect of missing variables on safety.

Models with several exogenous variables are developed and attempts to rank countries based on their road mortality level were made. Beenstock and Gafni (2000) show that there is a relationship between the downward trend in the rate of road accidents in Israel and other countries and suggest that this reflects the international propagation of road safety technology as it is embodied in motor vehicles and road design, rather than parochial road safety policy. Van Beeck et al (2000) examine the association between prosperity and traffic accident mortality in industrialized countries in a long-term perspective (1962-1990) and find that in the long-term the relation between prosperity and traffic accident mortality appears to be non-linear. Kopits and Cropper (2005) use linear and log-linear forms to model region specific trends of traffic fatality risk and per income growth using panel data from 1963 to 1999 for 88 countries. Abbas (2004) compares the road safety of Egypt with that of other Arab nations and G-7 countries, and develops predictive models for road safety.

Other analyses entail a specific road safety related problem, applying international macroscopic comparison techniques to a subset of road network users, such as novice or young drivers. Twisk & Stacey (2007) presented a general study of identified trends in young drivers risk and associated countermeasures in certain European countries. The relationship between general safety levels and young driver risks is stressed: the impact of general safety measures on the subgroup is greater than that of measures specifically targeting young drivers, especially for poorly performing countries.

The analysis presented in this paper studies the development of personal risk against motorisation rate over time, spanning a 45-year period, at least for the countries for which all required data are readily available since 1960. The analysis uses a flexible methodology for the simultaneous estimation of broken-line regression models (Muggeo, 2003). Such relationships are common in many fields, indicatively including epidemiology and toxicology. In the studied problem this is considered a most appropriate tool, as the motorization rate is empirically identified as an explanatory variable that yields piecewise linear relationships with responses such as traffic risk (i.e. fatalities suffered per motorized vehicle) or personal risk (i.e. fatalities suffered per head of population).

The remainder of this paper is structured as follows. Trends of personal risk in the European roads are presented in Section 2 followed by the methodology used for the analysis of the data in Section 3. In Section 4 the estimated models and analyses of the obtained results are presented, while in Section 5 the paper is concluded through further discussion and directions for future research are outlined.

2. Trends of personal risk in the European roads

Figure 1 provides an overview of the evolution of personal risk and motorization rate in selected European countries over time, using data between 1960 and the year of the latest available data (i.e. either 2008 or 2009). The top row of subfigures shows the personal risk trend for Austria and Belgium, which exhibit an increase in personal risk until the early 1970s, followed by a downward trend since. A similar pattern is visible for the Netherlands and Greece (for which the break-point occurs in the mid 1990s. The data for Czech Republic and Poland show a more elaborate set of two peaks. Finally, the data for Spain show a less clear trend, leaving more room for possible model fits.

Several observations can be made already from this figure. First, it appears that many of these eight countries show a similar pattern of increasing personal risk until a point, when a structural bend is observed in the trend and a downward trend continues from that point on. The breakpoint in the trend, however, is observed in different points in time. A third observation is that, while these breaks seem to be happening at a rather wide range of time (e.g. shortly after 1970 for the Netherlands and around 1995 for Greece), they seem to occur at a rather narrow range of personal risk (somewhere around 25 fatalities per 100 000 population, with the exception of Austria and Belgium that show a higher historical peak personal risk rate).

