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A Comprehensive Comparative Assessment of Road Safety in Developed Countries

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Abstract

One of the most significant costs associated with automobile travel is the number of road accidents and fatalities that this type of transportation incurs. Road fatalities in almost all developed countries have decreased over the last four decades. However, the rate of change varies tremendously from country to country. The discrepancy in road fatality records has been widely noted but there is no comprehensive sense of the contributing factors. Accordingly, the overall goal of this study is to develop a more comprehensive understanding of disparities in road fatality, and to assess the extent to which various potential contributing factors affect the observed differences between countries.

To achieve a more consistent understanding of all potential determinants of road safety we developed a conceptual framework based on an extensive review of the literature on the social, economic and environmental factors that have been demonstrated to affect traffic fatality .This framework was tested using a series of empirical econometrics models. These models are based on data from 1990 to 2010 for 16 developed countries including the US. The thesis is based on three main strands of analyses. First, we assess the factors affecting variations in absolute traffic fatality rate, then we investigate factors contributing differences in the rate of change of fatality over time, and finally we evaluate road fatality from the point of view of different age cohort in different countries.

In the first analysis, we used panel data modeling to understand the main determinants of the level of road fatality rate. We used the comprehensive conceptual framework to select our variables in the empirical models. The results suggest that improvements in health conditions in different countries have had the largest impact on the long-term decline in traffic fatality. Also,

the results indicate that fluctuations in gasoline prices and unemployment rate are two of the main underlying cause of the cyclical patterns observed in the road fatality rate.

In our second analysis, we developed a multi-step method to create two different road safety indices. By comparing these two sets of indices, we captured the effect and the role of country specific factors such as differences in infrastructure, policy, enforcement, mode share, and driving habits on the changes in road fatality rates. The results suggest that the USA has made limited progress relative to other countries in terms of addressing these important factors. In comparison, countries like Sweden and the Netherlands have performed much better in terms of these factors.

Lastly, we analyzed fatality rates for different age cohorts in developed countries. The findings showed tremendous variations in road fatality rates (in terms of the absolute values and the rates of improvement over time) among different age cohorts. Benchmarking analysis revealed that it is not just the so-called SUN (Sweden, the UK and the Netherlands) countries that are doing well. These SUN countries have frequently been identified has having superior performance in terms of traffic safety. However, our more detailed analysis looking at different age groups show pockets of superior performance in other countries including Switzerland, Germany and Japan for specific age groups. Finally, the results reveals that Children (0-14 years old) and Seniors (+65 years old) in the US, fared very poorly relative to their peers in other countries

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A Comprehensive Comparative Assessment of Road Safety in Developed Countries

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Contents

Chapter 1.Introduction

One of the most significant costs associated with automobile travel is the number of road accidents and fatalities that this type of transportation incurs. The “Global Road Safety Status” (WHO 2013) shows that road traffic fatalities are the eighth leading cause of death globally, and the leading cause of death for young people. This report states that over a million people die each year on the world’s roads incurring costs of billions of dollars. Furthermore, the trends suggest that road traffic deaths will become the fifth leading cause of death by 2030. All of these facts points to the importance of the road safety issue and the urgent need to take action in both developed and developing countries to mitigate this problem.

All counties suffer from the problems associated with road traffic safety. Yet the size of the problem is different from one country to another, because countries vary widely in their development levels, infrastructure conditions, and transportation safety policies. In most developed countries, the total number of road fatalities peaked in the 1970s, and has since decreased at a relatively steady pace. For example, from 1970 to 2010, the number of annual road fatalities in the United States decreased from 52,000 to 32,000. This downward trend is also evident in other ways of measuring road safety, such as fatalities per vehicle miles travelled (VMT) and fatalities per capita.

While road fatalities in almost all developed countries have decreased over the last four decades, the rate of change has varied tremendously from country to country. For example, in 1970, road fatality rates in the Netherlands and USA were almost identical at 24 and 25 fatalities per 100,000 persons, respectively. But by 2010, the Netherlands had far outpaced the USA having achieved a reduction of 85 percent in the fatality rate compared to a reduction of only 59

percent in the USA. This disparity in the rate of improvement means that the USA road fatality level is now three times higher than the Netherlands. Other countries, for example, Italy, has also experienced a relatively low rate of improvement in traffic safety.

The discrepancy in road fatality rate has been widely noted but there is no comprehensive sense of the contributing factors. The case is even worse when we analyze the rate of improvement, as there is limited knowledge about the overall pattern of change. Consequently, the overall goal of this study is to develop a more comprehensive understanding of disparities in road fatality, and to assess the extent to which various potential contributing factors affect the observed differences between countries. To this end, we have followed three main strands of analyses. First, we assess the factors affecting variations in absolute traffic fatality rate, then we investigate contributing factors affecting the rate of changes (improvement rates) in road fatality over time, and finally we evaluate road fatality from the point of view of different age cohort in different countries.

Perhaps, the most important potential contribution of our work is that the analysis is based on a comprehensive conceptual framework. Previous similar studies have been more ad hoc in nature and have not considered the issues from a holistic viewpoint. The theoretical framework was developed based on a comprehensive review of the literature on the social, economic and environmental factors that have been demonstrated to affect traffic fatality.

The framework was then tested using a series of empirical econometrics models. The data used for these models were traffic fatality data from 1990 to 2010 for the following 16 developed countries: the USA, Canada, Japan, Australia, Austria, Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Sweden, Switzerland, and the UK. In selecting the

countries the main factors considered were similarity in the level of their economic development and the relative stability of their political and social conditions over the study period. We were limited to analyzing the time period, 1990 to 2010, because we could not find reliable data for most of the explanatory variables for the period before 1990.

This dissertation consists of three additional chapters. First in the Chapter 2, we focus on getting a better understanding and delineating those factors that contribute to the absolute traffic fatality rates in our 16 countries. Our initial analysis of these trends suggests that there are two distinct patterns in the data: an overall declining trend that is seen for most of the countries in our study and a secondary cyclical trend overlaying the general downward pattern. Before conducting the statistical analysis we developed a comprehensive conceptual framework in order to understand the full range of factors that could be related to these two observed trends in the data. This framework was used to help select the data for the empirical model that was used to study both the overall declining trend and the cyclical trend in road fatality for our countries. In the model, the dependent variable is fatality per population, and gas price, unemployment, health index, mobility, and vehicle ownership are the independent variables that were found to be statistically significant. Overlay, the study provides a better understanding of the underlying causes of both the periodic and long-term variations in road fatalities. For example, the result reveals a significant inverse relationship between gas prices and unemployment rate, and the road fatality rate after controlling for vehicle miles traveled.

In the third Chapter, we propose a framework to have a better understanding of the factors affecting the rate of changes (improvement rate) in traffic fatality. For this purpose, we develop a multi-step method to examine the role of all factors that affect the road fatality changes over time. Among these factors some of them are directly entered in the model. These factors that are

referred to as observed factors include such factors as health conditions, macroeconomic factors, VMT measures, and gasoline price. In addition, the model allows us understand the potential role of factors for which we do not have data. These so called unobserved factors, include factors such as infrastructure conditions, technological changes and differences in road safety policies. Based on these models we created two indices to compare how well countries are doing with regards to traffic fatality at different points in time.

One index is the Overall Traffic Fatality Index (OTFI) that is based on the raw data but adjusted to control for structural factors that affect all countries over time. The second index, the Adjusted Traffic Fatality Index (ATFI), has additional controls for gasoline price, socio-economic factors, mobility levels, motorization and health care. The conceptual model of factors affecting traffic fatality levels, suggests that the ATF index largely reflects the role of country specific factors such as differences in infrastructure, policy, enforcement and driving habits.

In the Chapter 4, we analyze fatality rates for different age cohorts in developed countries to better understand how road traffic fatality patterns vary across countries by age cohort. We divided the population into 6 distinct age groups and studied fatality rates both in terms of the absolute values and the rates of improvement over time and between countries. We then developed following two methods to examine the research questions: a benchmarking analysis and a comparative index based on panel data modeling. Our findings illustrate tremendous variations in road traffic fatality among different age cohorts and between the various countries in our study of 16 countries.

The underlying premise of this dissertation is that having a better understanding of our own traffic fatality trends, and that of peer countries, is an important first step to identifying policies

that may lead to more rapid improvements in road safety. In January 2015, following the lead of New York City and San Francisco, the AASHTO and the USDOT announced that zero deaths was the official policy of the US federal government transportation safety system (USDOT, 2015). This policy envisions zero deaths as the ultimate road safety goal. Given that the zero deaths policy was inspired by Sweden's Vision Zero program it would seem that looking at initiatives in other developed countries would be a natural starting point for identifying innovative policies (Johansson, 2009). The three papers that compose this body of work adds to our understanding of how traffic fatality in the US compares to peer country that have much better traffic safety records. It is hoped that the findings of this study will help American policy makers design a more efficient road map for progress towards a zero death goal based on examining strategies and policies in the best performing countries.

Chapter 2. An investigation into the impact of fluctuations in gasoline prices and macroeconomic conditions on road safety in developed countries

Abstract:

In most developed countries, the total number of road fatalities peaked in the 1970s. Although the data for road fatalities evidence a distinctive downwards trend, a secondary signal that is more cyclical in nature is also evident. These cyclical variations closely track macroeconomic conditions (usually represented by the unemployment rate) and gasoline prices. While the relationship between transportation safety and unemployment and gasoline prices have been investigated, studies have looked at these variables in isolation from other important factors that impact traffic safety. Accordingly, we have developed a comprehensive conceptual model which considers a wide array of factors influencing traffic safety and used this framework to inform an empirical model. To study variation across both time and location, we employed a panel data model using observations for 16 industrialized countries between 1990 and 2010. In the panel model, the dependent variable was fatality per population, and gas price, unemployment, health index, mobility, and vehicle ownership were the independent variables. The results revealed a significant inverse relationship between gas prices and the road fatality rate after controlling for Vehicle Miles Travelled (VMT). The elasticity analysis indicates that a 10% decrease in gasoline prices resulted in a 2.19% increase in road fatalities. Likewise, a 10% decrease in unemployment rate resulted in a 0.65% increase in road fatalities. Also, the results implied that the health index has the highest impact on road fatality rates. Overall, these results provide a better understanding of the underlying causes of periodic variations in road fatalities.

Keywords: Road safety, Gas price, Macroeconomics Factors, International Analysis, Panel Data Model, Fluctuation Analysis, Mobility

1. INTRODUCTION

One of the most significant costs of automobile travel is the road accidents and fatalities that this type of transportation incurs. In most developed countries, the total number of road fatalities peaked in the 1970s, and decreased at a relatively steady pace thereafter. From 1970 to 2010, -annual road fatalities in the United States decreased from 52,000 to 32,000 (OECD (1)). This reduction is also evident in other ways of measuring road safety, such as fatalities per vehicle miles travelled (VMT) and fatalities per capita, suggesting an overall trend of improving safety. While true, the data also contain a secondary cyclical oscillation that overlays the primary downward trend in road fatalities. Figure 1 shows data for a sample of countries rebased to 1970 levels, clearing indicating the primary downwards trend in the data and the secondary signal.

The greatest and most protracted downturn in road fatalities has taken place during the most recent cycle. For example, in the U.S., between 1997 and 2010 (the most recent year for which data are available), road fatalities decreased by 22%. Corresponding figures for Australia, Canada, Italy and UK were 25%, 27%, 42%, and 46%, respectively. This is notable because it marks the first time since the start of the automobile era in 1908 that the U.S. has gone so long (over 14 years) without a notable increase in road fatalities. In addition, the magnitude of the reduction is the largest in history, excluding the period during World War II (2).

Several studies have shown that the long-term trend of improving fatalities is related to many factors including new enforcement policies (for example, the introduction of laws that make seat belt use mandatory), technological improvements in vehicle safety (for example, the introduction of airbags systems), and innovations in trauma management (3,4,5). However, the existing literature has largely ignored the causes of the short term variations in road fatalities that are a feature of the crash records in developed countries.

We believe that a comprehensive analysis of these largely overlooked cycles might help to better delineate which factors have led to the general improvement in road safety trend and which factors contribute to cyclical variations that are more short-term in nature, thereby providing new insights into causes of road fatalities. In this paper we analyze both long and short-term trends in road fatalities using data for from 1990 to 2010 for 16 developed countries: the U.S.A, Canada, Japan, Australia, Austria, Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Sweden, Switzerland, and the UK.

A preliminary examination of variables revealed that many of fluctuations in transportation safety data closely track changes in gasoline prices. Existing literature has established a strong link between gasoline prices and travel behavior. Accordingly, one of the factors that we examine is the extent to which gasoline prices influence road fatalities. Similarly, we have also designed the study to assess whether or not macroeconomic indicators, including the level of unemployment and GDP per population, influence road safety. Besides these factors that are exogenously related to transportation safety, we also accounted for specific factors that are endogenous to the transportation system, such as Vehicle Miles Travelled (VMT) per vehicle and number of vehicles per population. These relationships were tested using econometric panel models, which took into account both variations between countries and variations over time.

2. LITERATURE REVIEW

Most of the existing research on road fatalities has focused on the impact of factors such as traffic characteristics, road condition, user behavior and transportation policies, and found that all of these factors have a significant effect on long-term trends in traffic safety (3, 4, 5, and 6). Less attention has been paid to factors that create more short-term variations in road fatalities

such as the gas price and other factors of a macroeconomic nature. Hence, this literature review focuses on this latter category of research.

2.1 Relationship between Gasoline Price and Road Fatalities

The literature on the relationship between gas price and traffic safety is burgeoning. Theoretically, when gasoline prices increase, people drive at lower speeds to conserve fuel (7). Since crashes that occur at lower speeds have a lower risk of fatality, higher gas prices should result in lower road fatality rates. In addition, gas price increases incentivize people to reduce the amount of travel, resulting in fewer crashes. Leigh and Wilkinson (8) examined the relationship between gas price, gas tax, and road fatalities for all 50 states using a multiple regression framework. They found that a 10% increase in gas tax led to a 1.8%-2.0% reduction in road fatalities, but that gas prices were not statistically significant in explaining road fatalities. A later study by Grabowski et al., using 1983-2000 state level data and a panel model to investigate the relationship between gas prices and road fatalities, found that a 10% increase in gasoline prices reduced road fatalities by 3.4% (7). Leigh et al. (9) employed a simulation-based partial equilibrium model and found that a surge in oil prices is negatively correlated with the number of fatal crashes. After analyzing data on U.S. motor vehicle fatalities from 1990 to 2007, Wilson et al.(10) reported that when gas prices increase, people switch to cheaper modes of travel, like motorcycles, and consequently fatalities for the motorcycle mode increases. Using Mississippi data from 2004 to 2008, Chi et al. (11) employed a time-geography approach to investigate the relationship between gas price and road crashes. They showed that gasoline prices have both short-term and intermediate-term effects in reducing total traffic crashes, especially for younger people. Finally, in 2011 Chi et al, (12) developed a negative binomial regression model with the same data from Mississippi to study whether gas price has an effect on drunk-driving crashes and

found that gas prices and drunk-driving crashes are inversely related, with a stronger relationship than all other types of crashes in Mississippi.

2.2 Relationship between Macroeconomic Conditions and Road Fatalities

The relationship between macroeconomic conditions and road fatalities has been tested using numerous model specifications and variables, but the most common approach in the literature has been to use the unemployment rate. Theoretically, an increase in unemployment leads to fewer workers commuting and hence a lower rate of fatalities (13). In addition, unemployed people are purported to drive at lower speeds to save money on gas and avoid speeding tickets. (13). First in 1984, Partyka estimated annual U.S. road fatalities as a function of unemployment, employment, and non-labor force data using simple time regression models for 1960 to 1982. He found that fatalities decreased by 1.86 for every 1,000 increase in unemployment (13). Simultaneously, Wagenaar employed a dynamic time series model using data from the State of Michigan in the 1970s and early 1980s to study how the American economic depression in the 1980s affected road fatalities (14). Using unemployment as a proxy for economic recession, he found that unemployment and road fatalities are inversely related, but that the effect is quite small. He also showed that VMT is not a statistically significant predictor of traffic crashes when unemployment is considered as explanatory variable (14). In 1991, Reinfurt et al. developed a new version of the Partyka's models (13) to estimate the level of motor vehicle fatalities in the U.S. for various subpopulations. They did not find any evidence that unemployment explained motor vehicle fatalities (15). Leigh and Walden used data for all states from 1977-1980 to examine the relationship between unemployment and road fatalities and also found that an increase in unemployment is associated with a decrease in the road fatalities if

VMT is included in the model as a control variable (16). Finally, the Gerdtham et al. study of 23 OECD countries from 1960-1997 showed that a 1% reduction in the unemployment rate generated a 2.1% increase in road fatalities (17). All of these studies concentrated solely on the role of the unemployment on road safety and did not consider other transportation-related and macroeconomic factors like vehicle ownership, economic growth and gas prices.

