Safety trends in EU Member States: is there a learning pattern across nations?

Attila Borsos, Ph.D.*
Szechenyi Istvan University
Department of Transport Infrastructure and Water Resources Engineering
Egyetem ter 1, Gyor, 9026, Hungary
Voice +36-96-613-634
E-mail borsosa@sze.hu

Haneen Farah, Ph.D.
Delft University of Technology
Department of Transport and Planning
Stevinweg 1 2628 CN Delft
Voice +31 15 27 84301
E-mail H.Farah@tudelft.nl

Marjan Hagenzieker, Ph.D.
Delft University of Technology
Department of Transport and Planning
Stevinweg 1 2628 CN Delft
Voice +31 15 27 86374
E-mail m.p.hagenzieker@tudelft.nl

*Corresponding author

Submission date: August, 2020

Submitted for presentation at ISHGD 2020

Word count: 6846 + 9 figures × 0 + 1 table × 250 = 7096 total

ABSTRACT

It is generally accepted that the road safety trend of a country is influenced by many factors related to the infrastructure, vehicles, health care etc. Nevertheless, road safety improvement is also a result of a learning process, which can come at an individual and a societal level, according to the current available literature. The former is due to the relationship between exposure (number of events an individual experiences) and risk of road accidents, and the latter is due to the learning process in the society.

The authors argue that the long-term improvement in safety does not only happen through individual and societal (i.e., within society) learning, but also through a third dimension which is the learning process across nations (i.e., in between societies). In this paper we attempt to capture this phenomenon in two ways using data for the EU Member States.

We first analyze countries' progress in safety improvement in relation to their motorization level. Then we use panel regression to investigate whether the Human Development Index (HDI) as a measure of knowledge is a better predictor of safety instead of exposure measures (like car ownership level). The results show that for many countries lagging behind both in motorization and safety it took less time to converge in terms of safety than in motorization level. We also found that the HDI is overall a better predictor. While a few countries are already getting close to the saturation point in their motorization, an alternative knowledge-based predictor is needed for these countries to better describe trends in mortality rate.

Keywords: road safety trends, learning pattern, knowledge transfer, motorization, EU

INTRODUCTION

Road safety has a considerable impact on our society. According to the latest WHO report 1.35 million people died in 2016 in road accidents worldwide (WHO, 2018). There is an increasing global concern for road safety - it is placed at the top of the agenda not only in developed but also in developing countries. The European Union, which had approximately 25,000 fatalities in 2017 (EC, 2017), is also striving for radically improving its traffic safety. Since 2001 two White Papers (EC, 2001; EC, 2011) were published with similar objectives of halving the number of road fatalities within ten years and recently new strategies have been adopted to reach Vision Zero (EC, 2019).

Analyzing road safety trends plays an important role in knowing what we can learn from the past (and from others), where we are, and where we are heading to. These analyses have attracted a lot of attention ever since the first accident databases were created and were manifested in several forms: cross-sectional, time series studies or more complex models seeking for the best set of predictors to find the main influencers of safety. According to Al-Haji (2007) these can also be called as first, second or third generation models.

Macroscopic trend analysis gained popularity after Smeed (1949) published his formula for predicting road deaths by relating traffic fatalities to motor vehicle registrations and population. His model has been revisited by many authors (for instance Oppe, 1991a; Oppe 1991b; Adams, 1987; Andreassen, 1985; Broughton, 1988; Borsos et al., 2012), and the conclusions from these studies are twofold:

1) As for the relationship between the fatalities per motorization and motorization rate: the increase in the level of motorization leads to a decrease in the fatalities per vehicle.
2) As for the relationship between the mortality (fatalities per population) and motorization rate: the increase in the level of motorization first leads to an increase in the mortality rate but after a certain motorization level the declining trend changes into a long-term improvement phase. The existence of these three phases (declining, turning and long-term development) are statistically proven by Borsos et al. (2012) who developed a model in which mortality rate (D/P: fatalities per population) can be described by motorization rate (N/P: registered vehicles per population) using an equation: $D/P = a \times N/P \times e^{-b \cdot N/P}$, where a and b are coefficients to be estimated. This model has been validated by other researchers (e.g. Huang et al., 2016; Wang et al., 2018; Tsuboi and Yoshimi, 2018). In the declining phase the increasing fatality rate per population dominates due to growing traffic volume (described by the $a \times N/P$ term). In the turning phase the economic performance makes the change to an improving safety possible, if there is adequate social and political will. In the long-lasting improvement phase described by a negative exponential term ($e^{-b \cdot N/P}$) the pace of economic and technological development as well as the change in social attitude (e.g. acceptance of restrictive measures) is higher than the further growth in traffic volume. This also implies that the improvement slows down as the motorization further increases, in other words, the room for improvement shrinks.

Later authors tended to set up more complex models with the intention to identify the driving forces behind road safety trends. The list of these explanatory variables seems to be long. Page (2001) for instance provided a list of possible variables (over 40) and grouped them according to their nature (vehicle fleet, routes, exposure, population, meteorology, traffic safety, economics, others). Out of these, a few standard predictors turned out to be significant in statistical models, such as passenger cars per population, vehicle kilometers traveled and the Human Development Index (in for instance Page, 2001; Bester, 2001; Ahangari et al., 2014). Including other predictors is often limited by data availability, or statistical constraints such as multicollinearity.

In order to tackle the problem of predictor selection, more comprehensive frameworks were proposed in the form of road safety indices, which were constructed by finding the key indicators, normalizing, weighting and combining them into an index. Again, these indices use different sets of indicators. Al-Haji (2007) created the road safety development index (RSDI), which consists of system performance (e.g. age of cars, motorway length, education, health, GNP, HDI), human performance (e.g. safety belt and helmet use) and product performance (e.g. traffic risk, personal risk) indicators. Hermans et al. (2008) developed a road safety performance index using several indicators (alcohol and drugs, protective system, speed, visibility, vehicle, infrastructure, and trauma care), tested different weighting approaches and concluded that these approaches lead to different ranking of countries. The SUNflower project Wegman et al. (2008) also developed a composite index (SUNflower index) using three sets of indicators (road safety, policy and implementation performance indicators).

A few authors also referred to the learning process, which is related to the evolution of safety over time, as an interesting phenomenon influencing safety trends. This learning process can come at an individual and at a societal level (Adams, 1987; Elvik, 2015; Elvik, 2017; Jamroz et al., 2019).

As for the *individual learning* and looking at the relationship between exposure and risk of road accidents, several researchers found a negative relationship between the annual distance driven and accident rate (for instance Alvarez and Fierro, 2008; Langford et al., 2006; Hakamies-Blomqvist et al., 2002). Elvik (2015) further elaborated on this and argued that indeed there is a learning curve as road users learn from previous events how to prevent future events from developing into accidents, so there is a negative relationship between exposure (number of events, such as trips, experienced by an individual) and risk (the number of accidents per unit of exposure). He also proposed that perfect learning can be described by a hyperbolic risk function, i.e. a hyperbolic curve having exposure (number of events) as abscissa and accident rate per event as ordinate. In other words, if the rate of accidents is plotted as a function of the number of encounters (number of accidents divided by number of encounters), it will slope downwards.

As for the *societal learning* already in 1987 Adams suggested that the long-term decline in death rates is attributable to a learning process in the society. In other words, even if the motorization level increases resulting in more exposure the society as a whole is able to improve safety through learning over time. Oppe and Koornstra (1990) also argued that “the decrease in fatality rates over the years is assumed to be the result of a collective learning process for the entire nation".