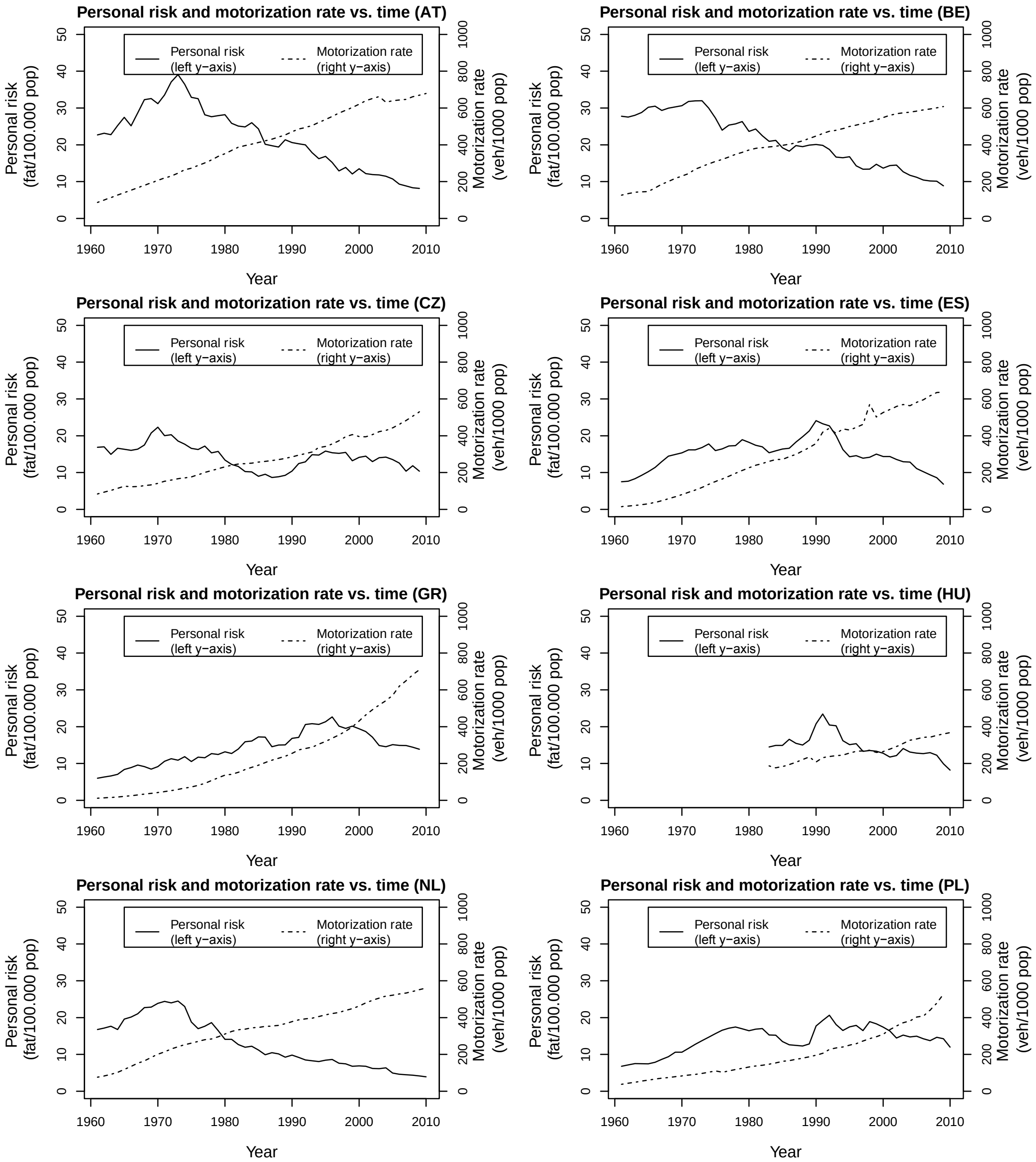

Fig. 1. Plot of Personal risk over Motorization rate for selected EU countries (1960-2008/2009). From top left to bottom right: Austria, ,Belgium, Czech Republic, Spain, Greece, Hungary, the Netherlands and Poland).

3. Methodology

The data presented in Figure 1 reveal linear trends and breakpoints. The objective of the methodology is to allow for the simultaneous estimation of regression models with unknown breakpoints in a way that provides estimates both for the breakpoints' locations and the slopes. The advantage of such a methodology is that the main estimates would be consistent, using information from the entire data range and not only from the regime that they span. The statistical approach that is used is described in Muggeo (2003) and is implemented using the R software for statistical computing (RDCT, 2010) with the "segmented" package (Muggeo, 2008). The methodology implemented within this package assumes that the number of breakpoints is known. This is a reasonable and practical requirement that can easily be fulfilled by visual inspection of the data. Whenever multiple model structures seem plausible, then alternative models can be explored and compared. The Schwarz/Bayesian Information Criterion (BIC, Schwarz, 1978) can be used to select among competing hypothesis, taking care to respect the rules for its applicability. (While a detailed discussion is outside of the scope of this paper, and there is a lot of specialized research on the topic, the BIC is best suited for the comparison of nested models and models with similarly computed log-likelihood measures.)

While a detailed statistical presentation of the used method is not within the scope of this paper, a brief description of estimation and testing processes for models developed with R's segmented package is provided, following the exposition used in Muggeo (2008). Muggeo (2003) can also be used by the interested reader as sources for further details.