Several other researchers have investigated the role of macroeconomic variables other than unemployment on road safety. Using data for New Zealand from 1970 to 1994 and time series analysis, Scuffham found that increases in real GDP are associated with decreases in traffic fatality rates, and also that the unemployment rate is inversely related to traffic fatalities even after controlling for changes in VMT (18). Kopits and Cropper used panel data from 1963 to 1999 for 88 countries and found that fatality rates first increase with income then reach a peak value after which point fatality rates decrease as income increase (19). In 2008, Traynor evaluated regional economic conditions and road death rates in a cross–county analysis in Ohio using 1999 to 2003 data. He observed a negative relationship between per capita income and fatality per VMT only in counties with very low shares of VMT on highways, and mentioned that in counties where a large proportion of VMT takes place on highways, income is directly related to road fatalities (20).

In a recent study, Cotti and Tefft considered unemployment, income per capita and gas tax as macroeconomic factors and studied how they related to road fatalities during the 2007 to 2009 economic downturn using quarterly data for those years for the 50 states. They found that as unemployment increased, road fatalities decreased, with road fatalities dropping by 17% during the 2007-2009 recession (21). Sivak et al. also developed a model to explain the recent reduction in U.S. road fatalities by comparing data for 2005 and 2008. They examined all 269 variables in

the FARS (Fatality Analysis Reporting System) data system which is classified into groups such as: crash type, infrastructure, and type of vehicle; and determined that 19 variables most effectively explained the reductions in fatalities (2). While these two papers (21,2) mentioned above took a more comprehensive approach to investigating the relative effect of various macroeconomic factors on road fatalities than previous research, several important elements are missing. Examples of overlooked factors including the effect of transportation variables such as VMT, and the effect of the health care system.

2.3 International Studies

Of all the international empirical studies of road safety, the most comprehensive conceptual model is the one that was developed by the World Health Organization Health (WHO) (22). This model considered income, exposure factors, preventive factors, and mitigating factors, as determinants of road traffic mortality. But this comprehensive conceptual did not take into account factors such as gas price, macroeconomic factors and other socioeconomic factors. Only a few international studies of these factors have been undertaken. Gerdtham et al. (17) and Kopits et al. (19) considered macroeconomics factors but did not examine the role of gas price, while Bester looked only at the role of general factors like the Human Development Index (HDI), and did not investigate specific economic factors or the impact of gas prices on road fatalities (5).

2.4 Synthesis

Only a small body of literature has addressed factors such as gas prices that are likely to create more short-term variations in traffic fatalities. Even less attention has been paid to including macroeconomic factors such as GDP variables, unemployment, transportation-related factors and

gas prices in a single comprehensive framework. While most of the existing research has investigated the relationship between gas price or macroeconomic factors and road fatalities at a regional or national level, there is a need to understand the extent to which these relationships are more widely applicable across countries. Accordingly, in this paper we set out a comprehensive framework designed to study the relationship between all determinants of road traffic fatalities such as macroeconomics factors, gas price changes, transportation characteristics and road fatalities at the international level. The methodology used to examine the relationship between traffic fatalities and other controlling and explanatory factors in previous research is based either on time series or cross locational methods. A model that considers both time and location in a same framework will give a better sense of the extent to which the observed relationships are more widely applicable. Consequently, in this research we employ a panel data model, which considers both time and location simultaneously.

3. CONCEPTUAL MODEL

This section contains a comprehensive conceptual framework that we have developed to explain traffic fatalities, supported by separate articulations of the theoretical linkages between gas prices and road safety, and unemployment (as a proxy for macroeconomic conditions) and road safety. This model is used to guide the selection of variables in the empirical modeling process.

3.1 Comprehensive Conceptual Framework

The comprehensive conceptual model, shown in Figure 2, based on existing literature, particularly the framework developed by WHO (22), explains the main determinants of road

fatalities. Exposure factors such as the number of vehicles per capita and road density are a function of each country's socioeconomic conditions (Arrow 1).   At the same time, socioeconomic conditions affect infrastructure (Arrow 2) and urban form (Arrow 3). Travel behavior is influenced by a combination of exposure factors (Arrow 4), urban form (Arrow 5), infrastructure factors (Arrow 6), and socioeconomic factors (Arrow 7). Road crashes are directly affected by urban form (Arrow 8), infrastructure factors (Arrow 9), travel behavior (Arrow 10), and moderating/preventing factors (Arrow 11); and indirectly affected by exposure factors (Arrow 12), socioeconomic factors (Arrow 13), and technological factors (Arrow 14). Mitigating factors are influenced by socioeconomic factors (Arrow 15) and technological factors (Arrow 16). The combined effect of road crashes (Arrow 17) and mitigation factors (Arrow 18) influence road fatalities. The model shows which factors should be taken into consideration when modeling road fatalities.

3.2 Relationship between Gas Prices and Road Fatalities

Research has shown that changes in gas price have varying effects on peoples travel behavior and, as a result, on road fatalities. The common assumption is that gas price is linked to road safety just in terms of changes in the amount of travel. However, there are at least two other linkages between these factors: i) through changes in travel mode; and ii) through changes in travel behavior (23). The first link is between gas price and the amount of travel. When gas price goes up, people try to save money by travelling less. These changes might mean fewer trips, shorter trips or changes in the timing of trips, all of which reduce the likelihood of a crash occurring. A good aggregate indicator of changes in travel is VMT. According to Grabowski et al.(7) the VMT responds almost immediately to a substantial change in gas prices. The second

way in which gas prices are linked to traffic safety is through the effect of price on the choice of travel mode. When the gas price increases private vehicle travel becomes less competitive relative to other modes, causing switching over the course of months. A related adjustment is in the type of vehicles that people drive. Over the long-term, increases in gas prices will lead some people to choose more fuel efficient vehicles including smaller cars and hybrid vehicles (9). These newer vehicles will tend to have better safety features, thus improving safety overall (9). The third linkage between gas price and road fatality is through driving behavior. When gas price increases, most drivers will reduce speed to conserve gas (22) and reduce the risk of receiving a speeding ticket (21). Travel speed reductions help to improve traffic safety by reducing the number of crashes as well as their severity.

3.3 Relationship between Unemployment and Road Fatalities

Similar to gas price, macroeconomics conditions are linked to road safety through VMT variations, pricing impacts, and driving behavior effect, but three additional links have been identified relating to mental stress, changes in economic activities, and changes in patterns of alcohol consumption. One of the most evident consequences of an economic recession is the physiological problems associated with mental stress (14). In extreme cases this mental stress can lead to depression and/or aggressive behavior. Both of these reactions can have significant impacts on people's driving behavior. The possibility of distraction in the depressed drivers is high (16). In addition, drivers who are angry have a higher change of being in an crash than drivers who are not under duress (16). As Leigh (16) stated, increased unemployment may result in less drinking since people do not have as much disposable income. On the other hand, some

may drink more in response to unemployment and, as such, we can expect an increased possibility of fatalities (Figure 3).

4. DATA AND EMPERICAL MODELING

This section contains a discussion of appropriate variables and available data to operationalize our conceptual model, and a description of the empirical model.

4.1 Data

To develop a reliable model based on the above conceptual framework, we need to select appropriate variables for both dependent and independent variables. The dependent variable in the study is road fatality per population calculated by dividing the total annual road fatalities by population. This represents the overall road safety conditions in a country.

As the above comprehensive conceptual model shows, the independent variables are generally divided into two groups: directly and indirectly related. Directly linked factors to road fatality are categorized in three groups: travel behavior factors (box D in Figure 2), infrastructure factors (box E), urban factors (box F), and traffic moderating factors (box G). First, we use "VMT per vehicle" as a representative variable for the travel behavior group. VMT per vehicle is a good proxy for the degree of vehicle mobility in the country. The second group of factors directly linked to road fatalities comprises traffic moderating/preventing factors, which can be interpreted as the regulation and enforcement regime in each country. Representative variables could include speed limits or seat belt regulation for every country, but a lack of appropriate historic data for all countries precluded us from including these factors in our empirical model.

Another group of factors directly linked to road fatalities include infrastructure conditions, and engineering. Although these factors have a significant influence on road fatalities, again, a lack of data precluded us from including them in any comprehensive way in our model. The last directly related factors are urban form and we did include the percentage of people who live in urban environments to represent this.

In the conceptual model, socioeconomics factors (Box A in figure 1) are indirectly related to road fatalities. The socioeconomic factors such as social norms and cultural differences vary across countries. The Human Development Index (HDI), which was developed by the United Nations Development Program (UNDP) in 1970 to quantify the level of human development for different countries, is a good proxy for the stage of development of individual countries. This composite indicator consists of three indices that pertain to income, education, and health. We use both overall HDI and HDI Education index as potential proxies for social conditions, and the HDI Health Index as a proxy for the health system. The explanatory variables of interest in this study are gas price and the vector of variables reflecting macroeconomic conditions as socioeconomic factors are indirectly related to road fatality. These factors are represented by the annual unemployment rate and GDP per population. Another indirectly related set of factors is transportation exposure. We chose vehicle ownership per population to represent the degree of dependency on private modes of travel.

The principal data source is the Organization for Economic Co-operation and Development (OECD) (24). Gaps in road fatalities data were filled with data from the International Road Traffic and Accident Database (IRTAD) annual report (1), also produced by the OECD. The HDI, HDI Health Index, and HDI Education Index data were obtained from the UNDP (25). The

World Bank database was used for data on the percentage of people who live in urban areas in each country (26). The variables and their source are presented in Table 1.

As the conceptual model shows, road crashes (Box I) and road fatalities (Box J) are mediated by mitigation factors (Box H) such as trauma management and crash response times that are features of the health care system. We use standardized values of the HDI Health Index to represent the condition of the health care system in each country. This metric uses life expectancy at birth as its main indicator, and is consistent with other studies of road safety that take into account health (4, 5).

4.2 Panel Data Model

Following Grabowski et al. (7), we used a panel data model to study the effect of gas price and macroeconomic conditions on the traffic safety while controlling for other associated factors, using data for 1990, 2000, 2004, and 2010. As such our data encompasses 64 observations (16 countries and 4 time periods). The issue of data availability leads to select this period of study. Because our dependent variable, fatality per population, has no discrete values, we used a natural-log transformed normal regression panel model (21) rather than Poisson or Negative Binomial panel models, specified as follows:

$$\log(fatpop_{it}) = \beta\log(X_{it}) + \alpha\log(T_{it}) + \gamma\log(Z_{it}) + (CX = F) + \sum\theta_t + \varepsilon_{it} \quad \text{(Equation 1)}$$

Where:

fatpop, refers to road fatality per 100,000 population;

X includes the set of macroeconomic and gas price variables;

T include the set of endogenous transportation factors;

Z is a set of exogenous control variables;

β, α, and λ refer to coefficients of X, T and Z;

ε is the error term for country i at time t;

(CX=F) represents the fixed effect for each country;

and θ_t represents time dummy variable.

Panel models can pick up the effect of any omitted variables in three ways: (Group1) country varying-time invariant variables (factors such as cultural that remain relatively constant within a country over time); (Group 2) country invariant-time varying variables (factors such as technological changes that evolve over time, but are relatively constant across countries); and (Group 3) country and time-varying variables (such as regulations and infrastructure that vary both over time and across countries). The proposed model helps us understand the characteristics of omitted variables after controlling for gas prices and macroeconomic conditions. Table 2 shows a list of omitted variables and the group to which each belongs. If the omitted variables correlate with the independent variables a fixed-effect model should be used (27). Since our omitted variables largely represent infrastructure conditions, enforcement system, and technology changes, we hypothesized that a fixed-effect model would be appropriate, but also compared the results of this model to a random effects model using a series of statistical tests, such as the Hausman test, to test whether our assumption was supported.

4.3 Modeling Steps and Preliminary Analysis

We ran five sets of models. Model 1 is a base model without any time or country effects. Model 2 is the same as Model 1 with the country effect added. Model 3 considers the issue of standard

deviation among countries and provides the robust version of Model 2. Model 4 adds the time effect to Model 3. And finally, the model 5 is the updated model 4 without insignificant variables. As correlation between independent variables may lead to problems with collinearity, we quantified the cross-correlation between variables, and considered a relationship as problematic if the covariance was over 0.7. HDI, the education index, GDP per capita and health index were all highly correlated. Based on the conceptual relationship and the correlation between these four factors with other independent variables, we selected only two of these four variables, the health index and the GDP per capita, for inclusion in the model theoretically these variables will be more strongly linked to road fatalities.

5. RESULTS

We compare the results from the five separate models that we ran to identify which of the various models performed better in explaining road fatalities. In all models the results of the Hausman test showed that a fixed-effect model is the most appropriate.

Model 1 is a base model that takes into account all of the explanatory variables but no panel fixed effects. The model has the R^2 of 0.68, and only three out of seven of the explanatory variables are statistically significant—gas prices (-), vehicles per population (+), and the HDI Health Index (-). The main point here is that gas prices and road fatalities are inversely related, and that the other two statistically significant variables also have the expected sign.

Model 2, which extends Model 1 by including country effects, has a much higher R^2, at 0.93, and six of the seven explanatory variables are statistically significant—gas price (-), unemployment (-), vehicle per capita (-), VMT per vehicle (+), level of urbanism (-), and the

HDI Health Index (-). All of these signs are as expected, with the exception of vehicle per capita, which is negative, rather than positive. After checking our model for heteroskedasticity, we found that the variances of the residuals are correlated with our observations, requiring the models to be rerun with a relaxation of the homoscedasticity assumption. Model 3 therefore uses a robust GLS (Generalized Least Square) model to estimate the coefficients under these conditions. The results showed that the R^2 was 0.96, and five of the seven explanatory variables were statistically significant—gas price (-), unemployment (-), VMT per vehicle (+), level of urbanism (-), and the HDI Health Index (-)—all with the expected signs. Model 4 included the addition of time dummy variables to the specification in Model 3 to capture the effect of time. The R^2 rose to 0.98, and six out of seven of the explanatory variables (and all of the dummy variables to represent time) were statistically significant—gas price (-), unemployment (-), GDP per capita (+), vehicles per population (-), VMT per vehicle (+), and the HDI Health Index (-). The signs of all of these variables are as expected, with the exception of vehicles per population, which, according to the literature should be positively related to road fatalities. GDP per capita also has a positive relationship to road fatalities, but the expected sign of this is debated in the literature. To develop the fifth and final model, we took out the level of the urbanism factor which is the insignificant variable in the Model 4. The findings of Model 5 are similarly to Model 4, but for all variables we obtain more significant statistical relationship.

6. DISCUSSION AND CONCLUSIONS

The evaluation of all models shows that gas prices have a consistent inverse relationship to road fatalities. The results of Model 5 may be more reliable because the model considers more

controlling and omitted factors, and in this instance, the elasticity of gas prices to road fatalities is -0.218, indicating that a 10% increase in gas price results in a 2.18% reduction in road fatalities. This effect is slightly smaller than in the study undertaken by Grabowski (7), which found a 10% increase in gasoline prices reduced road fatalities by 3.4%. Of the two macroeconomic factors considered (unemployment and GDP per population), unemployment has the strongest negative relationship with road fatalities in all models, with the elasticity ranging from -0.065 to -0.090, a fairly narrow range, suggesting that a 10% increase in the unemployment rate is associated with a decrease in traffic fatalities of 0.65%. This result is starkly different from the findings of Gerdtham (17) study of 23 OECD countries where they found that a 10% increase in the unemployment rate generated a 21% decrease in road fatalities. However, because they did not consider other transportation-related and macroeconomic factors like vehicle ownership, gas prices, and health indicators, it is possible that they overestimated the effect of the unemployment rate on road fatalities.

The GDP per population is significant only in Model 4 and 5, indicating that there is no systematic pattern in terms of the relationship between GDP per population and road fatalities. However, what is especially strong is the relationship between the HDI Health Index and road fatalities, with an elasticity ranging from -3.95 to -6.56. Taking Model 5 as an example, a 10% increase in health index factor is associated with a 41.5% reduction in road traffic fatality rate. As stated in the conceptual model, trauma management and crash response play an important role in determining whether or not road crashes result in fatalities.