Time as a dimension plays an important role in two aspects. The way society learns over time is a result of knowledge that was gathered and passed on to successive generations, showing an evolutionary pattern. Elvik in his paper (2017) raised an interesting question, whether evolutionary theory can explain the development of knowledge about the level of safety. There are two key elements of evolutionary theory, learning-by-doing and trial-and-error. The former refers to an improvement in safety due to the repetitive nature of for instance how the driving task is performed. Learning-by-doing may lead to trial-and-error, which is the purposeful search for improvements (Elvik, 2017).

Another aspect of time as a dimension is the time instant we consider as a reference point, and at that particular time instant where other societies (countries) are positioned. Koren and Borsos (2018) attempted to investigate this, and concluded that countries reaching a certain motorization level later in time can improve their safety at a quicker pace. This is due to many aspects, variables that were already mentioned before, such as better infrastructure, safer cars, improved health care, etc. At the same time there is also a transfer of knowledge that countries can pass onto each other, in other words, developing countries can benefit from the experience of the developed countries (Jamroz et al., 2019). If we investigate road safety trends of EU countries, it is clearly visible from Figure 1 that the long-term trends in the mortality rate of individual countries converge to each other and the differences between countries are gradually shrinking (difference between the worst and best mortality rate on the far-left vs. on the far-right side of the chart). The SunFlowerNext project report (Wegman et al., 2008) also highlighted that learning in between EU nations actually exists and can be facilitated in the form of benchmarking, for instance by analyzing the individual components of composite indicators pinpointing potential areas of improvement. From these results one can identify, understand and adapt best practices from well-performing countries.

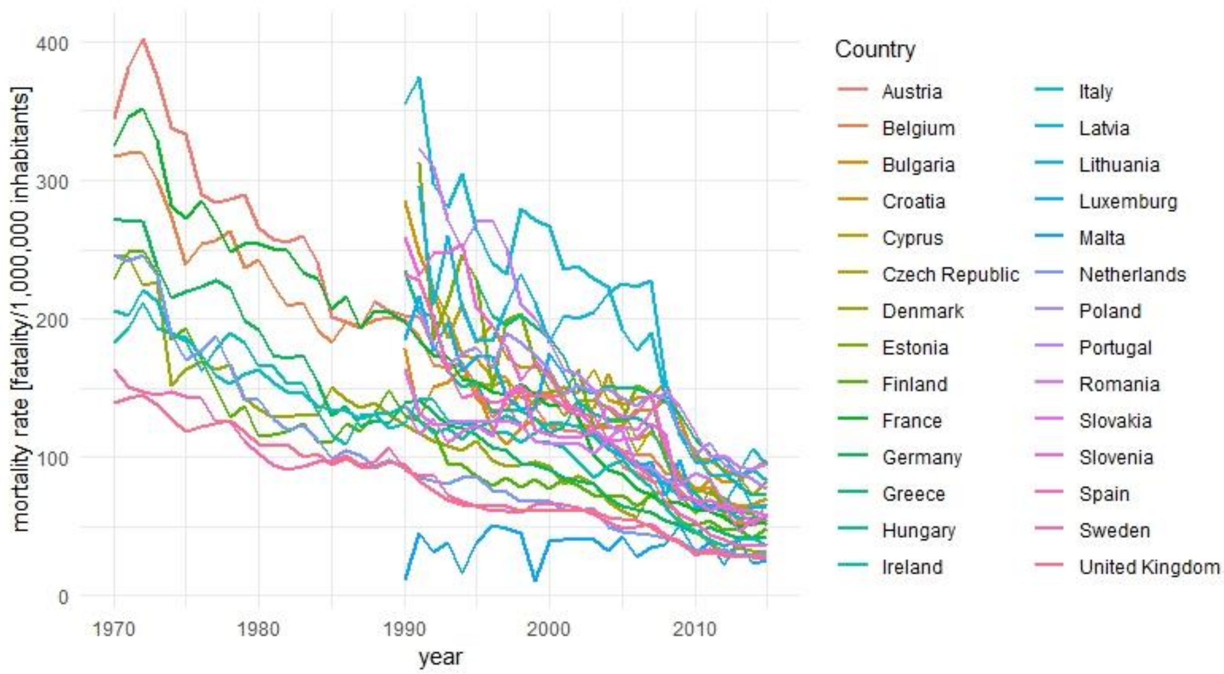

FIGURE 1 Mortality rate over time in the EU28

The above reasoning leads us to argue that the long-term improvement in safety does not only happen through individual and societal (within society) learning, but there is also a *learning process across nations* (in between societies) in which time as a dimension plays an important role. In relation to that this paper attempts to answer two research questions:

- What kind of differences are there in between countries regarding the speed of their improvement in safety in relation to their motorization level?
- What learning pattern can we identify across nations, if there is any?

DATA COLLECTION

Data of motorization and mortality rate were collected from several sources for two reasons: 1) filling missing data; and 2) cross-checking the same data that stem from different databases. The primary source for motorization and mortality rate was the European Commission's Statistical Pocketbook (EC, 2017), which provided data for years 1970, 1980, and 1990 onwards. The evolution of motorization level shows a clear upward – in most cases – linear trend, missing data points in between 1970 and 1980 as well as between 1980 and 1990 were thus calculated using linear interpolation. As for the mortality rate the IRTAD database (International Road Traffic and Accident Database) provided earlier data for several countries (Belgium, Denmark, Germany, Ireland, France, Italy, Netherlands, Austria, Finland, Sweden and United Kingdom).

Fatalities data refer to the 30-day definition of fatality, that is, a person dying within 30 days of the crash. Motorization level can be interpreted in several ways, it can be purely based on passenger cars, or include heavy vehicles, motorized two-wheelers etc. In this paper passenger vehicles will be only used, because the number of passenger vehicles in a country is assumed to be a more accurate reflection of the mobility of a population than vehicle ownership (Bester, 2001), (and also because of data accuracy issues for vehicle types other than passenger cars). In this paper motorization is used as a means of exposure. In general vehicle kilometers traveled would be a better predictor for that, however it is either not available (especially when it comes to long time series data) or inaccurate. The Human Development Index time series data come from the UN database (UN, 2019).

ANALYZING THE DELAY AND ADVANCE

This section addresses the first research question investigating what delay or advance in motorization and safety countries have within the EU in comparison with others. EU Member States can be grouped in several ways, however for the purpose of the present study the most plausible way of grouping them is into old and new Member States. Countries who founded and joined the EU before 1995 (Belgium, France, Germany, Italy, Luxembourg, Netherlands, Denmark, Ireland, United Kingdom, Greece, Portugal, Spain, Austria, Finland and Sweden) will be referred to as old Member States or EU15 and the ones joining the EU after 2004 (Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria, Romania, Croatia) will be referred to as new Member States or EU13.

By plotting time series data of mortality rate vs. motorization level (Figure 2) for these two clusters one can observe the following:

- There is an improving safety trend (the downward trend means fewer deaths per population), even though motorization is increasing.
- Old Member States had a slightly steeper trend after they reached 450 passenger cars per 1000 population at the turn of the century. That is due to the increase in motorization slowing down.
- Without considering motorization level New Member States are still worse in safety as the average mortality rate of EU15 and EU13 in 2015 were approximately 44 and 78, respectively (last data points in Figure 2).
- Taking into account motorization levels, new Member States are performing better, since for the same car ownership level they show a lower mortality rate than old Member States.