A segmented relationship between the mean response $\mu = E[Y]$ and the variable Z, for observation i = 1, 2, . . . , n is modelled by adding in the linear predictor the following terms:

$$\beta_1 z_i + \beta_2 (z_i - \psi)_+ \qquad (1)$$

where $(z_i - \psi)_+ = (z_i - \psi) \times I (z_i > \psi)$ and $I (\cdot)$ is the indicator function equal to one when the statement is true. According to such parameterization, β_1 is the left slope, β_2 is the difference-in-slopes and ψ is the breakpoint. It is tacitly assumed a GLM with a known link function and possible additional covariates, x_i, with linear parameters δ, namely $link(\mu_i) = x'_i \delta + \beta_1 z_i + \beta_2 (z_i - \psi)_+$; however, since the discussed methods only depend on (1), the response, the link function, and the possible linear covariates are left out from this presentation.

The package segmented offers facilities to estimate and summarize generalized linear models with segmented relationships; virtually, no limit on the number of segmented variables and on the number of change-point exists. "Segmented" uses a method that allows to estimate simultaneously all the model parameters yielding also, at the possible convergence, the approximate full covariance matrix.

With respect to testing for a breakpoint, if the breakpoint does not exist, then the difference-in-slopes parameter has to be zero. In this case, a natural test for the existence of ψ is

$$H_0 : \beta_2 (\psi) = 0 \qquad (2)$$

Note that $\beta_2(\psi)$ is presented in order to stress that the parameter of interest, β_2, depends on a nuisance parameter, ψ, which vanishes under H_0.

Therefore, conditions for validity of standard statistical tests (Wald, for instance) are not satisfied.

4. Estimated models

As is evident from Figure 1, while there are some general patterns that can be discerned for the evolution of personal risk, the exact patterns vary among the various countries. This section starts with a presentation of the “simpler” trends, observed e.g. in Belgium and Greece, before exploring examples of gradually more complex relationships. For the presentation of results (Figures 2 and 3), there are three subfigures for each country, ordered in a column. The top subfigure presents the personal risk data versus the motorization rate, and the estimated model. The next subfigure shows the same data and estimated model but uses a different x-axis for projection, i.e. the time. Even though the fitted model may appear to be non-linear in this subfigure, it is clarified that this is simply a result of the mapping of the explanatory variable (motorization) into the time axis. Finally, the bottom subfigure presents motorization rate, i.e. the evolution of the vehicle fleet at national level over time. The exact model estimation results are presented in the Appendix.

Figure 2 presents the model results for Austria, Belgium, Greece, Hungary and the Netherlands. Austria, Belgium, Greece and Hungary show the simpler pattern of an increasing trend until a maximum/breaking point is reached and a downward trend starts. The patterns and absolute numbers of the Austrian and Belgian data sets have many similarities, with the peak (of more than 30 fatalities per 100.000 population) occurring at about 230 and 245 vehicles per 1000 population respectively.

The structural break-point for Greece is observed at a motorization rate of 325 vehicles per 1000 inhabitants. It is noted that this breakpoint occurred about 20 years later than in Austria and Belgium. It is noted that –even though they correspond to a significant part of the traffic- mopeds are not included in the motorization rate for Greece (in order to maintain comparability with the data from other countries). The actual values may in fact be slightly different if one includes mopeds in the total vehicle fleet, given that mopeds appear to participate in serious injury and fatal accidents to a non-negligible extent. This is indeed a subtle point that calls for attention in cases where e.g. a generally less popular travel mode becomes rather common. Netherlands could also serve as a similar example, for the case of bicycles.

The available data for Hungary correspond to a much shorter time-span, which –however- includes the structural break-point of interest. However, the limited data (along with the “jerkiness” of the available data points) result in estimated coefficients that are not statistically significant (except for the downward slope).