This analysis shows that the primary beliefs about the role of transportation factors in road fatalities structure are more doubtful. The vehicles per population factor in all models which consider country effect (model 3, 4 and 5) show a negative relation with road safety rate. This is

not an expected result. This might be because the vehicle ownership is a good proxy for the level of socioeconomic and development conditions in the different countries. We would expect better transportation safety in more-developed countries. In contrast, VMT per vehicle shows a consistently positive relationship to road traffic fatality rate. As previously discussed, VMT per population shows the level of mobility in the area. Based on Model 5, a 10% reduction in VMT per vehicle is associated with a 2.07% reduction in the road traffic fatality rate.

Based on our theoretical framework we suggested three ways in which gas price and road safety are linked. In all models gas price has strong statistical connections with road fatality even after controlling VMT values. This suggests gas price have impact on road fatality not only through VMT reduction but also via price and travel behavior effects. A similar pattern exists in the relationship between the unemployment rate and road fatality rates. The panel model supports the idea in our conceptual framework that unemployment is linked to road fatality rates not only through the VMT effect but also through price, behavioral, and psychological effects

The results reveal that increases in gas prices can lead to decreases in road fatality rates. Policy-makers should be aware of the presence and implications of these short-term, more cyclical fluctuations in road fatality rates so as not to misinterpret short-term reduction in the road fatality as permanent progress in improving road safety conditions. Finally, it is important to point out that because these models have been created using data for developed countries. We do not know if the results are universally applicable to all countries.

The analysis of the time effect coefficients reveals the importance of omitted factors that change over time, such as technological transportation safety changes and infrastructure system conditions. The model assumes a value of zero for 1990 and it estimates -0.205, -0.307, and -

0.603 for 2000, 2004, and 2010, respectively. These values indicate the relative impact of technological enhancement and infrastructure improvements on road fatality over time.

However, more work is needed to validate these connections. Comparing the elasticity values of all significant variables in the model shows that health improvement has the largest impact on road fatality. Among all other significant variables unemployment rate has the lowest effect on rod fatality.

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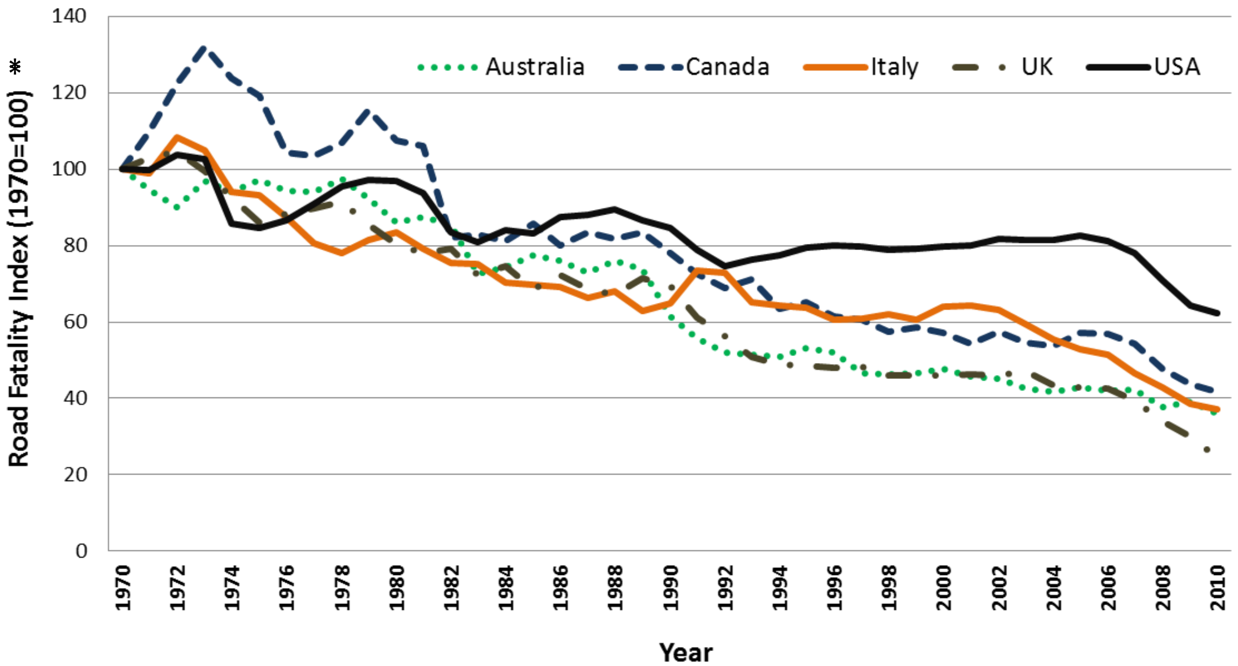

***.** To compare better road fatality changes in selected countries we rebased road fatality data. We set the 1970 road fatality values as 100 for each country and then recalculated the following years' values with respect to the 1970 values.

FIGURE 1 A comparison of road fatalities the U.S., Australia, Canada, Italy, and UK:1970 -2010 (OECD).

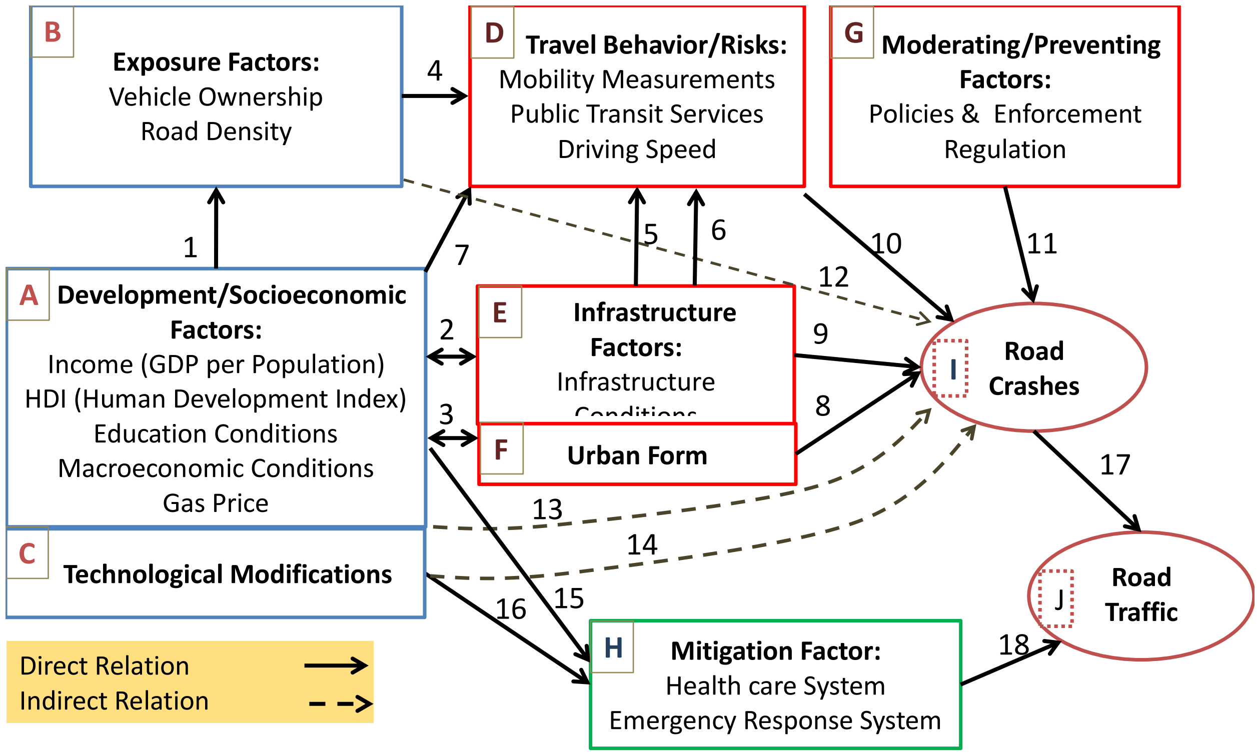

FIGURE 2 Comprehensive conceptual framework.

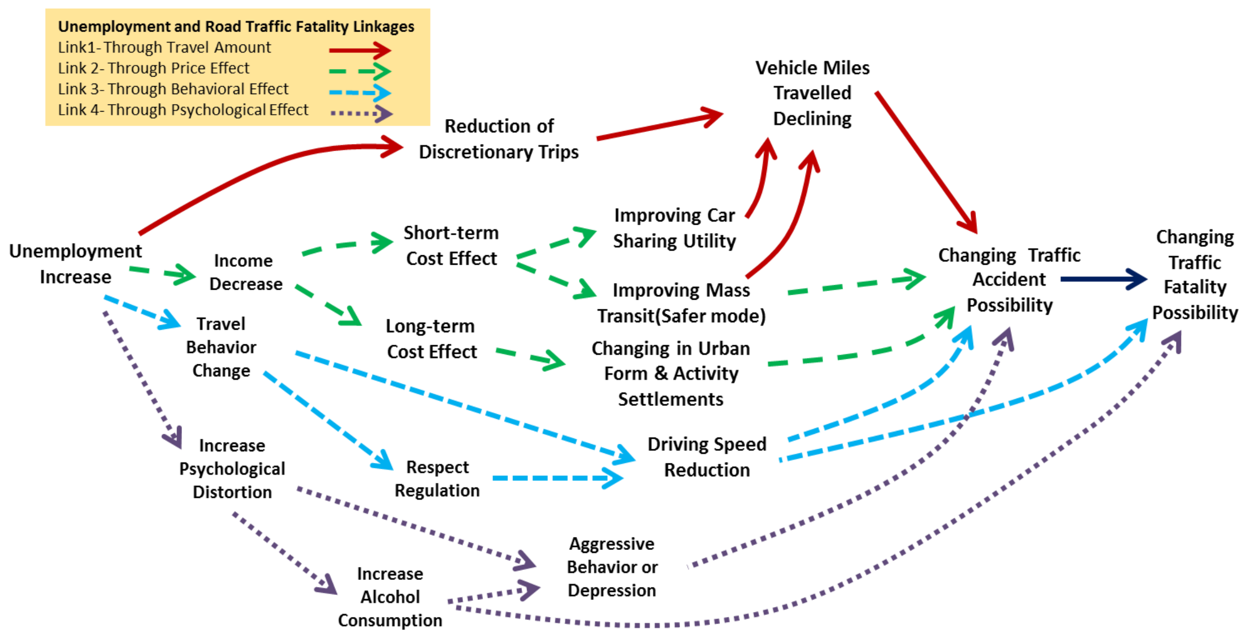

FIGURE 3 Theoretical relationships between unemployment and road fatalities.

TABLE 1 Source and Descriptive Statistics for Variables

Variable	Name	Data source	Min.	Max	Mean	SD	Category of Variables
Human Development Index	1-HDI	UNDP	0.77	0.952	0.87	0.04	Box H
(HDI) Education Index	2-EDUIND	UNDP	0.636	0.994	0.86	0.06	Box A
Average Annual Gas Price (real $) per liter (*)	3-GASPR	OECD	0.38	2.15	1.15	0.44	Box A
Mobility; Average VMT per vehicle	4-VMT_VEH	OECD	5260	15850	9340	1880	Box D
Vehicle ownership: Vehicle per capita	5-VEH_Cap	OECD	27.07	82.96	55.43	10.70	Box B
Unemployment rate	6- UNEMP	OECD	1.80	14.10	6.38	2.58	Box A
(HDI) Health Index	7-HLTHIND	UNDP	0.863	0.997	0.920	0.03	Box H
Percent of Urban Population	8-URBPER	World bank	57.00	97.00	77.87	9.07	Box E
Traffic Fatalities Per 100,000 people	Dependent Variable	OECD + IRTAD	2.80	20.17	9.33	4.13	

(*).The OECD database (24) does not cover the gas price data of 2010 so we provided gas price data from individual sources for each country.

TABLE 2 List of omitted variables

Omitted variables	Category in Conceptual Model	Time Variant*	Location Variant**	Category of Omitted Variables
Technological Effect	Technological Effect	Yes	No	Group 2
Road Density	Exposure Factors	No	Yes	Group 1
Infrastructure Conditions	Infrastructure Factors	Yes	Yes	Group 3
Engineering	Infrastructure Factors	No	Yes	Group 1
Public Transit Service	Travel Risk	No	Yes	Group 1
Driving Speed	Travel Risk	No	Yes	Group 1
Enforcement	Preventing Factors	No	Yes	Group 1
Policies & Regulation	Preventing Factors	No	Yes	Group 1
Emergency Response	Mitigation Factors	Yes	Yes	Group 3

*.Time variant means the variable changes during the time. **. Location variant means the variable changes among different areas.

TABLE 3 Road traffic fatality rate regressions

Dependent Var. / Independent var.	Model 1 *(fatpop)*	Model 2 *(fatpop)*	Model 3 *(fatpop)*	Model 4 *(fatpop)*	Model 5 (fatpop)
Real Gas price	-0.461 *	-0.521*	-0.520*	-0.230*	-0.218*
	(0.142)	(0.099)	(0.063)	(0.072)	(0.062)
	[-3.22]	[-5.24]	[-8.21]	[-3.17]	[-3.47]
Unemployment rate	0.084	-0.09***	-0.073**	-0.073*	-0.065*
	(0.095)	(0.052)	(0.032)	(0.021)	(0.018)
	[0.889]	[-1.74]	[-2.25]	[-3.40]	[-3.55]
Real GDP per capita	-0.170	0.168	0.187	0.266*	0.250*
	(0.122)	(0.127)	(0.086)	(0.063)	(0.054)
	[-1.40]	[1.32]	[2.16]	[4.22]	[4.58]
Vehicle per capita	0.409**	-0.463**	-0.407**	- 0.331*	-0.252*
	(0.235)	(0.232)	(0.138)	(0.078)	(0.059)
	[1.74]	[-1.99]	[-2.94]	[-4.21]	[-4.57]
VMT per Vehicle	-0.191	0.295***	0.346*	0.149***	0.207**
	(0.185)	(0.180)	(0.130)	(0.082)	(0.093)
	[-1.03]	[1.64]	[2.64]	[1.82]	[2.24]
Health Index	-6.562*	-5.55*	-6.437*	-3.953*	-4.148*
	(1.319)	(1.345)	(0.901)	(1.328)	(1.284)
	[-4.96]	[-4.13]	[-7.14]	[-2.976]	[-3.22]
Percent of Urban pop.	0.274	-1.35**	-1.046**	-0.418	
	(0.236)	(0.660)	(0.458)	(0.302)	
	[1.05]	[-2.05]	[-2.28]	[1.384]	
Intercept		8.630	6.88	2.98	1.13
Time -2000				-0.196*	-0.205*
				(0.072)	(0.047)
				[2.72]	[-4.39]
Time -2004				-0.294**	-.307*
				(0.126)	(0.076)
				[2.33]	[-4.03]
Time -2010				-0.582*	-0.603*
				(0.183)	(0.108)
				[3.18]	[-5.55]
Country Fixed Effect	No	Yes	Yes	Yes	Yes
R^2	0.68	0.93	0.96	0.98	0.98
GLS-OLS	OLS	OLS	GLS	GLS	GLS
SEE	0.272	0.105	0.102	0.095	0.094

- Standard errors are presented in the parentheses and t-test values are presented in bracket,
* Significant at 1% level, ** Significant at 5% level, *** Significant at 10% level,

Chapter 3. Assessing the Determinants of Changes in Traffic Fatality in Developed Countries

Abstract:

Road safety is a considerable public health concern around the world. National and local governments regularly introduce legislation or strengthen enforcement of existing laws to make roads safer. While road fatalities in almost all developed countries have decreased over the last four decades, the rate of change has varied tremendously from country to country. Our goal in this study is to provide a better understanding of the relative rate of improvement in road fatalities in different countries in the developed world over the last four decades. By using observations for 16 industrialized countries in series of panel data models, we created two indices to compare how well countries are doing with regards to traffic fatality at different points in time. One index is the Overall Traffic Fatality Index (OTFI) based on the raw data but adjusted to control for structural factors that affect all countries over time. The second index, the Adjusted Traffic Fatality Index (ATFI), has additional controls for gasoline price, socio-economic factors, mobility levels, motorization and health care. Based on our conceptual model of factors affecting traffic fatality levels we believe that the ATF index largely reflects the role of country specific factors such as differences in infrastructure, policy, enforcement and driving habits. The ATFI index therefore measures the safety regime for specific countries.