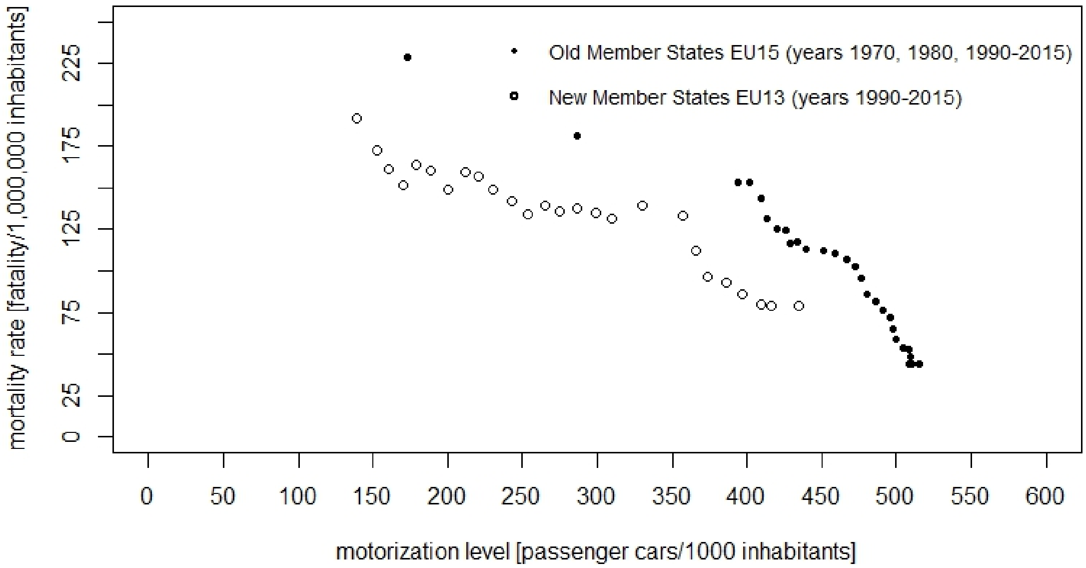

FIGURE 2 Motorization level vs. mortality rate in the EU15 and EU13 over time

The last statement in this list can be simply interpreted as those countries reaching a given motorization level later in time can show a better safety level, which we might call the advantage of latecomers. This was investigated earlier (Koren and Borsos, 2012), however the analysis related to that was restricted only to one preset value for the level of motorization (200 passenger cars per thousand population) and two values of mortality rate (10 and 15 fatalities per 100.000 population). In order to more thoroughly investigate the effect of time several threshold values were chosen for both indicators (motorization and mortality rate) and the years when these values were reached for different countries were collected.

As for the motorization level, threshold values were in the range of 200 and 550 with an increment of 50. Selecting the year for which the particular value was the closest for a certain country was straightforward as motorization level is constantly increasing in most cases. There were a few exceptions with sudden jumps (presumably due to changes in the vehicle registration rules) found in the database (for example, in countries like Bulgaria, Germany, Latvia, Lithuania, Estonia), these were filtered out.

As for the mortality rate, threshold values were in the range of 150 and 50 with an increment of 20 fatalities per 10^7 population. When setting the highest threshold of 150 the guiding principle was to select a value which was relevant for all the countries, i.e. they experienced it in the time period being analyzed. As we were interested in the speed of improvement, the so-called long-lasting development phase following the tipping point was considered. The year when reaching for instance 150 fatalities per 10^7 population was considered provided it was located in that particular phase. A good example is the Greek time series data where two observation points are present for this particular value in 1980 and in 2005, the former before and the latter after the tipping point, so obviously the latter was considered. The lowest threshold value was chosen to be 50; only four countries could reach 30 (Denmark, UK, Netherlands, and Sweden) and thus this threshold value was not used in the analysis. There were countries which had a clear trend and for them the selection of year when reaching a given value was straightforward. However, year selection was more complicated for certain countries due to fluctuations. In order to find the most appropriate year for reaching a given mortality rate, regression lines were fitted in these cases. These were either simple linear (for eight countries) or linear regressions with logarithmic transformation (for five countries). The selection of the trend line depended on the goodness-of-fit, the one with a better coefficient of determination was chosen. The type of regression used might slightly influence the later comparisons, nevertheless the aim was to approximate the years of reaching certain thresholds as good as possible. In certain cases (Romania is a typical example) this was simply not possible due to hectic changes in the mortality rate. Malta was removed from the analysis due to its low magnitude and random fluctuations being present in its mortality rate.

The resulting years then were compared to the old Member States' average. In other words, the EU15 average was used as a reference point to compare each country's performance with. Picking this reference level seems to be an arbitrary choice, however the reference point itself is less important than the relative difference of individual countries. For each possible pair of mortality rate (DP) (150, …, 50) and motorization level (NP) (200, …, 550) a plot can be produced showing the delay or advance in years for individual countries in relation to the EU15 average. Two examples are given in Figure 3 and Figure 4. These two examples are such combinations that were the actual corresponding pairs for the EU15, namely in year 1990 the EU15 DP average reached 150 and NP 400, in year 2000 it reached DP 110 and NP 450.

As for the first combination (NP400 and DP150) Figure 3 shows when these levels were reached by Member States compared to when the EU15 average reached it. A delay has a negative sign, while an advance has a positive sign. Countries in the top left had a delay in motorization but an advance in mortality rate, like the UK, Denmark or the Netherlands. Romania and Slovakia are exceptions here as over time they accumulated a few years delay, rather than improving their safety. Countries in the bottom right had an advance in motorization but a delay in mortality rate, such as France or Luxemburg, which could reach a higher motorization earlier but were lagging behind the EU15 in terms of safety. The ones in the top right had an advance in both indicators, these are highly motorized and yet safe countries such as Sweden or Germany. Countries in the bottom left are the ones which had a delay in both indicators, these are mostly countries who joined the EU after 2004 (however Greece, Portugal, Spain and Belgium are outliers in that sense). What we can see from this quadrant of the graph is that in relation to the EU15 average most of these countries needed fewer years to reach 150 fatalities per million inhabitants as compared to reaching 400 passenger cars per 1000 population (a few examples: Poland 13 vs. 16 years, Czech Republic 6 vs. 15 years, Estonia 9 vs. 16 years etc.). Out of the 12 New Member States only Latvia, Lithuania and Slovenia showed an opposite pattern, their motorization rate actually increased faster than how their safety improved.