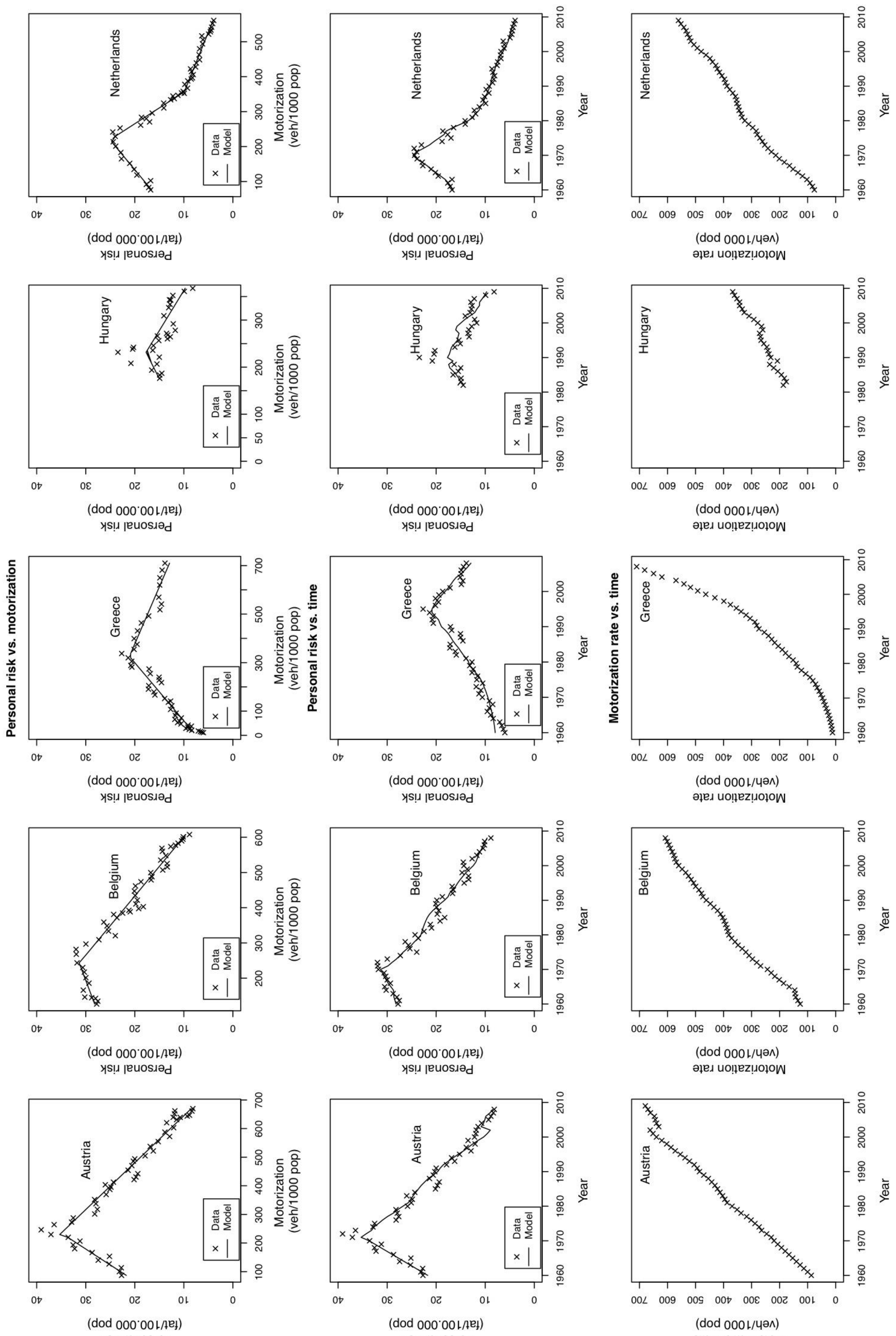

Fig. 2. Estimated model for Austria, Belgium (*using “killed on the spot” definition), Greece, Hungary and the Netherlands. Each column comprises three subfigures: Top → personal risk vs. motorization, in the middle → personal risk vs. time, bottom → motorization vs. time.

In the case of Netherlands the break point is recorded in the early 1970s. More impressively, this year corresponds to a value of motorization rate around 220 -a relatively low value compared to most other cases. The data from the Netherlands indicate that a secondary breakpoint took place when the motorization rate reached about a value of 360 (and respectively the personal risk was reduced to about 10 fatalities per 100 000 inhabitants). The rate of decrease of personal risk changed after that point (was almost halved). This is an interesting and intuitive finding: as personal risk becomes lower, there is less “room” for improvement. It is possible that as the personal risk in the other countries also decreases, then its rate of decrease may change. As stated by several researchers (e.g. Lassarre, 2001; Page, 2001), each basic road safety-related measure reasonably contributes to notable improvement in the early stages of its introduction, fading out as the system reaches a new equilibrium.