Keywords: Road safety Improvement Analysis, Determinants of Road Safety Changes, International road safety comparison, Panel Data Model, Country Effect, Omitted Factors

1. INTRODUCTION

Road safety is a considerable public health concern around the world with over a million people dying each year in traffic crashes (*1*). Automobile manufacturers are striving to improve safety features in vehicles, while national and local governments regularly introduce legislation or strengthen enforcement of existing laws to make roads safer (*2*). Rather than accept that traffic fatalities are an unavoidable consequence of vehicular travel, some jurisdictions have completely re-envisioned how road safety should be addressed. In 1997, just three years after the concept was realized, Sweden adopted a "Vision Zero Initiative" based on the underlying premise that any loss of life on roadways is unacceptable (*3*). This innovative approach recognizes that road fatalities occur because transportation systems have traditionally been designed for maximum capacity and mobility rather than safety, and argues that policymakers can and should shift their priorities so that safety comes first (*3*). The impressive headway that Sweden has made in moving towards its zero deaths vision without compromising mobility or economic productivity has inspired other places to rethink how they view transportation safety. Even though Sweden had one of the lowest rates of traffic fatalities in the developed world in 1970, it has still managed to improve its safety record and as of 2010 remains the safest of any of the developed countries. Plans similar to Sweden's "Vision Zero Initiative" have been adopted at various geographic scales across the world like "Target Zero" in Washington State, and "Vision Zero" in New York and San Francisco.

While road fatalities in almost all developed countries have decreased over the last four decades, the rate of change has varied tremendously from country to country. For example, in 1970, road fatality rates in the Netherlands and USA were almost identical at 24 and 25 fatalities per 100,000 persons, respectively (Figure 1). But by 2010, the Netherlands had far outpaced the

USA having achieved a reduction of 85 percent in the fatality rate compared to a reduction of only 59 percent in the USA. This disparity in the rate of improvement means that the USA road fatality level is now three times higher than the Netherlands (*4*). Italy has also experienced a relatively low rate of improvement in traffic safety. In 1970, the road fatality level in Italy was 21, lower than that in the Netherlands. Four decades later, the Italian road fatality rate has decreased to 7 per 100,000 population, almost twice that of the Netherlands.

Existing studies have suggested that the primary factors associated with low levels of road fatalities are tougher enforcement laws, safer vehicles, and better emergency response capabilities (*5, 6, 7, 8*). However, as the case of Sweden suggests some country-specific factors (such as the way in which transportation safety is envisioned) may also help to explain the high degree of variation in the rate of decrease in road fatality rates between different counties. The relationship between road fatality levels and changes in road fatality is analogous to that between GDP per population and growth in GDP. In the economic literature, a clear distinction is made between research relating to understanding why GDP is different between countries and why some countries show a higher level of GDP growth. As such there is a distinct line of economic research that focuses on factors contributing to GDP growth as opposed to research focusing on difference in GDP per capita. In contrast, equivalent literature in the traffic safety realm is sparse.

Accordingly, in this study we will contribute to the body of international safety research by providing a better understanding of the relative rate of improvement in road fatalities in the developed world over the course of the last four decades. The goal of this analysis is to create two indices that will quantify how countries are performing relative to each other in the traffic safety domain, in order to identify what factors are generating the variable performance across

countries. The study uses a conceptual framework previously developed by Ahangari et al. to compare road safety changes and to quantify the effect of observable and unobservable factors on changes in road fatality (*9*). In order to understand what factors are affecting changes in road safety, we use a series of panel data models based on data from 1990 to 2010 for the USA and 15 other developed countries: Canada, Japan, Australia, Austria, Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Sweden, Switzerland, and the UK.

2. LITERATURE REVIEW

Comparative analysis of international road safety conditions has attracted considerable attention over the last several decades (*6, 7, and 10*). In this section, we review two related groups of literature. First, we review comparative studies of traffic safety at the international level. Then we discuss studies that have focused on the relative improvement in traffic safety across countries. We use these two analyses to identify gaps in the literature, and illustrate how our study will address some of those gaps.

2.1 International Comparative Analysis

The first international study of traffic safety, conducted by Smeed in 1949, compared 20 industrialized countries for 1938 using simple regression modeling (*11*). He found an inverse relationship between the number of road fatalities and the level of motorization (vehicle per population). Smeed's work has influenced the study of traffic safety, with numerous researchers building upon his approach (Jacobs and Hutchinson (*12*), Jacobs and Sayer (*13*), Haight (*14*), Mekky(*15*)). In an important modification, Ernvall(*16*) and Wegman(*17*) substituted number of-vehicles for total vehicle miles travelled (VMT) in Smeed's model. All the studies rooted in Smeed's model have important limitations. First, all use cross-sectional model therefore provide no insight on how or why traffic fatality rates change over time. Second, these studies have

concentrated largely on the role of level of motorization on traffic fatality and paying limited attention to the role of other determinants of road safety such infrastructure and technology factors.

Time series analyses were developed to evaluate changes in road safety over time. In 1989, Oppe considered time as the independent variable and fatality per population as the dependent variable. Using annual data from 1950 to 1986, he found a decreasing road fatality trend in the Netherlands, the United States, West Germany, and Great Britain (*10*). Similarly, Navin et al. in 1994 employed a time series model to estimate road fatality levels based on Smeed's formulation with data from the US (1906-1991), Canada (1910-1990), UK (1905-1990), India (1961-1985), and China (1985). They found that developed countries such as USA and UK had passed their traffic fatality peak whereas developing countries such as India had not yet peaked (*18*). Yannis (2011) developed an auto-regressive non-linear time series model to analyze road safety conditions. By examining linkages between the motorization level and decreasing fatality rates across EU countries from 1970 to 2002, they were able to rank the performance of various countries in terms of traffic fatalities (*8*). The strand of research that has used a time series approach established conclusively a long-term trend of decreasing fatality rates for developed countries. However, little attention has been paid to the relative rate of decrease in the various countries.

Another strand of research on international road safety has taken a more comprehensive view of both exogenous and endogenous factors that are likely to affect traffic fatality rates such as transportation system specifications and socioeconomic conditions. In 2001, Bester developed stepwise regression analyses to explain traffic fatalities in 179 countries using data for 1994 or 1996. He found that factors such as national infrastructure, paved roads and socioeconomic

factors (GDP per capita, life expectancy, Human Development Index (HDI)) all contribute to the level of the traffic fatalities within the countries he studied (*19)*. Page used panel data models to compare road fatality in OECD countries from 1980 to 1994. He estimated the safety performance of each country with regards to several exogenous control variables including population levels, vehicles per capita, percentage of young people, and alcohol consumption. Based on the residual values and a Bayesian adjustment method for each country, he developed an index to measure country performance, and concluded that Sweden, the Netherlands and Norway had the best road safety records, and the USA, Belgium and Greece the worst (*5*). Kopits & Cropper conducted a panel data analysis using data for 88 selected countries from 1963 to 1999. They identified an inverted U-shaped relationship between levels of income and traffic fatality risk (*20*). In 2009, Koren et al. developed a series of statistical models to understand similarities and differences in road safety among 139 selected countries. They used a clustering model to classify countries into six groups using data on GDP per population, vehicle ownership and fatality level. They proposed that countries within the same cluster should preferably follow similar road safety improvement strategies (*21*). This strand of research sheds light on the underlying factors affecting road fatality rates. However, most of this research has not been supported by a comprehensive conceptual framework for selecting the independent variables used in the empirical models. Consequently in some cases, some of the variables are highly interrelated.

In the past decade, partly because of the issues identified above, another approach has emerged in which researchers have sought to assess road safety by cre-ating national composite indices. Koornstra (*22*), Al Haji (7), and Hermans (*23*) developed number of safety indices to compare road safety conditions among different countries. In 2002, the Sun Flower model

adopted a benchmarking approach that considers various aspects of transportation safety in the Netherlands, the UK, and Sweden, as best practices countries (*22*). The model was then used to compare other selected countries with these three countries as a way of identifying policy improvements. A few years later, Al Haji presented the Road Safety Development Index (RSDI) for eight European countries composed of thirteen indicators across three pillars (7). Hermans, developed the Road Safety Performance Index, which considers of eight dimensions and 13 indicators (*23*). An evaluation of these models reveals that all of them are based on a more comprehensive conceptual framework than previous streams of research. They help to provide an overall insight into road safety in different jurisdictions (*23*). One potential drawback with these indices is that they are based on a number of variables that may be correlated, and as such, may over or underestimate the influence of some factors. Overall, these models help identify the best performing countries but they tell us little about the history of how the countries got to their current level of traffic fatalities.

To better connect road safety theory with empirical modeling, Ahangari et al. (9) bridged these two realms by developing a series of panel models based upon a comprehensive conceptual framework. Using national data for 16 developed countries, they identified two distinct trends in road safety data over the last four decades. The first is a trend showing an overall decline caused by factors such as medical advances, reductions in the amount of travel, and motorization level. This trend is overlaid with a pattern of short-term fluctuations in the traffic fatality trend caused by cyclical factors such as gasoline prices and unemployment rates.

2.2 Studies of International Improvements in Traffic Fatality

Only a few handful of macro-scale studies have focused on the relative rate of improvement of traffic fatality in developed countries. In one such study, Lassare (*24*) used time series analysis for ten European countries to examine the relationship between road fatalities and traffic flow for annual data from 1950-1994. After developing an indicator of the rate of progress that took into account exposure (represented by vehicle-km travelled), he concluded that most European countries exhibited a rate of improvement of more than 4.5 percent per year. In 2003, Noland looked at the variation in the percentage change in road fatalities among industrialized countries. He found that improvements in medical treatment (as represented by infant mortality rate and number of physicians per capita) was the number one factor that driving the road fatality rate reduction in developed countries from 1950 to 1994 (*2*).

Yannis et al. used piecewise linear regression models to identify when traffic fatality rates started to decrease in selected European countries (*25*). They found that countries with the same motorization pattern reached a peak in their road fatality rates at almost the same time. In 2012, Borsos et al. developed a traffic safety trend analysis for 26 developed countries. Their model included both country-level (time series) and time-dependent (cross-section) analysis using annual data from 1965 to 2009. They found that road fatality trends changed over time. In some countries such as the US, the rate at which fatalities have changed has slowed with time. In others, such as the Netherlands, fatalities have decreased at a more persistent rate (*26*).

2.3 Synthesis of Literature

Three gaps in the existing literature on international road safety analysis are evident. First, some studies have been conducted with the idea of learning from countries with the best

road safety records in absolute terms. However, little attention has been paid to those countries that are improving their traffic fatality record at the fastest rate. Secondly, the bulk of the work has looked at factors associated with relative road fatality levels in different counties. There has been very little work done to characterize the relative rate of changes in the road fatality levels in different countries over time. As such there is little in the literature to suggest reasons why the rates of change vary so drastically from country to country and why countries such as the US and Italy are improving at a slower rate than other industrialized countries. The last point that has not received sufficient attention in the literature is empirical modeling based on a comprehensive theoretical framework that takes into account the full range of factors that address both spatial and temporal variations in traffic fatality. While research is needed to better understand why some countries are able to make such impressive improvements in their road safety records while others are faltering, the first step is to quantify their relative performance.

3. Theoretical conceptual framework

The starting point for our analysis is a comprehensive theoretical framework developed to conceptualize road fatality levels (*9*).This conceptual framework, initially inspired by a WHO model, describes eight sets of factors that either directly or indirectly influence road safety and show how they interact with one another. Socioeconomic (development), technological changes, and exposure factors (such as motorization level) are indirectly related to road crashes while urban form, infrastructure conditions, travel behavior, and moderating (policy and enforcement) along with mitigation (health and emergency response) factors are directly related to road deaths (see Figure 2).

4. Data and Empirical Modeling

Not all of the factors included in the theoretical model can be captured by data. In this section we describe the factors for which we do and do not have data for, and how those factors not represented by data are categorized as "unobserved" in our model. We then explain how observed and unobserved variables are treated in panel data models in general, and how we have operationalized the two sets of models that we have carried out for this study.

4.1 Data

To develop the empirical model we need to enter reliable data for both outcome (dependent) and explanatory (independent) variables. The outcome variable in the study is road fatalities per population calculated by dividing the total annual road fatalities by population, both of which came from an OECD database (4*)*

To select the best explanatory variables we need to consider all aspects of road safety that are presented in the conceptual model and ideally represent those factors by appropriate variables. However, some facets of the conceptual model cannot be represented either because the data are not available or because the factor cannot easily be quantified. Accordingly, we have two situations with regards to the independent variables: observed (or available) variables and unobserved (or unavailable) variables.

We identified data for the following variables from a number of international databases: gasoline price, unemployment rate, GDP per population (representative of socioeconomic) VMT per vehicle (representative of transportation behavior), vehicle ownership (representative of transportation exposure), and health factors (representative of mitigation factors). Data for the

unemployment rate, vehicle ownership, VMT, and GDP per population are derived from the OECD database (*4, and 27*). Gasoline prices came from the OECD database and a World Bank database (*28*)). The Health Index of HDI (Human Development Index), published by United Nation Development Program was used to represent health factors (UNDP (*29*)). Hence, we lacked data on technological changes, infrastructure conditions, and moderating factors. Also, the data of percent of urban population is available as a proxy of Urban Form but our findings in the precious paper showed that this factors is not significantly related to road fatality so we exclude it from the final models (9).

4.2 Preliminary Analysis of Data on Traffic Fatality Improvements

A preliminary analysis of traffic fatality changes in the last four decades shows a wide variety of progress for the 16 countries we studied (see Figure 3-a). It shows that the US had the lowest road fatality improvement over the period of analysis. The average annual change in traffic death in the US is more than two times lower than the best performing country. At the other end of the spectrum, Germany, Netherlands and Switzerland achieved the highest rate of improvement. In 1970, all three of these countries had higher than average road fatality rates. However, by 2010, after achieving high rates of improvement, the countries are ranked among the safest. In contrast, the level of fatalities in the US was around the average in 1970, but a relatively poor record of improvement has relegated it to the least safe country.

A comparison of the worst performing country (the USA), the best (the Netherlands), and the average is shown in Figure 3-b for five distinct points in time 1970, 1980, 1990, 2000, and 2010. In 1970, the USA fatality rate was equal to the average of other countries while by 2010 USA fatality rate was twice the average of other developed countries. In contrast, the

Netherlands, which in 1970 had road safety record similar to that of the USA, improved more than the USA (and the average for all countries) in the subsequent four decades.

4.3 Multi-Step Panel Data models

In order to analyze road safety changes among different jurisdictions, it is essential to use a method that is able to consider changes over time and variation between locations. Following the work of Grabowski et al. (*30*) and Ahangari et al. (*9*), we use panel data models to consider both time and country effects simultaneously. Panel models also allow us to consider the effects of omitted (unobserved) factors along with the effect of observed factors on road fatality. These unobserved factors may in turn be a structural factor common to all countries that changes over time, or something that is country specific.

Our findings in the previous paper indicate that country Fixed-Effect model is better than country Random-Effect model. This means that in international road safety models omitted variables are treated as being correlated with the dependent variables. Also, in the modeling phase we found that GLS (Generalized least squares) models works better than ordinary least square (OLS) models because the Standard Deviations of road fatality rate is not independent for each country (*9*).

By using panel models we can determine the effect of factors that relate exclusively to each country (country effect). We can use the country effect coefficient as an index to compare traffic fatality levels between the countries. By comparing country effects, we can quantify the role of unobservable factors such as infrastructure conditions, urban form, public transit quality, and driving behaviors on road safety conditions between different countries. In addition, the models generate outputs that describe the effect of unobserved factors that relate to time such as improvements in vehicle technology that we assume change over time but not between countries

with similar levels of development. A review of the conceptual model and the available data suggest the following list of potential omitted (unobserved) explanatory variables:

- Vehicle and other technologies (time variant)
- Infrastructure condition (location variant)
- Public transport, biking and waking (location variant)
- Enforcement (location variant)
- Policies and Regulations (location variant)
- Emergency response (both time and location variant)
- Driving Behavior, driving speed (location variant)

Each of these omitted variables can be designated as varying with time or with location or both. Thus when we obtain the country effect from the models we can consider those variables labeled ‘location variant’ as contributing to the country effect. The ‘time variant’ factors contribute to the time effect in the panel models.

To explore road safety changes in different countries we need to track changes over time for each country. To do this we develop panel models for three overlapping time intervals; first: 1990-1995-2000, second: 1995-2000-2004, and third: 2000-2004-2010. By using the country effects for each of three separate panel models we are able to quantify changes in road fatalities in each country. This approach was taken to overcome the limitations that single panel data models do not allow us to interact country and time effects.

To distinguish the effect of unobserved (omitted) factors at the country level we developed two different models: Overall Traffic Fatality (OFT) Model—a simple panel model which only includes time and country effect as independent variable, and Adjusted Traffic

Fatality (ATF) Model—a more complete model which controls for all of the quantifiable determinants of road fatalities such as health conditions, amount of travel, exposure factor, macroeconomic and socioeconomic conditions.