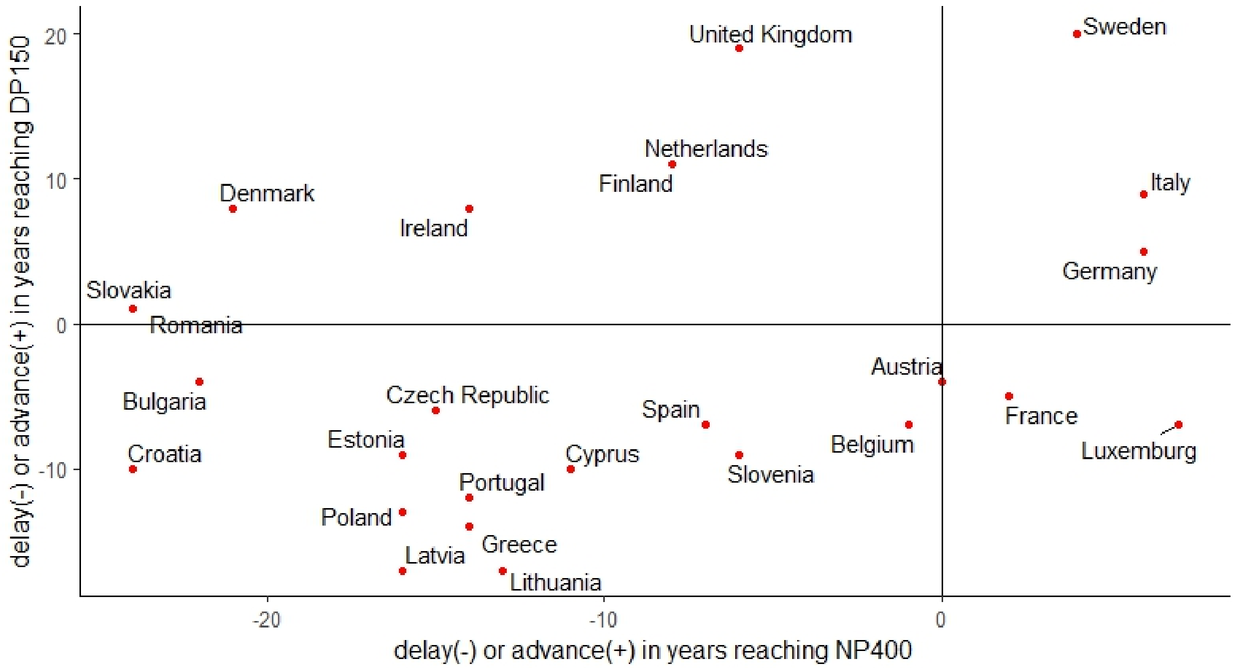

FIGURE 3 Delay or advance in years reaching NP400 (400 passenger cars per 1000 population) and DP150 (150 fatalities per 1 million population) in relation to EU15 average (A delay has a negative sign, while an advance has a positive sign.)

Figure 4 as another example for NP450 and DP110 levels illustrates that the position of countries change over time, or some countries even disappear from the chart meaning they have not reached either particular level yet. Some countries even move from one quadrant to another, like Sweden where the increase in motorization tended to slow down already at the turn of the century (around 400~450 passenger cars per 1000 population), and yet at that time it was roughly 20 years ahead of the EU15 in terms of safety.

These changes over time can also be shown in a more illustrative way by plotting both indicators for individual countries, Figure 5 and 6 show these trends for EU15 and EU12 countries, respectively. In these two graphs dots depict the motorization and circles the mortality rate, the vertical axis in years show either the delay or advance. The horizontal line at zero is again the EU15 average.

Most of the EU12 countries (Figure 5) show a delay in both indicators, however the delay in time for these individual indicators show different patterns. In general, dots are located below circles (with a few exceptions) meaning that the increase in motorization happens at a slower pace than how traffic safety improves. For most of these countries it took less time to come close to the mortality rate of the old Member States, than how much time it took them to converge in terms of motorization. Nevertheless, there seems to be convergence to the EU15 in both indicators, Romania is probably the only country where the difference in safety in relation to the EU15 average is growing.

As for the EU15 countries (Figure 6) the picture is more heterogeneous. Well performing nations such as the SUN countries (Sweden, UK, and Netherlands) – although being still the best ones – seem to be losing their many years of advance in traffic safety over time, and countries which were underperforming such as Portugal, Spain and Greece, – although still under the average – are catching up with the others. There are interesting patterns in motorization as well, the SUN countries are already slowing down in their motorization growth. The reasons behind can be that they are getting close to the saturation point as well as they tend to favor more sustainable transport solutions (for instance by promoting public transport and active modes such as cycling and walking).

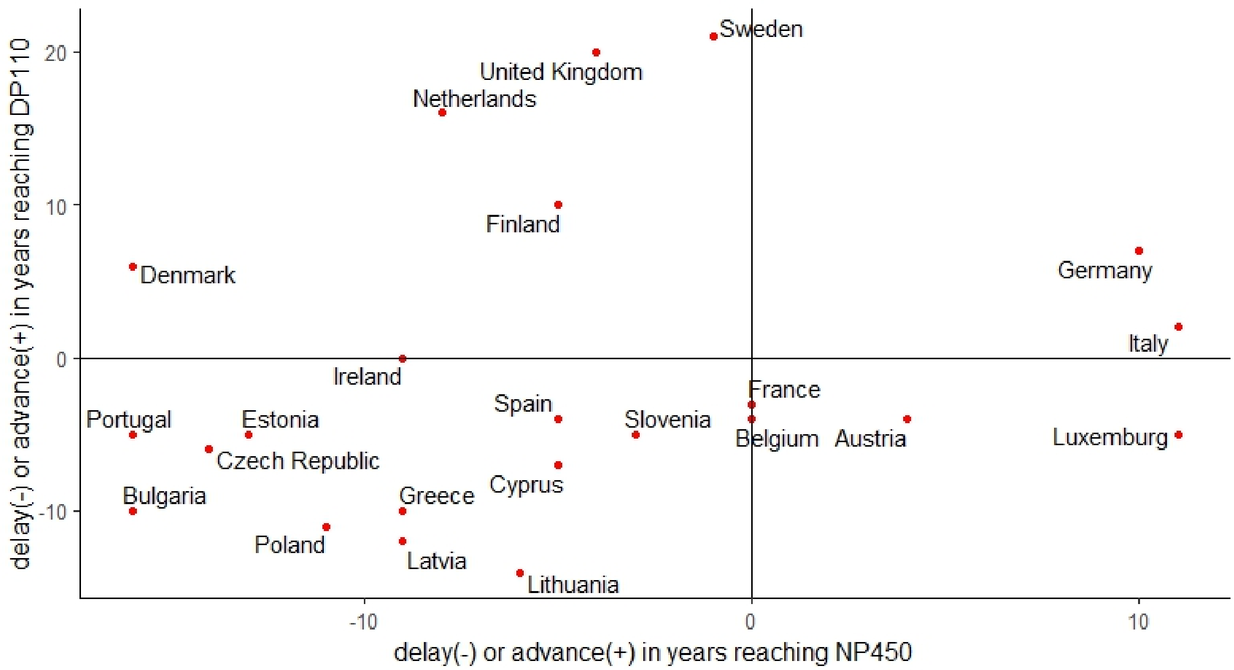

FIGURE 4 Delay or advance in years reaching NP450 (450 passenger cars per 1000 population) and DP110 (110 fatalities per 1 million population) in relation to EU15 average