Figure 3 presents the estimated models for the Czech Republic, Poland and Spain, which exhibit more elaborate patterns. Data from the Czech Republic reveal two clear consecutive peaks and a total of three breakpoints. Personal risk is increasing from very low motorization levels and the first break-point appears for a motorization rate of about 155 vehicles per 1000 inhabitants. After that point, personal risk decreases with motorization, until a threshold of 275 vehicles per 1000 inhabitants is reached, when personal risk starts to increase again. After another critical value of 320 vehicles per 1000 inhabitants, personal risk starts to decrease again, albeit at a lower rate. This complex image could be related to the change that occurred in the political regime at some point. Personal risk at country level started picking up again in the second half of the 80s, even more rapidly than in early years. The data for Poland reveal a similar pattern, with two peaks occurring at about 125 and 200 vehicles per 1000 population and a minimum at 185 vehicles per 1000 population.

After careful examination of the data points, two alternative models have been developed for Spain: one parsimonious (revealing one single break point, while being less sensitive to the other fluctuations), and one involving several breakpoints, in an attempt to more closely reflect the data. The former, simpler model captures the overall trends and breakpoint, and is in principle consistent with the models developed for the previous countries (with the main breakpoint observed at a motorization rate of approximately 365 vehicles per 1000 population); however, it does not capture some subtle patterns and local phenomena. The latter may be more accurate in mathematical terms, but it is much more complicated to interpret in a meaningful way. Therefore, it has to be examined in a more complete manner, presumably in parallel with the history of major national road safety-related programmes or specific measures, and possibly other socioeconomic developments.