The OTF Model that assumes that traffic fatality conditions are a function of country factors and time factors is specified as follow:

$$\text{Log(Fat.rate)}_{it} = Country\ Effect_i + \sum \theta_t + \ \xi_{it} \qquad \text{(Equation 1)}$$

Where:

Fat.rate, refers to road fatality per 100,000 population;

ξ_{it}, the error term for country i at time t;

$Country\ Effect_i$ .fixed effect (dummy) for each country;

And, θ_t time dummy variable,

In the OTF model, the country effect (dummy values) of each country represents the overall safety conditions in that country without controlling for any moderating factors and is called the Overall Traffic Fatality Index (OTFI).

The ATF Model is specified as follows:

$$\log(\text{Fat.rate}_{it}) = \ \beta.\log(X_{it}) + Country\ Effect_i + \sum \theta_t + \ \xi_{it} \qquad \text{(Equation 2)}$$

Where:

Fat.rate, ξ_{it}, $Country\ Effect_i$, And θ_t *are the same as OTF model;*

Xit, set of endogenous and exogenous control variables;

β, estimated coefficient.

In the ATF model series of contributing and controlling factors are considered as independent variables which in the previous research we have found that all of them have a statistically significant effect on road fatalities including: real gasoline price, unemployment rate, GDP per population, VMT per vehicle, vehicle ownership, and health factors as well interaction between gasoline price and VMT per vehicle. In the ATF Model, the country effect represents the road safety conditions in each country after controlling for several factors that affect road fatality.

5. RESULTS AND DISCUSSION

As discussed above, we have developed two separate models to examine the research questions in this study. The first model uses panel data modeling techniques to obtain an Overall Traffic Fatality Index (OTFI) for each country for three time windows 1990-2000, 1995-2004, and 2000-2010. This index allows us to see how the countries ranked in each time period and how they have changed relative to each other over time. The second model, also based on panel modeling, differs from the first model in that it includes a number of control variables that are known to affect traffic fatality. From this model we can extract an Adjusted Traffic Fatality Index (ATFI) for each country for the three time windows listed above. Since this index is adjusted for socio-economic factors and the level of mobility it is a good proxy for omitted factors such as safe infrastructure, good safety policy and other intrinsic differences that are not represented in the model.

The Overall Traffic Fatality models for all three time windows are shown in Table 1-a. We will use the values in column 1 for the 1990 to 2000 time period to illustrate how this model

can be interpreted. For this time period, the dummy variable for 1990 (the first year in the period) is set to zero. The variables for 1995 and 2000 are then estimated as -0.19 and -0.34, respectively. This suggests that structural factors that change over time such as vehicle technology improvements are creating wholesale improvements in traffic safety in all countries. Another component of this modeling is the country effect or the Overall Traffic Fatality Index for each country (Table 2). This will be discussed further below. The statistical analysis reveals that all the models fit well with adjusted R^2 of 95% or more.

The results of the Adjusted Traffic Fatality model for all three time intervals are presented in Table 1-b. As with the OTF models, the adjusted R^2 for the model for all three time period is more than 95%. The results indicate that not all the independent variables are significantly related to road fatality. Furthermore the suite of variables that are significant is not consistent from time period to time period. Similarly, the direction of the relationships also varies over time. The only variable that maintains a consistent pattern are the unemployment rate and the Health Index. As is the case with the OTF model, the time variable becomes more negative with time. In other words, this represents global improvement in safety due to such factors as improvement in vehicle technology.

The country effects from the OTF Model are designated as the Overall Traffic Fatality Index for each country (Table 2). The OTFI represents the overall safety condition in each country relative to other countries, and the larger the value, the less safe the country. Values near zero represents countries that are close to the average and values below zero are the safest countries. As Table 2 shows, in the first interval (1990 to 2000) the US was the third worst country in terms of overall traffic fatality level at 0.36, trailing only Belgium and France. Conversely, at -0.44, the UK was the safest overall followed closely by Sweden and Norway. In

the second interval (1995-2004), the US had moved into the worst places at 0.48 followed by Belgium and Austria. The UK remained the safest country with a rating of -0.44, Sweden was in second place, and the Netherlands had moved into third place, replacing Norway. In the last time period (2000-2010), at 0.58, the US continued to rank as the worst performing country by a larger margin over the next worst country, Belgium. Also in this period, Sweden (-0.48) took over from the UK as the best performing country and the Netherlands remained in third place.

Using this index the relative change in performance of the different countries is not very dramatic except for a few examples (Table 2). One noteworthy result is that the US shows the largest deterioration in overall traffic fatality level relative to the other countries. But other countries that have deteriorated in terms of overall traffic fatality level such as Italy. Conversely, Netherlands, Switzerland and Germany show relatively large improvement in traffic fatality levels.

The Adjusted Traffic Fatality Index was also determined based on the country effects from the ATF model (Table 2). This value is an adjusted index that takes into account socio-economic and mobility factors including gasoline prices, unemployment rate, GDP per population, VMT per population, Vehicle Per capita, and health index. In addition, changes related to time (such as changes in vehicle technology like air bag and ABS brakes) are also accounted for in this model by including a time effect for data from each year. Thus, the ATFI represents influence of factors such as infrastructure safety, traffic enforcement, traffic laws, safety policies, and driving behavior over different period of time.

The variations in the ATFI are much more pronounced than the OTFI. For example, the US shows the worst deterioration in OTF going from third worst to the worst over the course of

the 20 years considered in the study (Figure 4). In the first period (1990-2000), the ATFI for the US was 0.04, exactly at the mean value for the 16 countries. In other words, the US was in the middle of the pack in terms of traffic fatalities when socio-economic factors, mobility level and health care were taken into account. This suggest that safety conditions in the US from the point of view of such factors as infrastructure, traffic enforcement, traffic safety culture, safety policies, and driving behavior was about average. But by the third period (2000-2010) the US ATFI was 0.70, much worse than any other country. This suggests that the USA had fallen behind the other countries in terms of factors such as infrastructure safety, traffic enforcement, traffic laws, safety policies, and driving behavior. The figure 4 illustrate similar trends of OTFI and ATFI for Italy.

In contrast, in the Netherlands, Germany and Japan, the decrease in the ATFI in these countries was much more than their corresponding decrease in OTFI. This finding suggests that these countries may have made progress in terms of improvement in infrastructure safety, traffic enforcement, traffic laws, safety policies, and driving behavior. More investigation is needed to verify if this is correct, but the results do seem to suggest that the two different indices we have developed provide insight into how and why traffic fatality rates are changing over time in the various countries.

6. SUMMARY and CONCLUSION

In this paper we have created two different indices for comparing how well countries are doing with regards to traffic fatality at different points in time. One index is the Overall Traffic Fatality Index (OTFI) based on the raw data but corrected for changes in fatality over time. The second index, the Adjusted Traffic Fatality Index (ATFI), is corrected for time as well as socio-economic factors, mobility levels, motorization and health care. Based on our conceptual model

of factors affecting traffic fatality levels we believe that this ATF index largely reflects the role of country specific factors such as differences in infrastructure, policy, enforce, driving habits and other factors. These are factors for which there are no readily available data for international comparison. Therefore, analysis of this ATFI index gives us a sense of how countries are advancing in terms of those factors related to the safety regime in each country.

In general, the rate of change in OTFI between countries is much less pronounced that the rate of change in the ATFI. This suggests that factors such as changes in mobility level and healthcare might be masking the true extent to which the countries are diverging in terms of improvements in traffic safety conditions. The examples of the USA and the Netherlands are instructive. The increase in OTFI for the USA is larger than any other country. This is reflected in the fact that the USA went from the third worst to the worst country over the course of 20 years in terms of overall traffic fatality level. But when we look at the ATFI, the performance of the USA is even more troubling. In the first time period (1990-1994), the ATFI for the USA was close to the median for the countries examined in this study. By the third time period (2000-2010) the ATFI for the USA was by far the worst of any country. This suggests that the USA has made scant progress relative to other countries in terms of addressing such factors as safer infrastructure, better driving behavior, and improved safety policies and enforcement. In comparison, countries like Sweden and the Netherlands performed better in terms of the ATFI than OTFI. This suggests that the emphasis that these countries have placed on prioritizing road safety by emphasizing street design and considering vulnerable road users are paying dividends. Their outstanding performance suggests that road safety in other countries, specifically the USA, would benefit from more states other than Washington adopting target zero death or vision zero-inspired policies.

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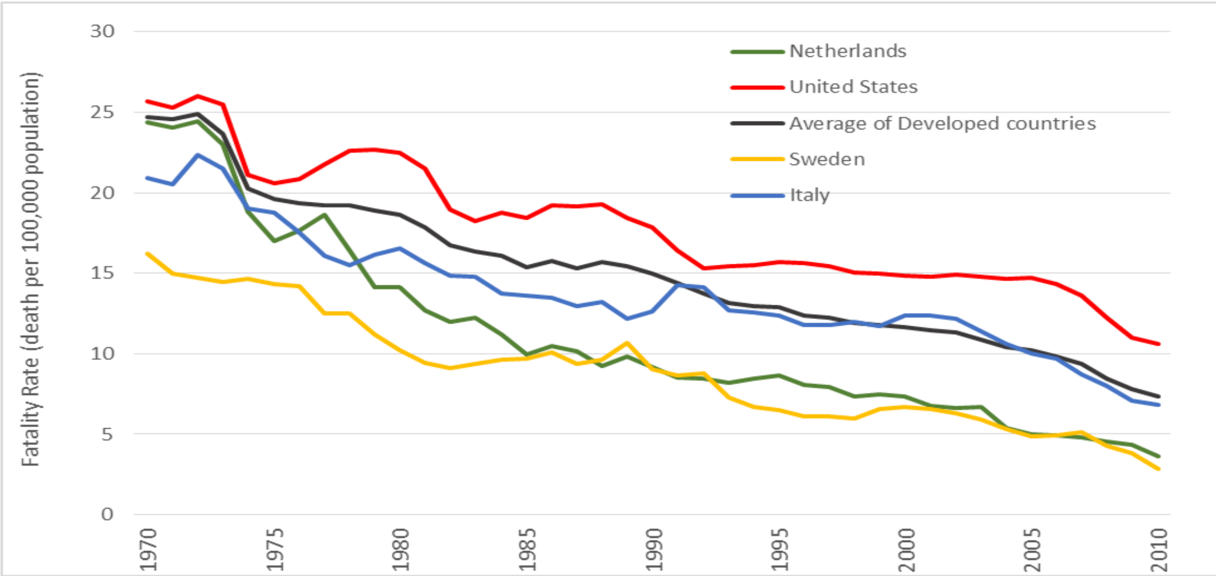


Figure 1 Road fatality rate trend in the USA, Netherland, Sweden, Italy and average of selected OECD countries from 1970 to 2010 (*4*)*

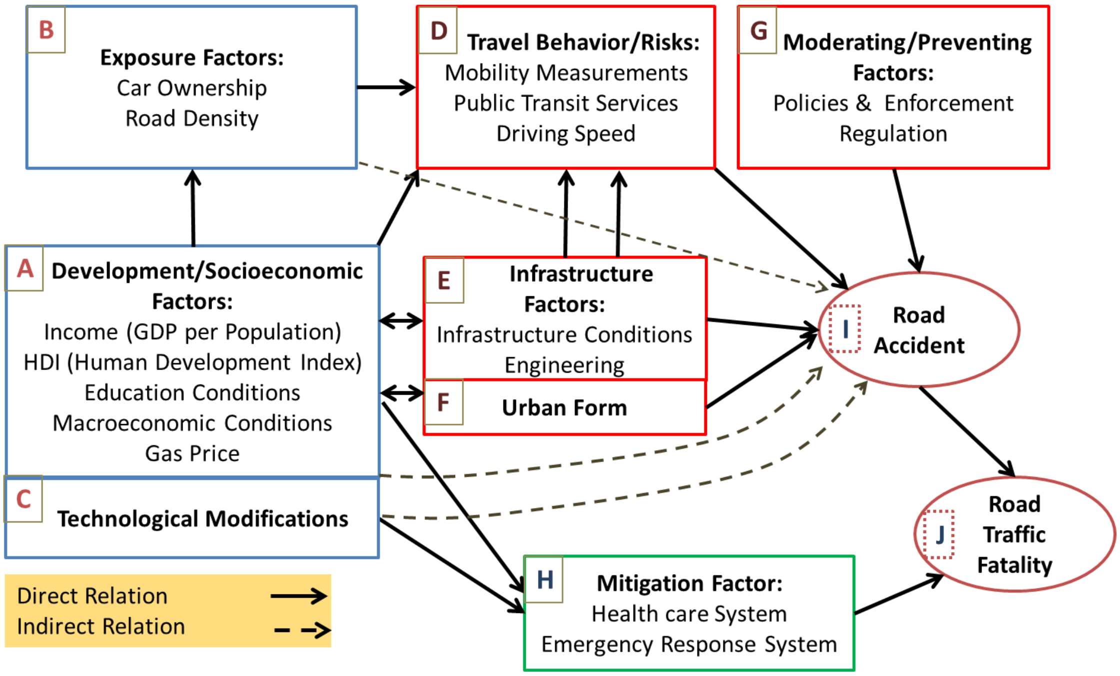


FIGURE 2 Comprehensive conceptual framework

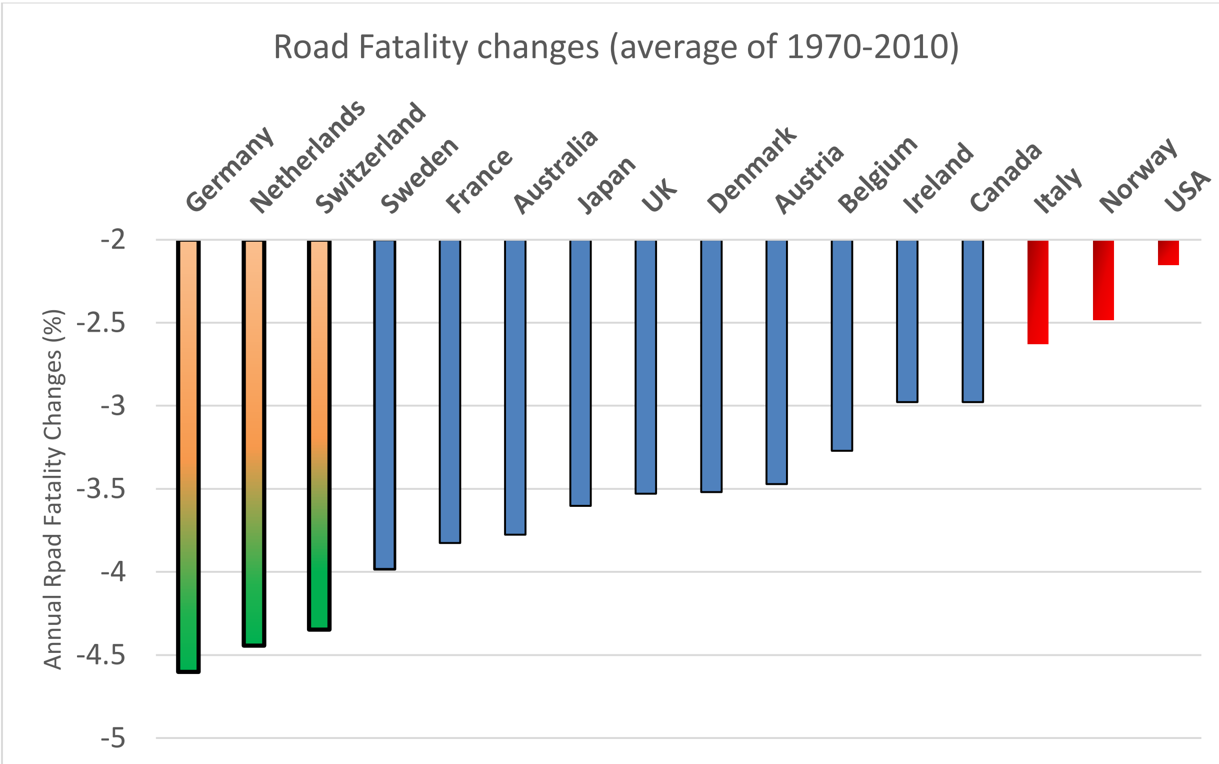


FIGURE 3-a Comparing average of traffic fatality changes in the last four decades