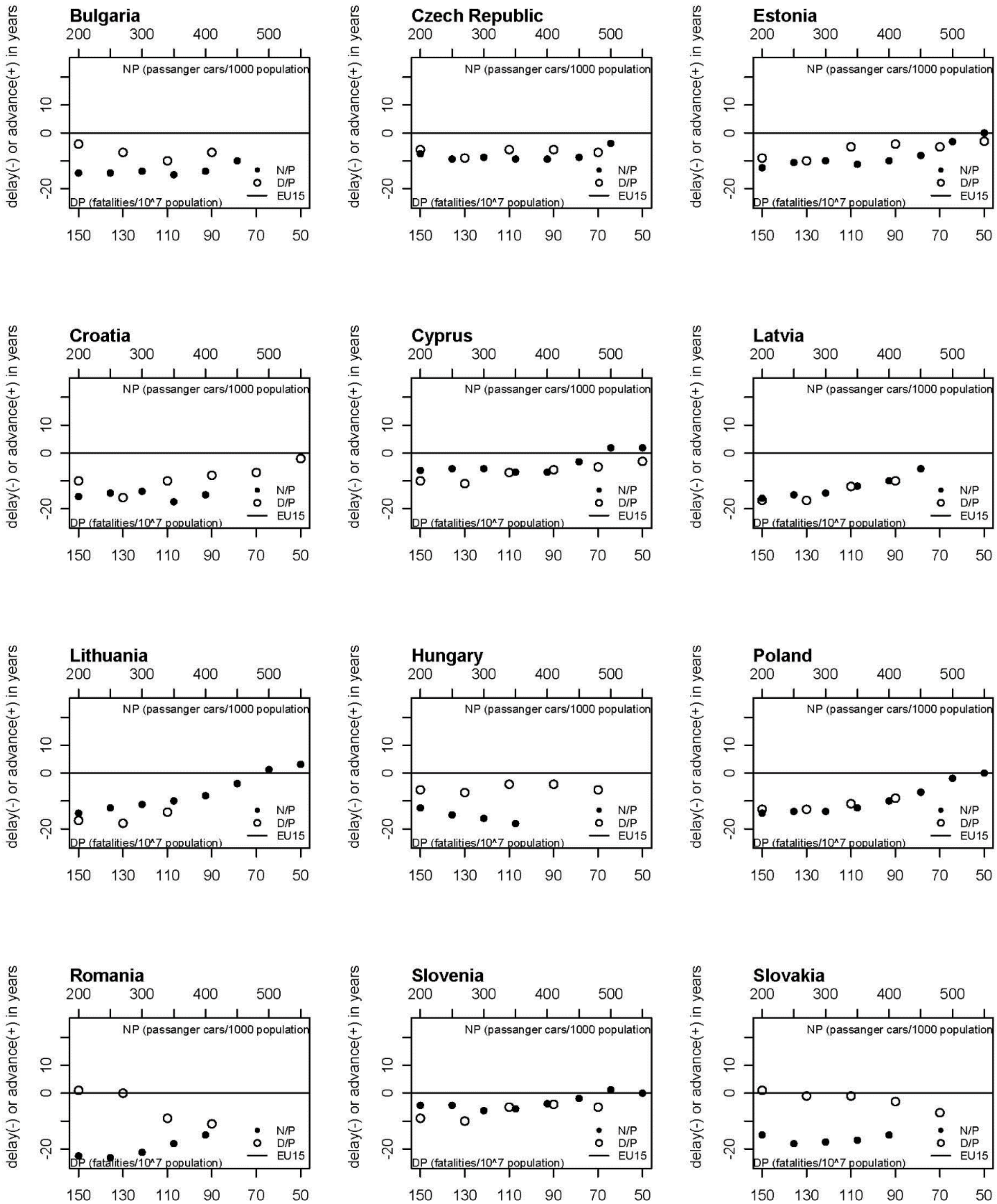

FIGURE 5 Delay and advance in years for reaching certain motorization levels and mortality rates in the EU12 compared to the EU15 average (circles depict the mortality rate and dots the motorization, the horizontal line at zero is the EU15 average).

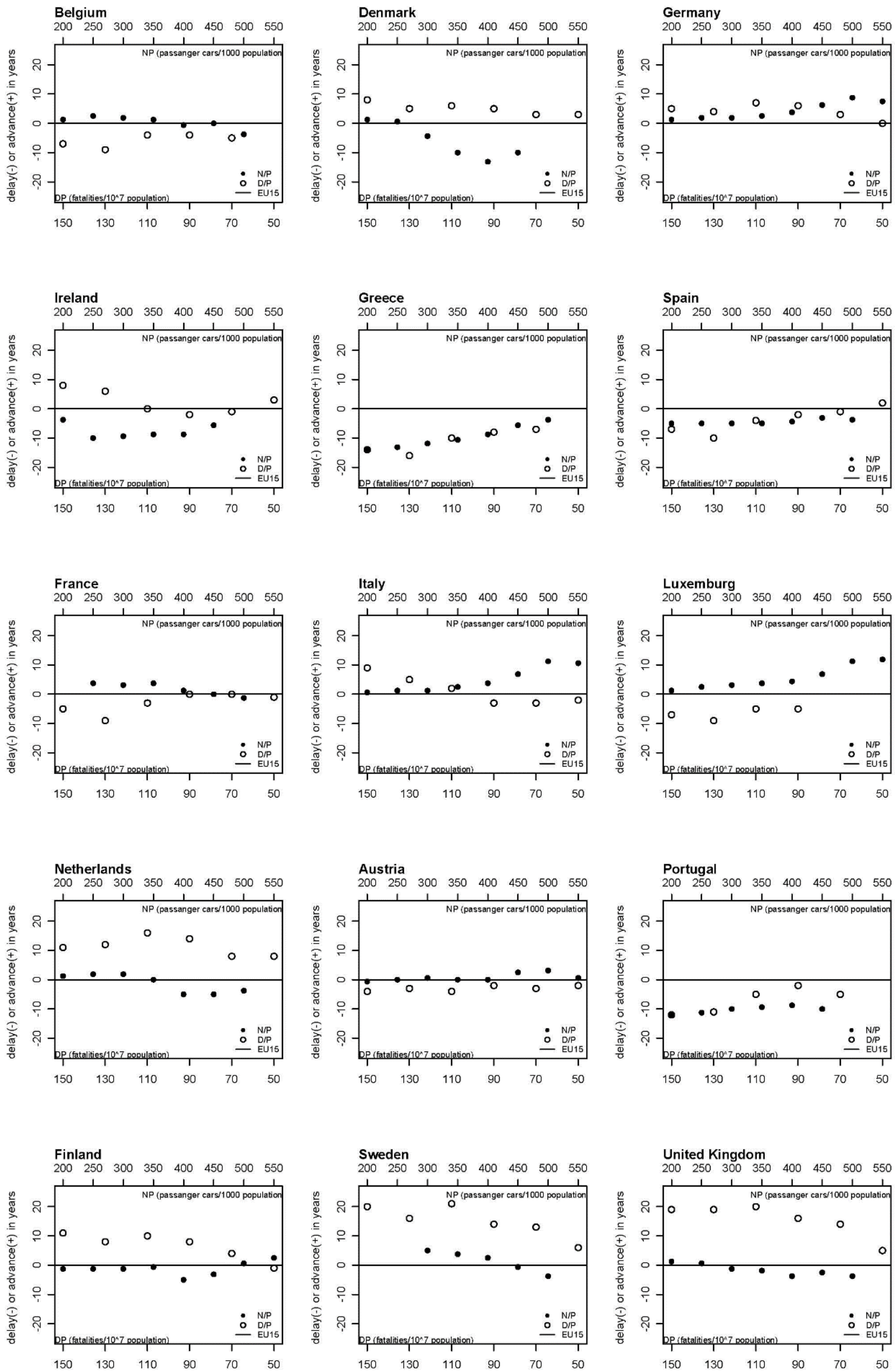
Belgium
Denmark
Germany
Ireland
Greece
Spain
France
Italy
Luxemburg
Netherlands
Austria
Portugal
Finland
Sweden
United Kingdom
NP (passanger cars/1000 population
DP (fatalities/10^7 population)
delay(-) or advance(+) in years
N/P
D/P
EU15
200 250 300 350 400 450 500 550
150 130 110 90 70 50
-20 -10 0 10 20

FIGURE 6 Delay and advance in years for reaching certain motorization levels and mortality rates in the EU15 compared to the EU15 average (circles depict the mortality rate and dots the motorization, the horizontal line at zero is the EU15 average.)

