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Latent risk and trend models for the evolution of annual fatality numbers in 30 European countries

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ABSTRACT

In this paper a unified methodology is presented for the modelling of the evolution of road safety in 30 European countries. For each country, annual data of the best available exposure indicator and of the number of fatalities were simultaneously analysed with the bivariate latent risk time series model. This model is based on the assumption that the amount of exposure and the number of fatalities are intrinsically related. It captures the dynamic evolution in the fatalities as the product of the dynamic evolution in two latent trends: the trend in the fatality risk and the trend in the exposure to that risk. Before applying the latent risk model to the different countries it was first investigated and tested whether the exposure indicator at hand and the fatalities in each country were in fact related at all. If they were, the latent risk model was applied to that country; if not, a univariate local linear trend model was applied to the fatalities series only, unless the latent risk time series model was found to yield better forecasts than the univariate local linear trend model. In either case, the temporal structure of the unobserved components of the optimal model was established, and structural breaks in the trends related to external events were identified and captured by adding intervention variables to the appropriate components of the model. As a final step, for each country the optimally modelled developments were projected into the future, thus yielding forecasts for the number of fatalities up to and including 2020.

1. Introduction

The temporal evolution of the number of accidents and victims (fatalities, severely injured, injured) is a major topic of interest in many road safety studies (see, e.g., COST 329, 2004; Lassarre et al., 2012; Commandeur et al., 2013). These quantities are counted on a monthly or yearly basis in all European countries. Both basic and more sophisticated statistical models have been proposed to capture these evolutions. Many models assume only a (log) linear function of time for the modelling of the number of fatalities, for instance some of the models discussed in Elvik (2010).

Accidents and their consequences in terms of victims are occurrences of failures in the road transportation system. Each time a road user makes a trip, he or she is exposed to harm with a certain probability of being involved in an accident or being killed. The number of traffic fatalities in a certain period is obviously dependent on the total exposure resulting from the amount of traffic in the traffic system in that same period. The amount of exposure determines the scale of the road safety problem and is therefore an essential factor in the assessment of road safety. Many models include some measure of traffic volume as an approximation of exposure. Frequently (e.g., Oppe, 1989, 1991) the total number of

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motor vehicle kilometres travelled is used as a measure of traffic volume, which is only an approximation of exposure (because it is based on survey data, for example). It is then used to calculate the empirical risk as the number of fatalities divided by the number of kilometres travelled.

This paper tries to overcome the limitations of previous models by considering three issues. First, it is acknowledged that the actual exposure is latent and can only be approximated by whichever measure of traffic volume is chosen. Consequent on the assumption of latent exposure, the risk derived analogous to that reported by Oppe (1989, 1991) now becomes a latent risk by definition. Second, latent exposure and the latent risk are simultaneously used for the modelling of the number of fatalities instead of in two separate steps as was done in Oppe (1989, 1991). When seeking to understand the evolution in the number of fatalities or accidents this approach makes it easier to decide whether a change is to be attributed to a change in exposure or to a change in the risk road users are exposed to. Finally, as indicated in Elvik (2010), the trends underlying the developments of the number of traffic fatalities need not be stable over time, with the consequence that modelling them as stable may yield poor in-sample predictions as well as poor forecasting results. Another aspect paramount to the analysis of data spanning an extended period of time, therefore, is that relations need not be invariant over the whole observed period. One way to handle such changes is to allow (model) parameters to be time varying as well, thus yielding improved in-sample predictions and forecasting results. The model described and applied in this paper – called the Latent Risk Time series model (Bijleveld et al., 2008; Bijleveld, 2008; COST 329, 2004) – is designed to accommodate all three of the above-mentioned properties.

The aim of the analyses presented in this paper is to obtain forecasts for the number of traffic fatalities in each of the European countries in 2020 in a similar way by means of the structural time series approach, using comparable data as much as possible. As the purpose is to provide some comparable robust forecasts to help policy makers develop long-term targets and strategies for successful road safety policies, the models are focused to the analysis of two basic components: exposure and risk, and the introduction of idiosyncratic explanatory factors has been avoided whenever possible.

In total, the results for some 30 countries are presented in this paper that are based on the work performed for the EC FP7 project DaCoTA (see Martensen and Dupont, 2010; Dupont and Martensen, 2012; Lassarre et al., 2012).