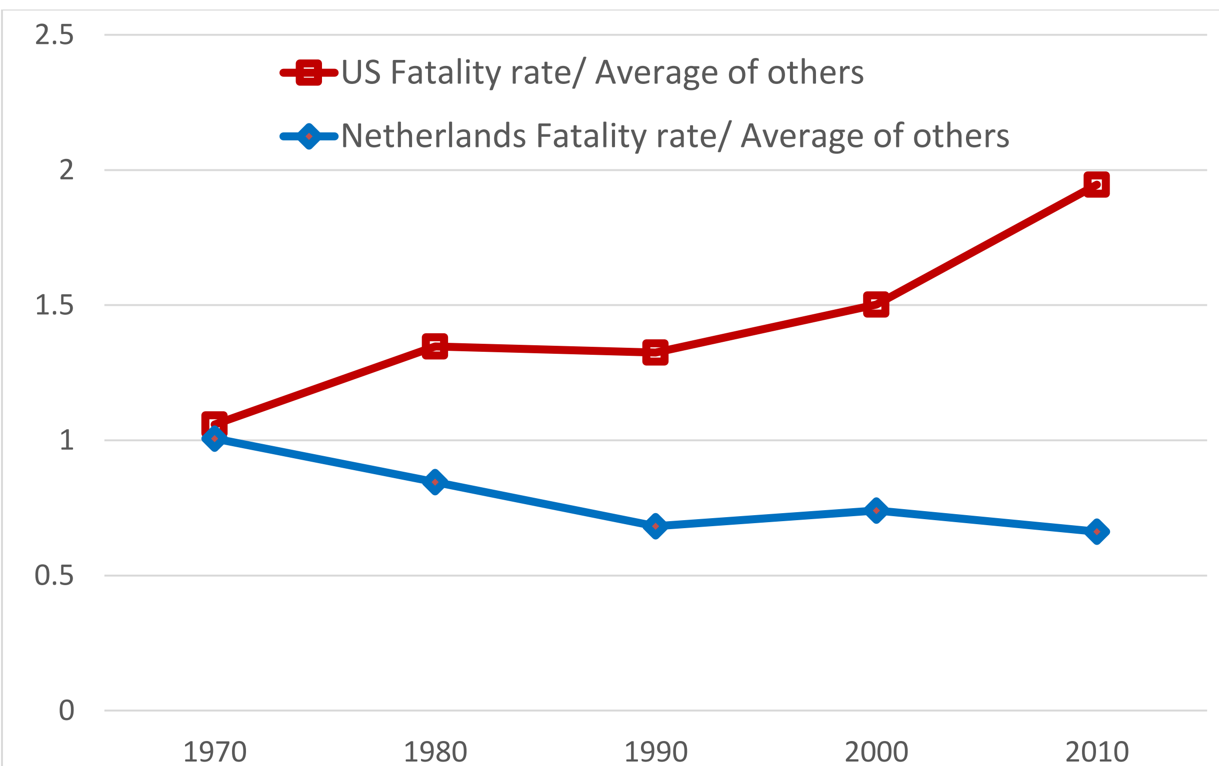


FIGURE 3-b Comparing fatality level in USA and Netherlands with the average of developed countries

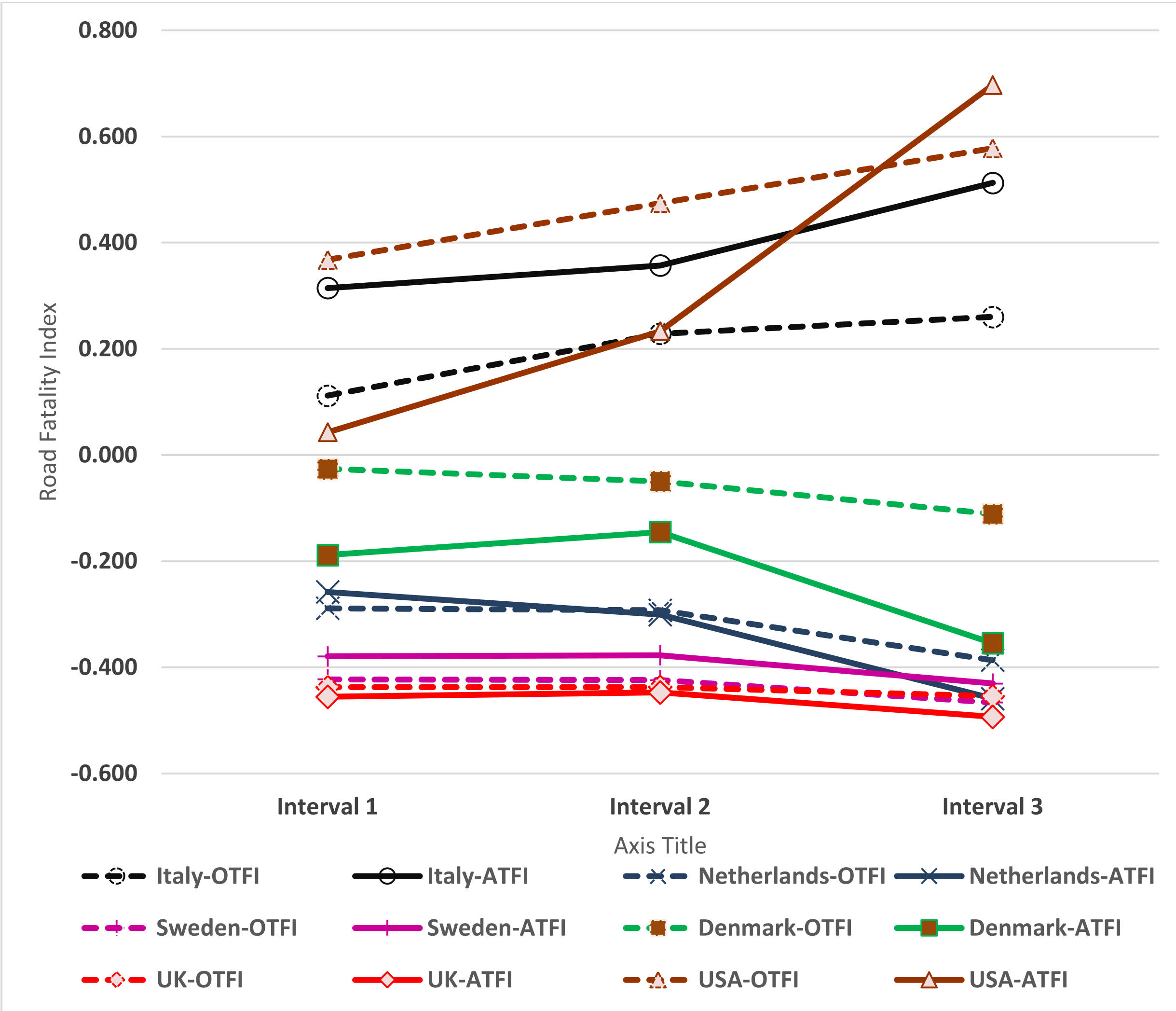


FIGURE 4 Comparing OTFI and ATFI in selected countries

Table 1-a Modeling results for OTFI Model (without road safety determinant)†

Independent Var. / Dependent Var.	**Fatality rate 1990-2000**	**Fatality rate 1995-2004**	**Fatality rate 2000-2010**
Intercept	2.586*	2.400*	2.26*
1990	0	-	-
1995	-0.19*	0	-
2000	-0.34*	-0.15*	0
2004	-	-0.34*	-0.20*
2010	-	-	-0.64*
R^2-Adjusted	0.97	0.96	0.98

Table 1-b Modeling results for ATFI Model (with road safety determinant)

Independent Var. / Dependent Var.	**Fatality rate 1990-2000**	**Fatality rate 1995-2004**	**Fatality rate 2000-2010**
Intercept	2.140*	2.392*	1.256
Real Gasoline Price	-0.096***	-0.023	-0.138***
Unemployment Rate	-0.047*	-0.073**	-0.066**
GDP per Population	0.158**	0.088***	0.204*
VMT per Vehicle	0.404*	0.331*	-0.365*
Vehicle per capita	0.105	0.150	-0.746**
Health Index	-3.594**	-1.965	-3.688
1990	0	-	-
1995	-0.16*	0	-
2000	-0.26*	-0.14*	0
2004	-	-0.23*	-0.13*
2010	-	-	-0.46*
R^2-Adjusted	0.98	0.96	0.96

†.To develop these models we used Eview-8 software package.
* Significant at 1% level,** Significant at 5% level, *** Significant at 10% level.

TABLE 2 Estimation of OTFI and ATFI for all Three Time Intervals

Index / Country	OTFI-Overall Traffic Fatality Index			ATFI- Adjusted Traffic Fatality Index		
	1990-2000	**1995-2004**	**2000-2010**	**1990-2000**	**1995-2004**	**2000-2010**
Australia	0.01	0.00	0.04	0.06	0.04	0.21
Austria	0.33	0.30	0.25	0.31	0.28	0.27
Belgium	0.37	0.32	0.34	0.36	0.31	0.35
Canada	0.03	0.03	0.08	0.02	0.02	0.18
Denmark	-0.03	-0.05	-0.11	-0.19	-0.15	-0.35
France	0.37	0.29	0.23	0.48	0.37	0.37
Germany	0.02	-0.03	-0.12	0.04	0.04	-0.09
Ireland	0.09	0.13	0.05	-0.06	0.03	-0.04
Italy	0.11	0.23	0.26	0.31	0.36	0.51
Japan	-0.12	-0.13	-0.17	0.13	0.02	-0.14
Netherlands	-0.29	-0.29	-0.39	-0.26	-0.30	-0.46
Norway	-0.34	-0.28	-0.27	-0.33	-0.29	-0.38
Sweden	-0.42	-0.42	-0.48	-0.38	-0.38	-0.43
Switzerland	-0.07	-0.13	-0.18	-0.09	-0.14	-0.19
UK	-0.44	-0.44	-0.45	-0.46	-0.45	-0.49
USA	0.36	0.47	0.58	0.04	0.23	0.70

Chapter 4. Progress Towards Zero, An International Comparison: Improvements in Traffic Fatality from 1990 to 2010, for Different Age Groups in the USA and 15 of its Peers

Abstract

In January 2015, the United States Department of Transportation (USDOT) announced that the official target of the federal government transportation safety policy was zero deaths. Having a better understanding of traffic fatality trends of various age cohorts—and to what extent the US is lagging other countries—is a crucial first step to identifying policies that may help the USDOT achieve its goal. In this paper we analyze fatality rates for different age cohorts in developed countries to better understand how road traffic fatality patterns vary across countries by age cohort. Using benchmarking analysis and comparative index analysis based on panel data modelling and data for selected years between 1990 and 2010, we compare changes in the rate of road traffic fatality over time, as well as the absolute level of road traffic fatality for six age groups in the US, with 15 other developed countries.

Our findings illustrate tremendous variations in road fatality rates (both in terms of the absolute values and the rates of improvement over time) among different age cohorts in all of the 16 countries. Looking specifically at the US, our analysis shows that safety improvements for Youngsters (15-17 years old) was much better than for other age groups, and closely tracked peer countries. In sharp contrast, Children (0-14 years old) and Seniors (+65 years old) in the US, fare very poorly when compared to peer countries. For example, in 2010, Children in the US were a stunning five times more likely to experience a road traffic fatality than Children in the UK. This startling statistic suggests an immediate need to explore further the causes and potential solutions to these disparities. This is especially important if countries, including the US, are to achieve the ambitious goals set out in Zero Vision initiatives.

Keywords:

Road safety Analysis, Age Cohort Analysis, International Comparative Studies, Zero Death Vision, Road Safety Improvements, Panel data analysis, Benchmarking analysis

1. INTROCUDTION

Claiming over one million lives a year around the world, road traffic fatality is a major global public health concern (WHO, 2013). For this reason, several international institutions including the Organization for Economic Cooperation and Development (OECD), the World Bank, and the World Health Organization (WHO) closely track road fatality trends in individual countries. Over the last four decades, road fatalities in almost all developed countries have decreased. This decrease is attributable to many factors including improvements in vehicle technology, emergency response technologies and medical treatment; and more stringent enforcement of road safety regulations (Ahangari et al., 2014, Noland, 2003, Page, 2001, Hakim, 1991). However, considerable variation exists in both the rate of improvement and the absolute values of road traffic fatality across different countries, even for those with similar levels of development.

The US, in particular, has underperformed most of its peers. Figure (1) shows that the average annual improvement in road traffic fatality in the US over the last four decades was just over 2%. This rate of improvement is less than half of that achieved by the best performing countries—Germany and the Netherlands— both of whom improved at annual rates of just over 4.5%. Prior research into the underperformance in the US has examined the potential role of latent factors such as safety culture, infrastructure conditions and safety polices on changes in road fatality levels (Ahangari et al., 2015). However, very little research has examined trends in traffic safety by age cohort, even though the existence of public policies directed towards different age groups suggests that the various age groups should have different rates of improvement.

In this paper we analyze the fatality rate for different age cohorts in developed countries to better understand how road traffic fatality patterns vary across countries by age cohort. One very specific question that we seek to answer is how the US is doing relative to its peers for the various age cohorts. Using data for selected years between 1990 and 2010 (1990, 1995, 2000, 2004, and 2010), we compare changes in the rate of traffic fatality over time, as well as the absolute level of traffic fatality for six age groups in the US and 15 other developed countries (Australia, Austria, Belgium, Canada, Denmark, France, Germany, Ireland, Italy, Japan, Norway, Sweden, Switzerland, and the UK). We used the OECD's terminology for age grouping, which is as follows: Children: Age 0-14, Youngster: Age 15-17, Late Teens: Age 18-20, Young Adult: Age 21-24, Adult: Age 25-64, and Senior: Age +65.

To better understand how fatality patterns vary across countries and by age cohort, we have identified the best-performing country for each age cohort. This analysis will help policy-makers identify which countries and for what age groups significant improvements have been achieved in traffic safety. Subsequent research will be needed to pinpoint exactly which policies were responsible for the improvements, which may then help other countries emulate the success of the best performing countries.

In January 2015, following the lead of New York City and San Francisco, AASHTO and the USDOT announced that zero deaths was the official policy of the US federal government transportation safety system (USDOT, 2015). This policy envisions zero deaths as the ultimate road safety goal. Having a better understanding of the traffic fatality trends of the various age cohorts—and to what extent the US is lagging other countries—is a crucial first step to identifying policies that may lead to more rapid improvements in road safety. Given that the zero deaths policy was inspired by Sweden's Zero Death Vision program, announced in 1997,

looking at initiatives in other developed countries would seem to be a natural starting point for innovative policies (Johansson, 2009). Furthermore, the findings of the benchmarking analysis for different age groups may help policymakers to develop a more effective road map toward a zero death goal by examining strategies and policies in the best performing countries for each age group.

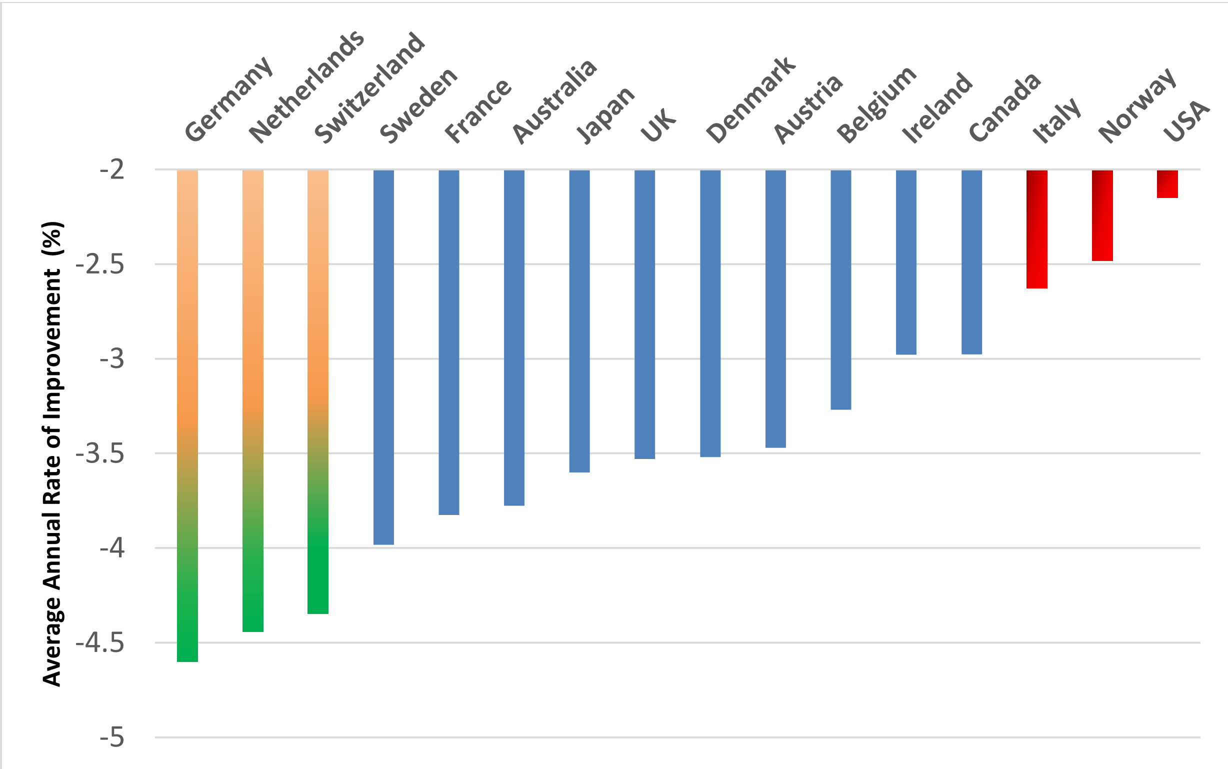


FIGURE 1 Average Annual Improvement in Traffic Fatality (1970-2010)

The paper is laid out as follows. Section two contains a review of pertinent literature that establishes that there is very little existing research on road traffic fatality trends by age cohort at an international scale. Section three articulates a conceptual framework that we have created based on the literature to theorize how and why different age cohorts may experience variation in road traffic fatality. Section four contains the empirical analysis that explains the two major

approaches that we took to analyzing the data. First, we created benchmarks using raw data for 1990 compared to 2010. This allowed us to identify the best-performing country in each age cohort at the beginning and end of our study period. In order to verify the statistical significance and robustness of these findings, we then created an index to compare the performance of each country over time using panel data modeling techniques. The results of these two complementary individual analyses were combined to quantify variations in the fatality rate for different age cohorts in developed countries, and changes in fatality rate over time. The final section of the paper contains a discussion of our results and the conclusions.