LEARNING ACROSS NATIONS

Answering the second research question is not straightforward and has to come with certain assumptions. Knowledge transfer between nations is intangible, such a variable does not exist and thus cannot be measured directly. One could claim a few plausible ideas for measuring know-how transfer between EU Member States, such as:

- Research funding received by a country in the frame of road safety related international projects.
- Intensity of collaborations in road safety between countries.
- Transfer of knowledge on new technological, design etc. solutions.
- A country's ability to receive and adopt safety related knowledge.

The above non-exhaustive list is a mere indication of aspects that are present but from a statistical modeling point of view hard to be used as predictors simply because in most cases their accurate measurement is not possible.

Let us change our perspective temporarily and look at an indicator which has people and their capabilities in the forefront. This composite indicator is the Human Development Index (HDI) measuring three dimensions of human development: a long and healthy life, being knowledgeable, and have a decent standard of living (UN, 2019). The HDI is the geometric mean of normalized indices for each of the three dimensions, the life expectancy index, education index, and the Gross National Income (GNI). This composite indicator has already been used by a few traffic safety researchers in modeling along with other predictors, however no attention was paid to its characteristics that are different from standard measures.

Even though this indicator is not the most appropriate to capture the knowledge transfer between societies, it still tells a lot about a nation's human development and also has implications on traffic safety. It is reasonable to make certain assumptions about how life expectancy and education relate to traffic safety. High life expectancy for instance could imply that life in general is considered to be greatly valued, thus saving lives from accidents is in the general mindset; a good education index suggests that a nation has the necessary intellectual values to tackle traffic safety. As for the last item representing economic power (GNI) it has to be noted, that Kopits and Copper already came to the conclusion that there is a certain income level at which traffic fatality risk first starts to decline (Kopits and Cropper, 2005).

The question now is how HDI can indirectly be used to describe whether there is a learning pattern across nations in relation to road safety. To answer this, time series data for EU27 Member States (excluding Malta) are plotted in Figure 7. The left side of this figure shows the mortality rate vs. passenger car ownership (NP), which is one of the most widely used – yet not the best – measure of exposure. The state-of-the-art approach is that there is a negative exponential learning function, that is, as motorization level increases the mortality rate decreases in a negative exponential fashion. However, if we look at individual countries, we already see that in a few cases motorization growth has slowed down significantly, this saturation in motorization can also be indirectly observed in Figure 2 from the aggregated data of the Old Member States. In other words, there is a certain motorization level above which it simply cannot be used with the same learning function to model mortality rate. Another aspect in Figure 7 is that high motorization rate still comes with a variation in the mortality rate.

The right side of Figure 7 shows the same relationship but with HDI. It is clear from this plot that at lower HDI indices there is a high variation in between countries in terms of their mortality rate, whereas higher indices lead to very small variation and low fatality figures. Also, as the index increases the mortality rate tends to further improve. In other words, the convergence between EU countries in their safety can be better explained with such an indicator rather than motorization.

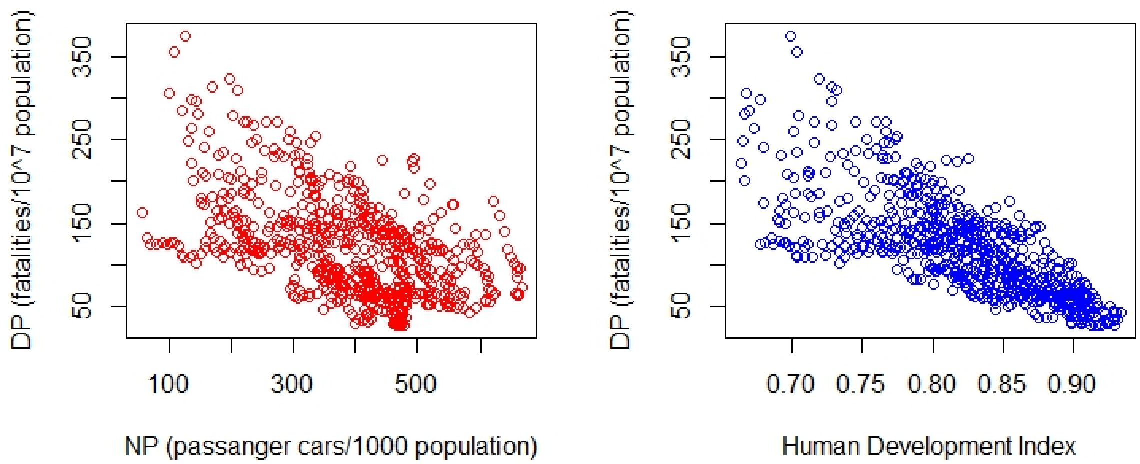

FIGURE 7 Motorization rate and Human Development Index vs. mortality rate in the EU27 between 1990 and 2015

To further investigate this, panel regression models were tested. These models combine cross-sectional and time series data and were run in R (R Core Team, 2013) using the plm package (Croissant and Millo, 2019). One of the advantages of panel models is that they are more appropriate to study complex effects which cannot be observed in cross-sectional or time series data alone. A general panel regression model is given in Equation (1):

$$y_{it} = \alpha + \beta x_{it} + u_{it} \tag{1}$$

where y is the dependent variable, α and β are coefficients and u_{it} is the error term, i and t are indices for individuals (i.e. countries) and time (i.e. years). In this general model, also called pooled regression, the intercept (α) as well as the slope (β) are constant for all individuals and time. This model can be extended in many ways. The intercept can change over countries and/or years; these are called fixed effects models (individual, time and two-ways). This is illustrated in

Equation 2 where the intercept (α) changes over individuals (i) as well as time (t) and thus is a two-way fixed-effects model.

$$y_{it} = \alpha_{it} + \beta x_{it} + u_{it} \tag{2}$$

Fixed effects models assume that unique attributes of individuals are correlated with the individual dependent variables. However, if they are not, random effects model has to be used, in which the error term has two components, one of which is the individual-specific component (μ_{it}), that is uncorrelated with the dependent variables (see Equation 3).

$$y_{it} = \alpha + \beta x_{it} + \mu_{it} + \varepsilon_{it} \tag{3}$$

This unobservable component (μ_{it}) is treated as a component of the random error term, which varies between individuals but not within individuals. The other component (ε_{it}) is the element which varies over individuals and time, also called as idiosyncratic error.

The panel regression models fitted to the data shown in Figure 7 are parsimonious models using only one descriptor at a time, either passenger car ownership (NP) or Human Development Index (HDI). At this point it has to be noted that they cannot be used in one model as their Pearson correlation is 0.80 (highly significant as p-value is $2.2e^{-16}$), moreover the aim is to compare the two indicators not to build models with several explanatory variables. As it was noted before, the negative exponential learning function is applied, therefore the logarithmic value of mortality rate is used as an independent variable.

Several tests were run before fitting the models. To decide between fixed or random effects one can run the Hausman test where the null hypothesis is that the preferred model is random effects vs. the alternative, the fixed effects. It tests whether the individual-specific error component is correlated with the dependent variable, the null hypothesis is that it is not. For all pairs of models (random vs. fixed effects) a significant result was received, therefore the null hypothesis could be rejected and random effects modeling could be discarded. This is actually in line with previous modeling efforts using panel regression for analyzing road safety trends (Ahangari et al., 2014).

The next test aimed for investigating whether adding individual and time effects to the model is significant or not. Here the fixed effects models were tested against the pooled model by means of F tests, which all yielded significant effects for both the individual as well as for time effects.

The dataset had missing values that might lead to unbalanced data. This unbalance in the data was also tested with two measures (γ and ν); these were both close to 1 (both 0.99) which indicated balanced data (Croissant and Millo, 2019), thus no further action was needed.