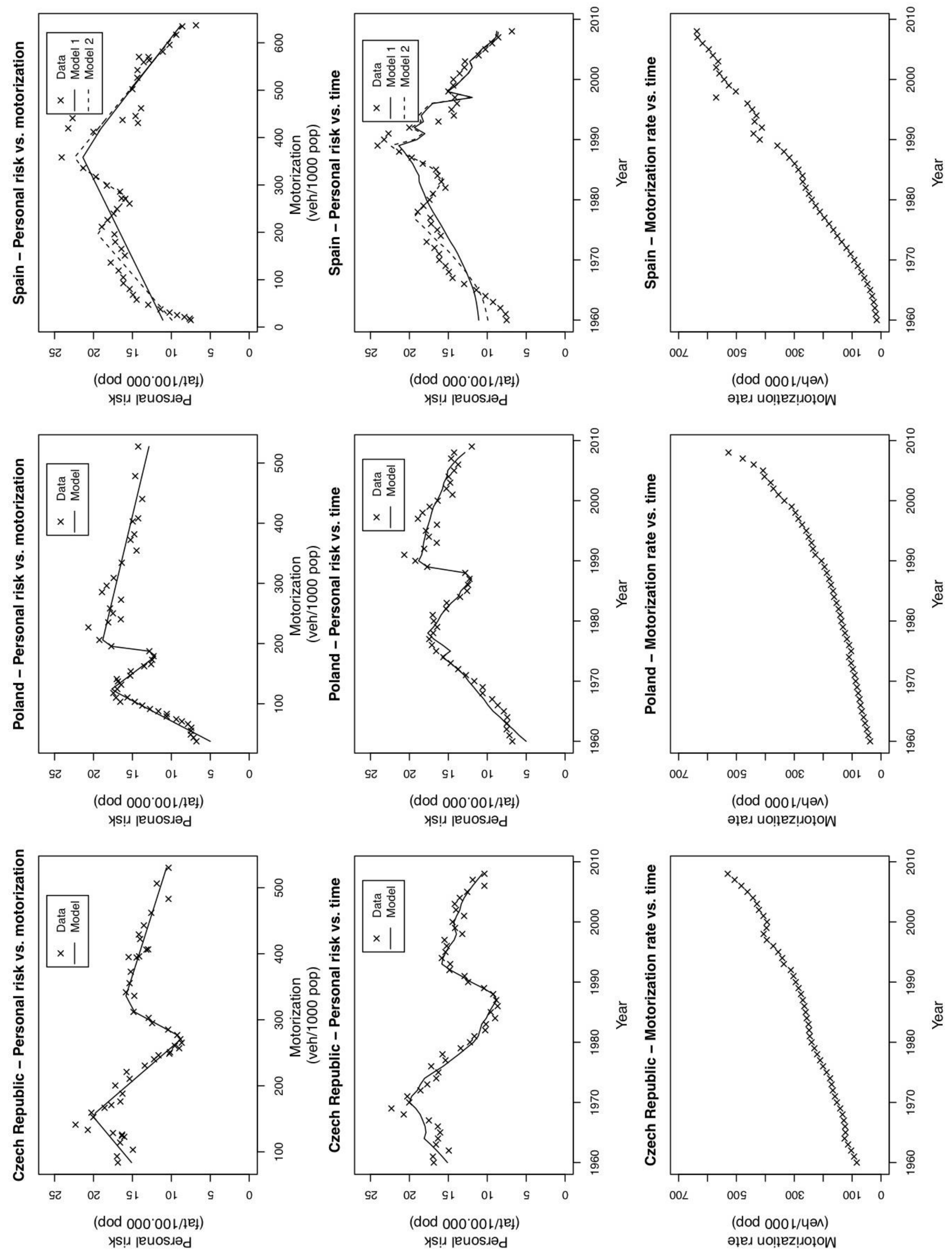

Fig. 3. Estimated models for the Czech Republic, Poland and Spain. Each column comprises three subfigures: Top → personal risk vs. motorization, in the middle → personal risk vs. time, bottom → motorization vs. time.

5. Discussion

In this paper, the trends of road traffic fatalities in several EU countries have been examined given the evolution of basic socioeconomic indicators, namely motorised vehicle fleet and population, at country level. Simultaneous estimation of piece-wise linear regression functions was selected for this analysis by means of the segmented package of the R software. The motorization rate, i.e. the number of vehicles per 1000 inhabitants, has been selected as independent variable, since it incorporates both parameters of interest (vehicles and population).

Figure 4 summarizes all estimated models, providing a concise overview that can be used to draw conclusions, including the following:

- Different countries reached specific motorization rates at different (and sometimes distant) moments in time (temporal landmarks);
- Some of those countries exhibit a break point within a narrow range of motorization rate values, implying perhaps similar social and economic conditions and/or similar road safety culture;
- This range is different for certain subgroups among the examined countries, providing a hint that some grouping may be of meaning in geographic and socioeconomic context.

Before strong conclusions can be drawn based on the interpretation of the obtained results, several considerations must be made to ensure that the models are indeed directly comparable, e.g. the data definition across countries. The nominator of the motorization rate (fatalities), for example, may be regarded more or less well-defined, after many efforts put at pan-European level for a common definition (30-day fatalities). As far as the denominator is concerned, however, available data of vehicle fleet show some slight discrepancies, e.g. the total number of vehicles in Spain reveals some irregular steps for specific years. Furthermore, each vehicle class is ruled by specific particularities, presumably implying a camouflage for systematic errors (Katsochis et al., 2006). The application of common definitions should be further examined, so that there is an as-common-as-possible base for comparison.

This effort should be followed by similar groupings involving specific vehicle types and population subsets (age groups or gender). It will then be much easier to distinguish cases and consider the presence of true impact due to GDP, vehicle fleet or other growth-related parameters; so, it is not advised to neglect the study of such elementary indicators, especially when difficulties are encountered in the reliability of more exposure-oriented analyses (e.g. using vehicle-kilometres travelled).

Furthermore, such a course of work will allow facilitating to a larger extent the results obtained from other analyses. For instance, Eksler et al. (2008) studied data from 25 EU member states and concluded that, on average, a 10% increase in population density is linked to a 3.2% decrease in road fatalities. It would be interesting to have an estimate of this effect’s part to be appointed to vehicle fleet-related trends, as densely populated areas often tend to develop in a varying manner.