2. LITERATURE REVIEW

A comprehensive analysis of existing research reveals a lack of research on road safety for different age groups at an international scale. Instead, existing research follows two distinct themes: (1) road safety outcomes by age cohort within individual countries; and (2) studies that have examined the traffic safety improvements for the population as a whole across different countries. To date, no research has brought together these two strands of literature. In the subsequent subsections, we summarize these two strands of literature.

2.1. The Effect of Age Composition on Traffic Fatality

One of the first studies of traffic safety that illustrated the need to examine different age groups was conducted by Sivak (1983). Using data for the 50 states as well as the District of Columbia, Sivak (1983) found that the risk of road fatality in areas with a higher percentage of young drivers was higher than in other jurisdictions. This pattern was not seen for other age groups including older drivers. In 1987, Loeb investigated the determinants of road fatality across states and found that states with a higher percentage of adult and senior drivers had lower traffic

fatality rates. Both studies suggested that the presence of young drivers plays an important role in road safety but stopped short of articulating a theoretical relationship between age and road fatality.

After highlighting the importance of younger age groups in road safety analysis, and in response to the lack of theoretical frameworks, a second stream of age-related research emerged. This body of work, strongly rooted in behavioral psychology, focused on the conceptual connections between young drivers' behavior and road safety. The aim of these studies was to isolate factors exclusive to road safety for youths (Gregersen and Bjurulf ,1996; Deery,1999 Juarez et al., 2006). For example, Deery (1999) stated that road fatality rates for young people were higher because they underestimated risk and overestimated their own skills. Consequently, numerous studies focused on the effect of policies such as the Graduated Driver Licensing (GDL), which restricts the conditions under which new drivers can operate. These studies recommended the implementation of GDL policies to improve safety for this age cohort. Research conducted after the implementation of GDL policies used approaches such as analyzing trends in data and before-and-after rates to evaluate the effectiveness of GDL policies (Williams ,2003 ,2010; Shope ,2007; and Rogers et al.,2011).

Very little research has used comprehensive statistical models populated with empirical data to examine the relationship between age cohort and road safety, and that which does exist tends to focus on young drivers (the highest risk group). For example, Dee et al. (2005) developed a negative binomial model using annual data for 1992 to 2002 for all states to assess the effect of GDL programs on the rate of youth road fatality. The results indicate that GDL regulations reduced traffic fatalities among 15–17-year-olds by at least 5.6%. In another study, Morrisey et al. (2011) used annual data for 1985 to 2006 for all states and found that gasoline

prices and beer taxes were statistically significant predictors of youth traffic fatality. Results from a suite of models indicated that a 10% increase in gasoline prices reduced fatalities for different age cohorts by between 3.2 and 6.2%, with the largest percentage reductions occurring among drivers aged 15-17 years old. In addition, they found that a 10% increase in beer taxes was associated with a 1.3 % reduction in road traffic fatality rates of drivers? aged 15-17 years old.

Very few studies have addressed road safety performance for other age groups. After reviewing the available literature, Laflamme (2000) recommended that road traffic fatality for Children deserved closer scrutiny in future research. Zeedyk et al. (2001) found that educating Children about traffic safety had little effect on road traffic fatality rates for this age cohort. Using data for 2002 through 2006 in Scotland, Pearson and Stone (2010) illustrated that road fatality is the leading cause of death for Children in three distinct age groups (0-4, 5-9, and 10-14). More recently, Sivak separated data on US fatalities from 1958 to 2008 into different age groups, and found that the reduction in road traffic fatality for both the youngest and oldest groups were steeper than for any other age cohorts (Sivak, 2011).

2.2. International Improvements in Traffic Fatality

Only a handful of macro-scale studies have focused on the relative rate of improvement of traffic fatality between developed countries. In one such study, Lassare (2001) used a linear trend model to develop an indicator that tracks the long-term rates of progress in road safety in different countries. He analyzed road safety patterns in ten European countries using annual data from 1950 to 1994. After developing an indicator of the rate of progress that took into account exposure (represented by vehicle-km travelled), he concluded that most European countries

exhibited a rate of improvement of more than 4.5 percent per year. He also found that Sweden had one the highest rate of improvements. In 2003, Noland looked at the variation in the percentage change in road fatalities among industrialized countries. He found that improvements in medical treatment (as represented by infant mortality rate and number of physicians per capita) was the number one factor that explained the reduction in road fatality rates in developed countries from 1950 to 1994.

In 2012, Borsos et al. developed a traffic safety trend analysis for 26 developed countries. Their model included both country-level (time series) and time-dependent (cross-section) analysis using annual data from 1965 to 2009. They found that the trends in road fatalities changed over time. In some countries such as the US, the rate at which fatalities have changed has slowed with time. In others, such as the Netherlands, fatalities have decreased at a more persistent rate. Using data for 16 developed countries from 1990-2010, Ahangari et al. (2015) developed a two-step panel model to analyze the rate of improvement in road fatality. After controlling for macroeconomic conditions, gasoline price, motorization level, health factors, and Vehicle Miles Travelled (VMT) they found that country specific factors such as safety culture, safety policies, and infrastructure conditions shape road traffic fatality performance. The model produced an index of relative performance and showed that hard to quantify country-specific factors have a positive outcome in the Netherlands, Germany, and the UK, but a negative outcome (in relative terms) in the US and Italy.

A more recent trend in international safety is the development and use of various composite indices for benchmarking or comparing the performance of countries. Benchmarking allow countries to potentially learn from peer countries that are performing in a superior manner. One of the first international bench marking model was developed by Kornestra et al. based on a

study of road safety performance and policies in Sweden, the United Kingdom, and Netherlands. The data for these countries, dubbed the S.U.N. countries, was used to develop a composite index for characterizing the performances of these countries. The model itself was called the SUNflower model. The later version of the model, the SUNflower *Next*, consists of three types of indicator: road *safety outcomes* such as fatality numbers and social costs, *implementation performance indicator*, which quantify the implementation of road safety policies, and *policy performance indicators*, (Wegman et al, 2008). This model has been used to compare other European countries with the three SUN countries as a way of identifying potential improvements to policy that should be implemented (Kornestra et al., 2002).

In 2007, Al Haji (2007) developed the Road Safety Development Index (RSDI) for eight European and five Asian countries. The RSDI consisted of thirteen indicators across three pillars. Based on the RSDI, Al Haji also found that Sweden and UK were the best performing countries. Hermans et al. (2008) developed a similar Road Safety Performance Index to conduct benchmarking analysis for European countries. Finally, in 2010, Wegman and Oppe, developed a grouping analysis based on the SUNflower model to identify the best performing groups of countries. It should be noted that while these benchmarking studies have been very useful, none of these analyses have considered age variations in traffic safety or changes in relative performance over time.

2.3. Synthesis of Literature

Two gaps in the existing literature on age composition analysis in road safety are evident. (1) There is no comprehensive conceptual framework that explains how and why different age groups might have different outcomes for road traffic fatality. (2) Very little research has been

undertaken at the international scale to compare road traffic fatality rates for distinct age cohorts (even for youths, the most often studied group within individual countries). While the main aim of this paper is to address the second issue, doing so requires us to first address the issue of a conceptual framework for understanding how and why there might be differences in traffic safety outcomes for different age groups.

3. CONCEPTUAL FRAMEWORK

As mentioned above, in this section, we briefly sketch the broad contours of a theoretical framework that explains how different age groups might have different outcomes in terms of road traffic fatality, focusing on how specific policies targeted at individual age groups can shape these outcomes. This framework is tied to the research literature. We have synthesized six sets of factors that determine road safety at various scales from the micro (individual) to macro (societal), as shown in Figure 2.

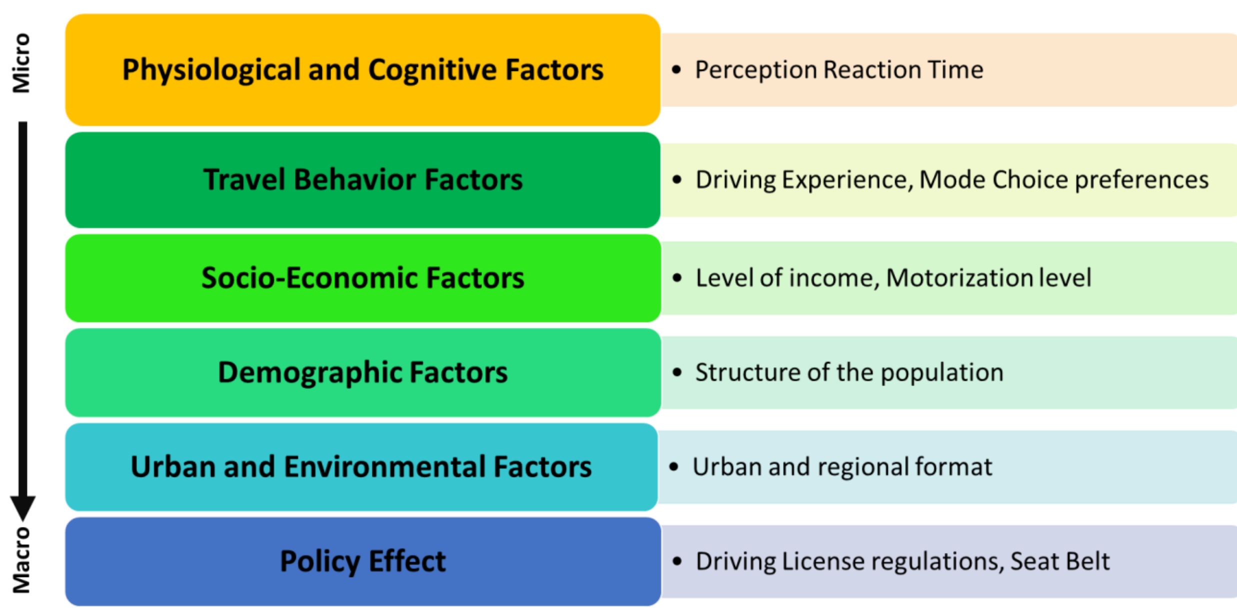


FIGURE 2 Conceptual Relations between Age Differences and Road Safety

The first determinant of road safety relates to an individual's physiological and cognitive capabilities (see for example Safety Net (2009)). The extent to which perception-reaction time varies among different age groups is an example of a cognitive factor affecting road safety in different ways for the various age cohorts (Deery,1999). A second set of factors that influence road safety across age groups relates to travel behavior, specifically mode choice, amount of driving, and driving experience. For example, Seniors are less likely than young people to choose driving for long trips. However, the younger a person is, the less likely they are to have much experience driving. On the other hand, people with more experience may be willing to drive in more risky conditions such as inclement weather (Shope and Bingham, 2008). The third set of factors that tie age to road safety are socio-economic characteristics such as level of income. Consider, for example, a newly-licensed high school student with little to no income driving an inexpensive old vehicle without airbags and anti-lock brakes compared to a middle-aged, middle-class family head driving the latest minivan loaded with safety features such as rear-view cameras (Shope and Bingham, 2008).

We have identified three different sets of contextual factors, relating to the social context, the built environment, and the policy regime. The social context, such as the demographic structure of the population, has a demonstrated effect on road fatality. As shown by Loeb (1987), areas with more young people have higher levels of road fatality. The built environment could also theoretically affect road safety differently for different age cohorts. For example, American Children are much more likely to live in suburban, automobile-oriented environments, than in cities. With greater exposure through higher levels of VMT, their risk of death increases. The final set of factors that shape how age relates to road safety is through government policies. As discussed in the literature review, one of the most prominent examples

of this is the GDL, which has improved road safety for young drivers (Morrisey and Grabowski, 2011).

4. EMPRICIAL STUDY

4.1. Data & Preliminary Analysis

We used traffic fatality data for 1990, 1995, 2000, 2004, and 2010 from the OECD for six age groups (Children: Age 0-14, Youngster: Age 15-17, Young Driver: Age 18-20, Young Adult: Age 21-24, Adult: Age 25-64, and Senior: Age +65) for 16 countries (Australia, Austria, Belgium, Canada, Denmark, France, Germany, Ireland, Italy, Japan, Norway, Sweden, Switzerland, the UK, and the US) (OECD). A preliminary analysis of the raw data showed stark differences in fatality rates (1) between age groups; (2) between countries and (3) over time. Looking first at the between age group variation, in 2010, in 11 of the 16 countries, the age cohort with the highest rate of road traffic fatality was Late teens (Age 18-20). The exceptions were Ireland and the US where Young Adults (age 21-24) had the highest rate, and Japan, the Netherlands, and Switzerland where the highest rate was for Seniors (Age 65+). In all countries, road traffic fatality rates are lowest for Children (Age 0-14). The ratio between the highest and lowest road traffic fatality rates for the different age groups is as high as 27, in this case for Norway. While some of this high ratio can be attributed to the fact that Norway has one of the lowest traffic fatality rates for Children, it means that a person in the highest risk category (Late Teen, 18-21), is 27 times more likely to experience a road traffic fatality.

Turning now to variation between countries, as of 2010, the US had the highest overall traffic fatality rate. At 10.5 per 100,000 per capita, this is a factor of 3.7 times that of the safest country, Sweden. Examining changes over time shows two very important facts. The first is

that all countries have improved in traffic safety over time. Secondly the rate of improvement is unrelated to the absolute level at the beginning of the time period. In other words, in 1990, Sweden had an overall road traffic fatality rate of 9.0 per 100,000 population compared to 17.5 for the US. Nevertheless, by 2010, Sweden had improved by 69%, whereas the US had managed only a 40% improvement despite starting at a higher rate. This preliminary analysis suggests the need to use methodologies that capture the variation across all of the above-mentioned dimensions—between age, between country, and over time.

4.2. Methodologies

To study all the above variations we develop two types of methodologies: a benchmarking analysis and a comparative index analysis. In this section, we first discuss the method that we used for benchmarking analysis. Then we discuss the panel data model used to understand road safety changes among different age groups.

4.2.1. Benchmarking

For the benchmarking analysis we compared the absolute levels of road fatality for the overall population as of 1990 and 2010 for each country. We then examined these data for each age cohort by country and over time. This allowed us to rank countries in terms of their absolute level of fatalities for each age group and determine how those rankings changed between 1990 and 2010. A second benchmarking analysis based on the annual rate of improvement attained from 1990 to 2010 allowed us to rank countries in terms of their rate of improvement. Taken together, these analyses allow us to identify which countries had the best absolute levels of road traffic fatality by age cohort, and which countries experienced the highest rate of improvement. The absolute level reflects the overall safety condition for each age cohort at a particular point in

time while the analysis of changes in that rate over time identifies which countries may have implemented policies that have had a pronounced impact on specific age cohorts.