Three kinds of models were used: 1) pooled regression where the regression was pooled over all data points assuming that the intercept and the slope coefficients are constant over time and countries with the error term capturing the differences; 2) time-fixed effects where the intercept varies over years and the slope coefficient is constant; 3) country-fixed effects where the intercept varies over countries and the slope coefficient is constant. The modeling results are summarized in Table 1, in which the simplest pooled model and fixed effects models are shown for both NP and HDI. Country and year coefficients are not shown but the results are summarized.

TABLE 1 Selected outputs of panel regressions

Model	Passenger car ownership (NP)			Human development index (HDI)		
	Intercept	Slope	R^2	Intercept	Slope	R^2
Pooled	5.431***	-0.0020***	0.2425	9.9982***	-6.5065***	0.5991
Fixed effects (time)	year specific[1]	-0.0009***	0.5251	year specific[3]	-5.1539***	0.7029
Fixed effects (country)	country specific[2]	-0.0040***	0.7554	country specific[4]	-7.7605***	0.8131

Significance codes: * p≤0.05 **p≤0.01 ***p≤0.001

1 All years highly significant, years 1991-2000 are not significantly different from 1990, years 2001-2015 are significantly different from 1990 used as a reference level.

2 All countries highly significant, Belgium, Cyprus, Germany, Lithuania, and Slovenia are not significantly different from Austria used as a reference level.

3 All years highly significant, years 1991-2008 are not significantly different from 1990, years 2009-2015 are significantly different from 1990 used as a reference level.

4 All countries highly significant, Cyprus, France, Germany, Greece, Latvia, Lithuania, and Slovenia are not significantly different from Austria used as a reference level.

For all model pairs the HDI models outperform the NP ones, the best fit can be attributed to the individual fixed effects models. Even though the coefficient of determination is 0.81, it can be considered convincing knowing that only one predictor is used. The greatest difference can be found in the simplest pooled models. Overall, these results suggest that when exposure measures are used in panel models, due to their variation across countries and over time they are less efficient for prediction. HDI on the other hand shows less variation in relation to mortality rate, especially at higher indices.

Another explanation is that as certain countries already tend towards saturated motorization, their fatality rates can be predicted less accurately from motorization. In Figure 8 two illustrative examples are given for France and Spain. From these plots it can be seen that in both countries around 480 passenger cars per 1000 inhabitants the motorization rate stopped to grow further, and data points tend to cluster around that particular value. This also means that above this motorization level this exposure related measure cannot be further used to describe the future trends in mortality rate.

Figure 7 also shows that the increase in HDI and the decrease in fatality rate go together more consistently. The convergence in the right side of the range of HDI values implies that there is some kind of invisible force that pulls countries together, and knowledge transfer between countries is part of it. This however cannot be empirically proven from this analysis, thus more research is needed on this.

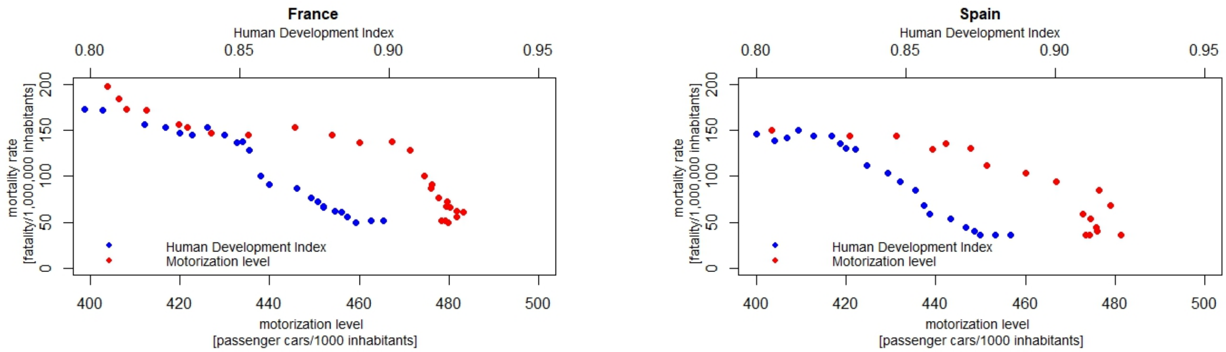

FIGURE 8 Motorization level vs. Human Development Index in relation to mortality rate (left: France, right: Spain)

DISCUSSION AND CONCLUSIONS

This research raised two questions related to the speed of road safety improvement and the presence of a learning pattern across societies. By analyzing the delay and advance in years for motorization level and mortality rate over time for EU countries we found that most of the countries joining the EU after 2004 could catch up with the old member states faster in their safety than in their motorization level. This advance is partly due to many plausible factors (infrastructure, vehicle, health care etc.), but it is also noted that there must be other, less tangible factors behind the convergence of countries in their safety level.

It was assumed that a knowledge transfer across nations, called as learning across societies is also contributing to safety improvement. To investigate this assumption the relationship of two indicators to mortality rate was analyzed through panel regression models. One indicator was a widely accepted indicator for exposure, namely motorization in terms of passenger cars per population, which now tends to reach its saturation point in some countries. The other indicator was the Human Development Index focusing on societal knowledge and economic power. The models showed that the latter gives a better prediction, especially thanks to its accuracy to predict mortality rate in the higher range of HDI indices, where the convergence of countries is more visible.

This analysis also revealed that above a certain motorization level (which is different from country to country) the number of passenger cars per population simply cannot be used to describe safety. Al-Haji (2007) raised an interesting question already ten years ago in relation to this issue: "What will happen to the expected number of fatalities if a country's trend towards full motorization is realized?" Unfortunately, the question had been left unanswered, partly because it is not a trivial one. In this paper we argued that as countries reach saturated motorization an alternative indicator has to be used. As an attempt HDI was tested and proved to be a good alternative.

The authors are aware of the fact that HDI is not the most proper indicator to analyze the presence of learning across societies. However, it is clear from this analysis that exposure-based indicators have the previously explained limitation and considering a "knowledge-based" indicator would not only be more appropriate to predict the expected number of fatalities after the saturation point in motorization but also to better describe the safety benefits of interaction between countries.

Overall three layers of learning can be identified, a schematic graph of these is given in Figure 9. An individual learning in the form of a hyperbolic curve proposed by Elvik (2015), which happens at the level of the individual road users, simply saying that the more we drive the less likely we will be involved in an accident. The second layer is the societal learning which happens at the level of a society leading to a long-term improvement after a declining phase and a turning point in the national safety trend (Borsos et al., 2012; Jamroz et al., 2019; Oppe and Koornstra, 1990). The third layer that we propose is learning across societies leading to convergence between countries who are actively cooperating or learning from each other in order to improve their traffic safety. This cooperation can be seen in several domains, for instance in the professional activity of international organizations such as CEDR Conference of European Directors of Road, and ETSC European Transport Safety Council; or in common European traffic safety related projects; or in inter-governmental agreements (for instance the Partners for Roads program which helped Hungary to set up Road Safety Audits with the help of Dutch experts fifteen years ago).