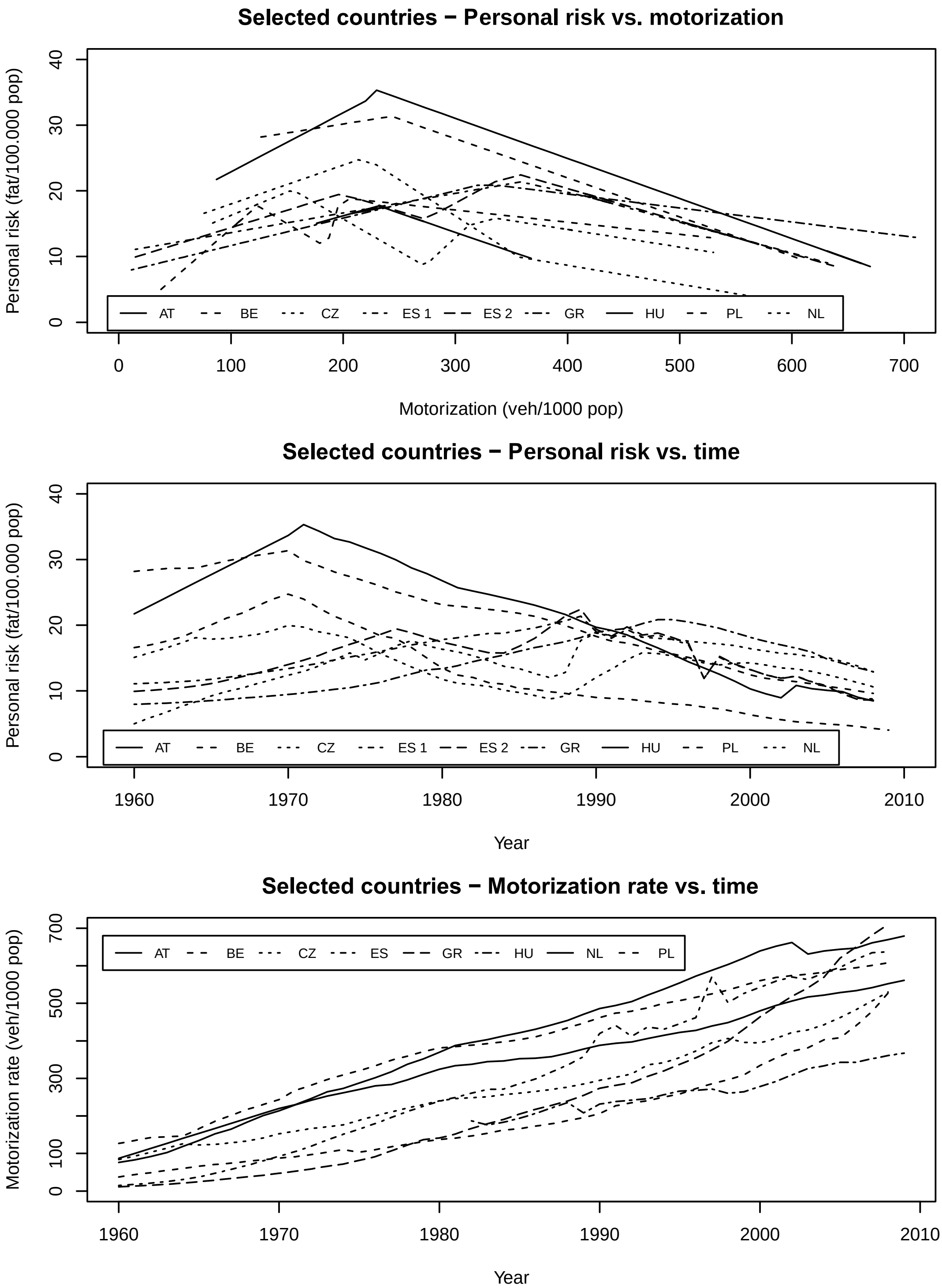

Fig. 4. All estimated models. Three subfigures: Top → personal risk vs. motorization, in the middle → personal risk vs. time, bottom: motorization vs. time.

Motorization rate is only one of the primary indices that can be used for analyses such as the one presented in this paper. Recent research has provided insight into how urban sprawl can be a risk factor in road traffic fatalities (Ewing et al., 2003), how oil prices can affect vehicle travel and therefore traffic safety (Sivak, 2008), how per capita traffic fatalities decline as public transit and non-motorized travel activity (Litman, 2006) or mild transport modes (walking and biking) (Jacobsen, 2003) increase. Incorporating all these parameters into the analysis of macroscopic trends would be an interesting exercise. However, it would also restrict the applicability of the resulting methodology only to situations where all this data is available.