The use of the homogeneous modelling technique allows to compare the past and future developments of the various countries and to address the following important questions:

- Has there been a continuous, smooth development of road safety or were there abrupt changes in these developments?
- If there were changes, can these be attributed to changes in the risk, or rather to changes in exposure?
- Where does the past development tend to (if continued)?

This last issue is particularly important for the setting of realistic road safety targets by policy makers. The European Commission has set the target to halve the number of road deaths in 2020 as compared to 2010.

2. Methodology

One of the most important outcomes of road safety – quantified as the number of fatalities – is a joint function of the "level of dangerousness" of the traffic system, or road *risk*, and of the extent in which road users are confronted with this risk, here defined as the *exposure* to risk. This framework, where the fatality trend is decomposed into a risk and exposure trend, was made popular by Oppe (1989, 1991). This decomposition implies that two series of observations have to be analysed in parallel in order to model the development of road safety: one for the road safety indicator, the other for the exposure indicator. In the models presented here, the number of fatalities is the road safety indicator. The indicator for exposure is related to traffic volume and either the number of vehicle kilometres travelled or the size of the vehicle fleet can be used, depending on the availability of mobility data in the different European countries.

The assumption that the development in traffic safety is the product of the respective developments in exposure and risk can be summarised as follows:

$$\begin{aligned} &\mathit{Vehicle\ kilometres} = \mathit{Exposure} \\ &\mathit{Fatalities} = \mathit{Exposure} \times \mathit{Risk} \end{aligned} \tag{1}$$

Except for the time dependent specification, these two equations define the Latent Risk Time series model (LRT). In the LRT model both traffic volume and fatalities are treated as dependent variables. *Traffic volume* is modelled as a measure of "*exposure*" which can be subject to error. The number of fatalities, on the other hand, is defined as the product of "*exposure*" and "*risk*" and is also subject to random variation. Traffic volume and the number of fatalities are considered to be the *manifest* counterparts of "exposure" and "exposure times risk", respectively, where "exposure" and "risk" are treated as *latent* (i.e., *unobserved*) *variables.* By taking the logarithm of the two equations in (1) (thus turning the multiplicative model into an additive one), and adding an error term (also known as a disturbance term) to the latent variables, we obtain:

$$\begin{aligned} &\log(\mathit{Traffic\ Volume}) = \log(\mathit{Exposure}) + \mathit{error}(\mathit{Exposure}) \\ &\log(\mathit{Fatalities}) = \log(\mathit{Exposure}) + \log(\mathit{Risk}) + \mathit{error}(\mathit{Fatalities}) \end{aligned} \tag{2}$$

This implies that the disturbances in the original model formulation (1) should also be considered a multiplicative variable. This may seem a questionable assumption. One should note, however, that the additive Gaussian noise model (with constant variance) might not be appropriate for fatality count data, and possibly even not for traffic volume data. The implicit assumption of multiplicative errors is actually quite commonly applied, if only for practical reasons, as it substantially simplifies modelling.

Because the equations in (2) define the way in which the latent variables exposure and risk can be inferred from the observations, they are called the *measurement* equations. When observed over time, these equations can therefore be interpreted as a decomposition of an observed time series (e.g., $\log(\mathit{Traffic\ Volume}_t)$) into a trend, which is the latent variable $\log(\mathit{Exposure}_t)$, and an error term, which is then also known as an irregular component (the error term $\mathit{error}(\mathit{Exposure}_t)$).

As can be seen in (2), the $\log(\mathit{Exposure})$ is present in both measurement equations. There is a trend in this bivariate process, which depends in both equations on the exposure plus a specific trend related to the risk for the number of fatalities.

In order to specify the dynamics of the model, two linear state equations are introduced for each of the latent variables $\log(\mathit{Exposure})$ and $\log(\mathit{Risk})$ in addition to the measurement equations in (2).

One of these state equations is called the level equation, and the other the slope equation. The equations are linear, and define that the slope component at a certain time point is equal to the slope component at the previous time point plus some additive random disturbance, while the level at a certain time point is equal to the level at the previous time point plus the slope at the previous time point plus some additive random disturbance. In the absence of any random disturbance, this means that the level follows a straight