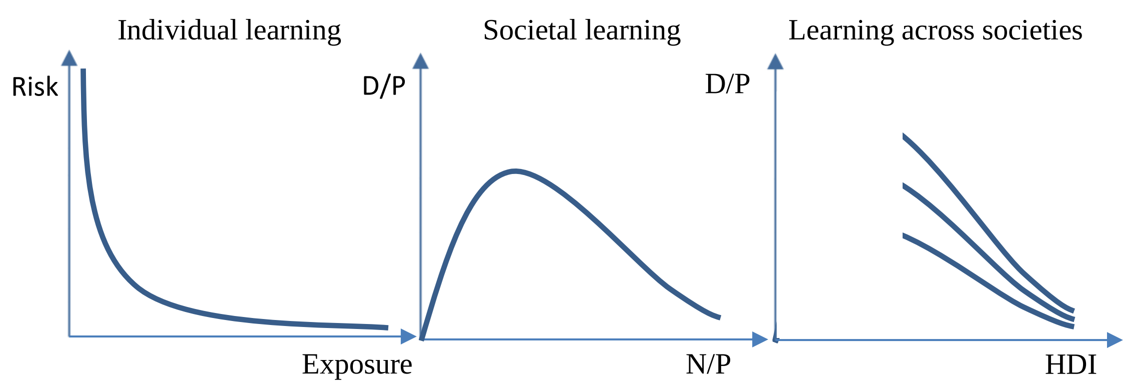

FIGURE 9 Layers of learning in traffic safety

The first two layers can be empirically analyzed, the third layer is hard to be proven as no proper indicator describing inter-societal knowledge transfer is at hand. At this point we would like to refer back to Elvik's paper (2017) in which he also came to the conclusion that evolutionary theory related to the development of knowledge cannot be tested, since history does not produce a control group that followed a different path in development. Yet we can accept the assumption that the long-term improvement in safety is not only the result of better roads and vehicles but also a knowledge transfer between countries.

To further research this assumption the convergence of EU countries in their traffic safety performance could be compared to other clusters of countries that do or do not have close cooperation in traffic safety (e.g. the United States of America, or a group of certain Asian countries). This analysis could serve as a sort of comparison group study and might reveal further aspects on the effects of knowledge transfer between nations.

REFERENCES

Adams, J.G.U., 1987. Smeed's law: some further thoughts, Traffic Engineering and Control, pp. 70-73.

Ahangari, H., Outlaw, J., Atkinson-Palombo, C., and Norman G., 2014. "Investigation into impact of fluctuations in gasoline prices and macroeconomic conditions on road safety in developed countries." Transportation Research Record: Journal of the Transportation Research Board 2465. pp. 48-56.

Al-Haji, G., 2007. Road safety development index: theory, philosophy and practice. Dissertation 811 Linköping University Electronic Press

Alvarez, F.J., Fierro, I., 2008. Older drivers medical condition, medical impairment and crash risk. Accident Analysis and Prevention 40, pp. 55–60.

Andreassen, D.C., 1985. Linking deaths with vehicles and population, Traffic Engineering and Control, 26(11), pp. 547-549.

Bester, C.J., 2001. "Explaining national road fatalities." Accident Analysis & Prevention 33.5, pp. 663-672.

Borsos, A., Koren, C., Ivan, J.N., Ravishanker, N., 2012. Long-Term Safety Trends as a Function of Vehicle Ownership in 26 Countries Transportation Research Record 2280 pp. 154-161.

Broughton, J., 1988. Predictive models of road accident fatalities, Traffic Engineering and Control, 29, pp. 296-300.

Croissant, Y., Millo, G., 2019. Panel data econometrics in R: the plm package, Accessed on May 4, 2019. https://cran.r-project.org/web/packages/plm/vignettes/plmPackage.html

Elvik, R., 2015. Some implications of an event-based definition of exposure to the risk of road accident, Accident Analysis & Prevention, Volume 76, pp. 15-24, ISSN 0001-4575

Elvik, R., 2017. Can evolutionary theory explain the slow development of knowledge about the level of safety built into roads?, Accident Analysis & Prevention, Volume 106, pp. 166-172, ISSN 0001-4575

European Commission (EC), 2001. White Paper, European transport policy for 2010: Time to decide, Brussels, p. 124

European Commission (EC), 2011. White Paper, Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, Brussels, p. 30

European Commission (EC), 2019. EU Road Safety Policy Framework 2021-2030 – Next step towards "Vision Zero", Brussels p. 33

European Commission, 2017. Statistical Pocketbook 2017 https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2017_en

Hakamies-Blomqvist, L., Raitanen, T., O'Neill, D., 2002. Driver ageing does not cause higher accident rates per km. Transportation Research Part F 5, pp. 271–274.

Hermans, E., Van den Bossche, F. and Wets, G., 2008. "Combining road safety information in a performance index." Accident Analysis & Prevention 40.4, pp. 1337-1344.

Huang, H., Yin, Q., Schwebel, D.C., Li, L., Hu, G., 2016. Examining Road Traffic Mortality Status in China: A Simulation Study, PLoS ONE 11(4)

Jamroz, K.; Budzyński, M.; Romanowska, A.; Żukowska, J.; Oskarbski, J.; Kustra, W., 2019. Experiences and Challenges in Fatality Reduction on Polish Roads. Sustainability, 11, 959

Kopits, E., Cropper, M., 2005. Traffic fatalities and economic growth, Accident Analysis and Prevention, Vol. 37, Issue 1 January, pp. 169-178

Koren, Cs., Borsos, A., 2012. The advantage of late-comers: Analysis of road fatality rates in the EU Member States. In: TRA Transportation Research Arena Europe 2012 Athens, Greece, Paper: 435

Langford, J., Methorst, R., Hakamies-Blomqvist, L., 2006. Older drivers do not have a high crash risk – a replication of low mileage bias. Accident Analysis and Prevention 38, pp. 574–578.

Oppe, S., 1991a. The development of traffic and traffic safety in six developed countries, Accident Analysis and Prevention, Volume 23. No. 5, pp. 401-412

Oppe, S., 1991b. Development of traffic and traffic safety: global trends and incidental fluctuations, Accident Analysis and Prevention, Volume 23. No. 5, pp. 413-422.

Oppe, S.; Koornstra, M.J., 1990. A mathematical theory for related long term developments of road traffic and safety. Proceedings of the Eleventh International symposium on Transportation and traffic theory, Yokohama, Japan, July 18-20

Page, Y., 2001. A statistical model to compare road mortality in OECD countries. Accident 905 Analysis & Prevention 33.3 pp. 371-385.

R Core Team R. A language and environment for statistical computing, 2013. R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0, http://www.R-project.org/

Smeed, R.J., 1949. Some statistical aspects of road safety research, Journal of Royal Statistical Society, Series A (General), Vol. 112, No. 1, pp. 1-34.

Tsuboi, T., Yoshimi, T., 2018. Dynamic Macro Numeric Analysis of Fatal Traffic Accident. International Conference on Advances in Computing, Communications and Informatics (ICACCI) September 19-22, 2018, Bangalore, India, pp. 1350-1357.

United Nations Development Programme, 2019. Human Development Reports. Accessed on May 21, 2019. http://hdr.undp.org/en/data#

Wang, L., Yu, C., Zhang, Y., Luo, L., Zhang, G., 2018. An analysis of the characteristics of road traffic injuries and a prediction of fatalities in China from 1996 to 2015, Traffic Injury Prevention, 19:7, pp. 749-754.

Wegman, F., Commandeur, J., Doveh, E., Eksler, V., Gitelman, V., Hakkert, S., Lynam, D., and Siem O., 2008. “SUNflowerNext: Towards a composite road safety performance index." SWOV, Leidschendam

WHO, 2018. Global status report on road safety 2018. Geneva: World Health Organization; 2018. Licence: CC BYNC-SA 3.0 IGO.