The present analysis, on the other hand, can essentially be performed for any region or country, as it has rather modest data requirements. More specifically, the proposed method may allow for a straightforward identification of macroscopic trends and breakpoints and their association to specific basic temporal or socioeconomic thresholds. Existing studies adequately support a general pattern according to which personal risk initially increases and then decreases with motorization.

Nevertheless, although the estimated thresholds of motorization rate and personal risk, on which the breakpoints are situated, are quite consistent overall, the results for the examined EU countries suggest that positive or negative deviations from this pattern may be observed. For example, an improved picture is observed in the Netherlands, corresponding to a more timely action plan towards the road safety problem, not allowing the maximum personal risk observed in other countries to be experienced there. On the other hand, socioeconomic developments in the Czech Republic resulted in a recurrence of the road safety problem while at a decreasing trend, making the general pattern to be experienced twice. These findings could be particularly useful for analyzing similar situations, especially in countries or regions where a breakpoint has not occurred yet (e.g. in developing countries).

Appendix. Model estimation results

	Austria model output		Belgium model output		Greece model output		Hungary model output		Netherlands model output	
Estimated Break-Point(s):										
Notation	*Estimate*	*Std. Error*	*Estimate*	*Std. Error*	*Estimate*	*Std. Error*	*Estimate*	*Std. Error*	*Estimate*	*Std. Error*
Break point 1	228.6	8.05	246.4	11.71	325.8	12.07	231.4	22.74	219.4	3.71
Break point 2									356.7	5.36
Meaningful coefficients of the linear terms:										
Notation	*Estimate*	*t value*	*Estimate*	*t value*	*Estimate*	*t value*	*Estimate*	*t value*	*Estimate*	*t value*
(Intercept)	13.93	7.07	24.75	12.72	7.49	21.89	6.52	0.549	12.09	16.68
Slope 1	0.089	7.25	0.027	2.52	0.042	19.76	0.04	0.802	0.06	11.9
Slope 2 - slope 1	-0.151	-12.02	-0.087	-7.87	-0.063	-18.19	-0.1	-1.744	-0.17	-24.91
Slope 3 - slope 2									0.08	15.48
Null deviance:	3406.36 on 48 degrees of freedom		2441.84 on 48 degrees of freedom		925.0 on 45 degrees of freedom		296.45 on 27 degrees of freedom		2066.7 on 49 degrees of freedom	
Residual deviance:	133.97 on 45 degrees of freedom		89.614 on 45 degrees of freedom		61.2 on 42 degrees of freedom		133.71 on 24 degrees of freedom		25.38 on 44 degrees of freedom	
AIC:	198.34		178.64		153.65		133.24		122	

	Model outputs for Czech Republic		Model outputs for Poland		Model outputs for Spain: A. Complex model:		Model outputs for Spain: B. Simplified model:	
Estimated Break-Point(s):								
Notation	*Estimate*	*Std. Error*	*Estimate*	*Std. Error*	*Estimate*	*Std. Error*	*Estimate*	*Std. Error*
Break point 1	154.9	5.41	123.6	3.15	197.9	20.2	365.3	19.45
Break point 2	272.6	4.48	184.9	2.17	273.4	16.62		
Break point 3	321.4	7.44	197.6	2.24	350.7	17.86		
Meaningful coefficients of the linear terms:								
Notation	*Estimate*	*t value*	*Estimate*	*t value*	*Estimate*	*t value*	*Estimate*	*t value*
(Intercept)	9.17	4.21	-0.555	-0.658	9.14	11.25	10.65	14.26
Slope 1	0.071	3.96	0.148	14.65	0.053	6.71	0.029	7.79
Slope 2 - slope 1	-0.169	-8.71	-0.251	-11.85	-0.104	-2.93	-0.077	-9.74
Slope 3 - slope 2	0.255	6.05	0.699	3.936	0.144	2.32		
Slope 4 - slope 3	-0.184	-4.39	-0.615	-3.48	-0.142	-2.75		
Null deviance:	518.7 on 48 degrees of freedom		624.03 on 48 degrees of freedom		796.6 on 48 degrees of freedom		796.6 on 48 degrees of freedom	
Residual deviance:	54.59 on 41 degrees of freedom		42.84 on 41 degrees of freedom		153.63 on 41 degrees of freedom		229.09 on 45 degrees of freedom	
AIC:	162.35		150.48		213.05		224.63	

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