4.2.2. Panel Data Analysis

We complemented the benchmarking analysis with panel data models for two reasons. First, the panel data models allow us to consider more time intervals, which provide a more nuanced understanding of improvements in smaller time increments. The panel data models also help us to explore road safety changes in different countries in a way that allows us to verify the statistical significance of our findings. Accordingly, we developed panel models for three overlapping time intervals: (1) 1990-1995-2000; (2) 1995-2000-2004; and (3) 2000-2004-2010. To estimate the relative performance of countries in each age group, we ran a series of six simple panel models with the dependent variable as fatality rate (for each of the six age cohorts) and time and country effect as independent variables. Following Ahangari et al. (2015), the resultant Overall Traffic Fatality (OTF) Model assumes that traffic fatality conditions for each age cohort are a function of country factors and time factors and specified as follows:

$$\text{Log(Fat.rate)}_{it} = Country\ Effect_i + \sum \theta_t + \xi_{it} \qquad \text{(Equation 1)}$$

Where:

Fat.rate, refers to road fatality per 100,000 population;

ξ_{it}, the error term for country i at time t;

$Country\ Effect_i$ .fixed effect (dummy) for each country;

And, θ_t time dummy variable,

Based on Ahangari et al. (2014), the country effect dummy estimate in this model captures the relative safety conditions in each country. The estimated value of the country effect

is a relative level of fatality for each country. A country with an average rate of fatality will have a value of zero for this index. A country with a negative value will have a fatality rate lower than average. By using the country effects for each of three separate panel models we are able to quantify changes over time in road fatalities in each country relative to the other countries. This approach was taken to overcome the limitation resulting from the fact that a single panel data model do not allow us to interact country and time effects.

5. RESULTS

In this section first we presents results of benchmarking analysis for two dimensions of road safety: the absolute number of fatality rate and the relative improvement rates. Then we determine best performing countries in both dimensions. In the rest of the section we provide the results of panel data modeling to develop comparative indices for all age cohorts over time.

5.1. Benchmarking analysis

Our first benchmarking analysis compared the absolute levels of road fatality for the overall population as of 1990 and 2010 for each country. The resultant rankings for each country on an overall basis, as well as by age cohort are set out in Figure 3. Figure 3.1 presents the overall road fatality ranking in all countries in 1990 and 2010. It shows that in 1990 the safest countries were Norway and Sweden, but after two decades Sweden attained first place followed by the UK. At the other end of the spectrum, Austria and Belgium had the worst absolute levels of overall traffic fatality in 1990. Two decades later, the US was in last place replacing Austria while Belgium still remained as the second worst country.

The results of our examination of these data for each age cohort by country and over time (and ordered highest to lowest) are shown in Figures 3.2-3.7. The results for each age group are discussed below.

Figure 3.2, Children (0-14)*:* In 1990 the safest places among these 16 countries for the Children were Norway and Switzerland with rates of 2.2 and 2.5. In contrast, the least safe countries were Belgium and Denmark with rates of 6.0 and 5.5 respectively. After two decades of improvement in all countries, the UK has become the safest place with a rate of 0.38 and Norway settled in second place with a rate of 0.4. In 2010, the US dropped to the position of the least safe country with a rate of 2.0, 30 percent higher than the rate of the second least safe country for Children, Australia, with the rate of 1.3 road fatality per 100,000 Children.

Figure 3.3, Youngsters (15-17): Sweden and Switzerland were the safest countries for Youngsters in 1990 at 10.0 and 10.8 fatality rate, respectively. With 25.2 and 20.2, the US and France had the two highest levels of road fatality rates for Youngsters. In 2010, Sweden kept its position as the safest country for Youngsters with a rate of 2.3, and the Netherlands moved to second place with the rate of 3.3. The US remained the worst country with 9.1 fatalities per 100,000 Youngsters followed by Austria with 9.0.

Figure 3.4, Late Teens (18-20): In 1990, Netherlands was the safest country for this age group with a rate of 18.6 followed by Denmark with a rate of 20.4. At this time Austria was the worst country with a surprisingly high rate: 61.4. Belgium at 49.8 was the second least safe country. After two decades, in 2010, Sweden with a very sharp improvement jumped five places to the level of safest country for Late Teens with a rate of 5.3. Japan also showed marked improvement

and moved to second place with a rate of 5.8. The US and Belgium were the two least safe countries for young people with rates of 18.5 and 17.8, respectively.

Figure 3.5, Young Adults (21-24): As the figure shows, in 1990 Norway with 12.6 fatality per 100,000 Young Adults had the best rate followed by Sweden with a value of 13.6. At the same time, France and Belgium with rate of 45.1 and 42.2 respectively, were the countries with the highest risk for Young Adults. In 2010, after a very big leap from the rank of 12th, Switzerland captured the first place with the rate of 4.0. Similar to Switzerland Japan enhanced its ranking significantly and became the second safest country for this age group with a rate of 4.1 fatality rate. On the other hand, the USA dropped to last place with fatality rate of 19.0 while Belgium remained as the second worst country with a rate of 17.0 per 100,000 Young Adults.

Figure 3.6, Adults (25-64): In 1990, the safest country for adults in terms of road fatality were Norway and the Netherlands with rates of 7.0 and 7.7, respectively. France and Austria were the least safe countries for adults with road fatality rates of 19.7 and 19.0, respectively. After two decades, the ranking of countries changed significantly with Sweden jumping from fourth to first place with a rate of 2.8 followed by Japan with a rate of 3.0. The US slipped four slots to last place with a fatality rate of 11.6 per 100,000 adults. Not only does the US occupy the last place, but also the rate is significantly higher than the second worst country, Belgium, with a rate of 9.3.

Figure 3.7, Seniors (+65): In 1990, Norway with 9.0 fatalities per 100,000 Seniors had the best rate followed by Sweden with a rate of 12.6. Austria and Japan with rate of 24.0 and 23.8, respectively, were the highest risk countries for Seniors. In 2010, the UK moved into first place with a rate of 3.7 while Sweden remained in second place with a rate of 3.7. The US dropped

sharply from 11th to last (16th) place with a fatality rate of 13.4, much worse than the second worst country, Japan, with a rate of 10.2.

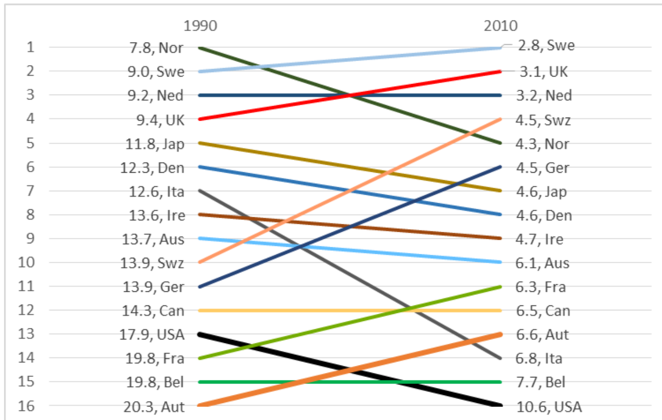
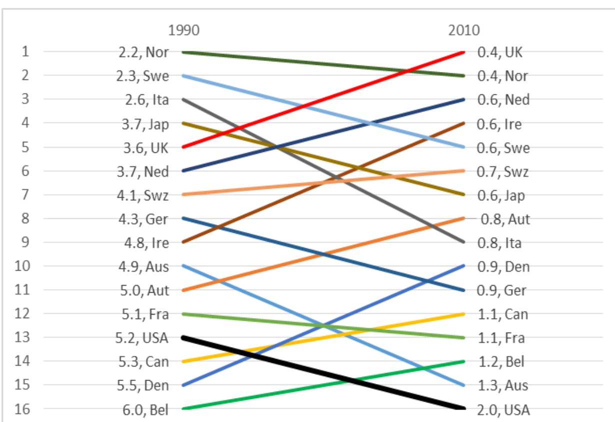


FIGURE 3-1 Overall road safety Ranking



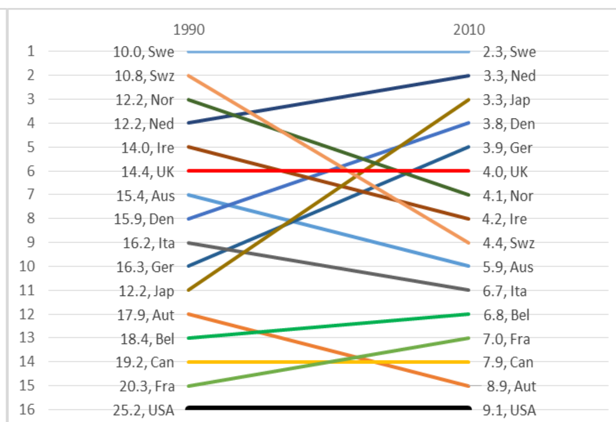
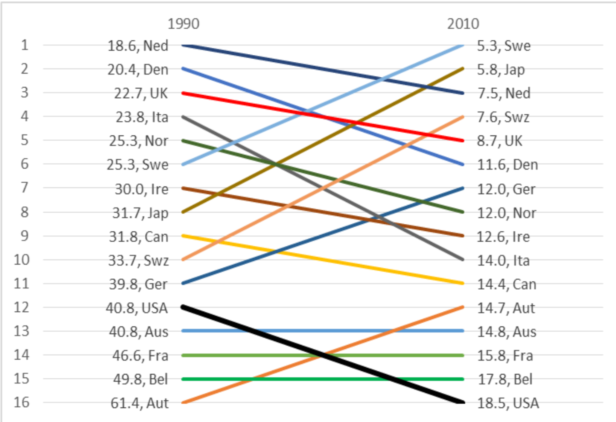


FIGURE 3-2 Ranking of fatality rate-Children **FIGURE 3-3 Ranking of fatality rate-Youngster**



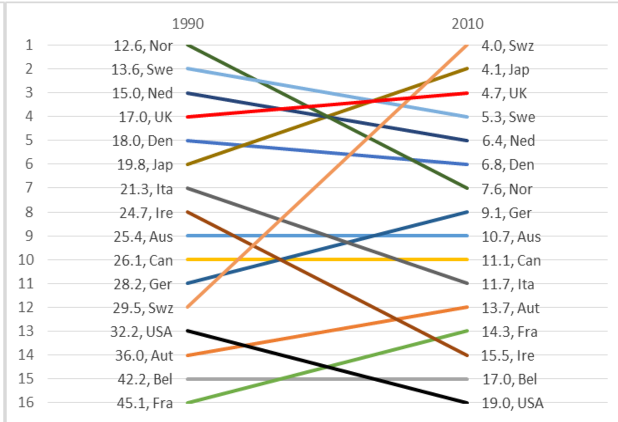
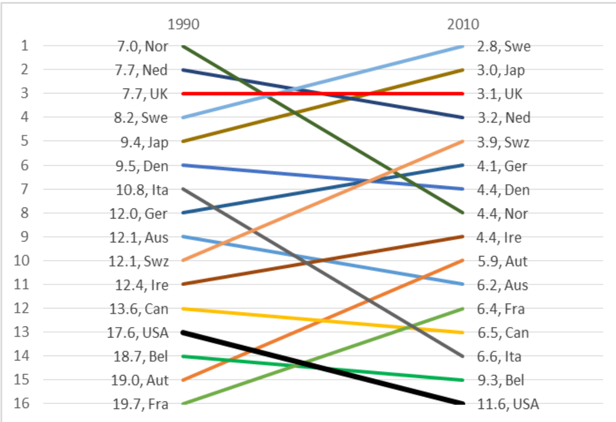


FIGURE 3-4 Ranking of fatality rate-Young Driver **FIGURE 3-5 Ranking of fatality rate-Young adult**



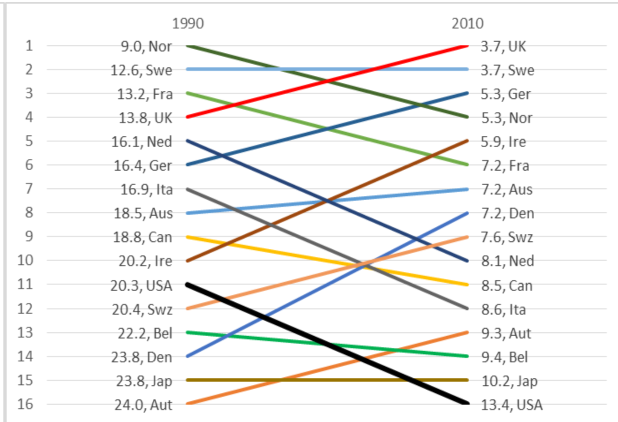


FIGURE 3-6 Ranking of fatality rate-Adult **FIGURE 3-7 Ranking of fatality rate-Senior**

A second benchmarking analysis based on the annual rate of improvement attained from 1990 to 2010 allowed us to rank countries in terms of their rate of improvement. Table 1 shows the average annual percentage rate of improvement for all six age groups in 16 selected countries.

TABLE 1 Average Annual Rate of Road Safety Improvements 1990-2010

COUNTRY	CHILDREN 0-14	YOUNGSTER 15-17	YOUNG DRIVER 18-20	YOUNG ADULT 21-24	ADULT 25-64	SENIOR +65
AUS	3.7	3.1	3.2	2.9	2.4	3.0
AUT	4.2	2.5	3.8	3.1	3.4	3.0
BEL	4.0	3.2	3.2	3.0	2.5	2.9
CAN	4.0	2.9	2.7	2.9	2.6	2.7
DEN	4.2	3.8	2.2	3.1	2.7	3.5
FRA	3.9	3.3	3.3	3.4	3.4	2.3
GER	3.9	3.8	3.5	3.4	3.3	3.4
IRE	4.3	3.5	2.9	1.9	3.2	3.5
ITA	3.5	2.9	2.1	2.3	2.0	2.4
JAP	3.7	4.0	4.1	4.0	3.4	2.9
NED	4.2	3.7	3.0	2.9	2.9	2.5
NOR	4.0	3.3	2.6	2.0	1.8	2.0
SWE	3.6	3.8	4.0	3.1	3.3	3.5
SWZ	4.2	3.0	3.9	4.3	3.4	3.1
UK	4.5	3.6	3.1	3.6	3.0	3.7
USA	3.1	3.2	2.7	2.0	1.7	1.7

*Children (0-14)***:** Column 2 in the Table (1) shows annual rate of improvement for all countries in the last two decades for Children age group. As the table shows, the UK has the highest rate of improvement (4.5% per annum), which translates into a 90% improvement from 1990 to 2010. Ireland has the second highest rate of improvement, with 4.3% a year. At the other end of the spectrum the US registered the lowest rate of improvement with 3.1% per year, translating to 62% decrease over the twenty year period.

Youngsters (15-17): From 1990 to 2010 the Youngsters fatality rate in Japan improved by 4.0% each year, translating into an 80% improvement over the two decades. Germany and Denmark tied for second place with annual improvements of 3.8%. Austria showed the lowest level of annual improvements (2.5%) followed by Canada and Italy with 3% annual

improvements. In this age category, the US achieved a 3.2% annual improvement, which was better than six other countries.

Late Teens (18-20): With annual reductions of 4.1% and 4.0%, respectively, Japan and Sweden had the highest rate of improvements from 1990 to 2010. The lowest levels of improvement are observed in the Italy and Denmark with only a 2.0 and 2.2 percent annual rate of reduction. For this age cohort, the US shows a 2.7% annual improvements, which is better than five other countries.

Young Adults (21-24): With average annual rates of improvement of 4.3% and 4.0% respectively, Switzerland and Japan performed the best in this age category. The lowest improvements were in Ireland (1.9%), Norway (2.0%) and the US (2.0%).

Adults (25-64): Three countries (Austria, Switzerland and Denmark) registered improvements of 3.4% in this age category, twice the rate of the US, which had the smallest rate of improvement (1.7%).

Seniors (+65): The best performing countries in this age cohort were the UK and Sweden, with average annual improvements of 3.7% and 3.5% respectively. Again, the US had the lowest level of improvement, at 1.7%.

5.2. Best performing countries

A review of each country's safety record based on the absolute fatality rate allows us to identify the best performing country in each cohort. Table 2 shows the best performing country in each age group in 1990 and 2010, along with the range for all of the countries, the average rate for all countries, and (in the final column), the rate for the US.

TABLE 2 Best Performing Countries

	Year	*Range for All Countries*	*Best Country*	*Fatality rate of Best Country*	*Average*	*USA rate*
Children	1990	2.2-6.0	Norway	2.2	4.2	5.2
0-14	2010	0.4-1.9	UK	0.4	0.8	1.9
Youngster	1990	10.0-36.9	Sweden	10.0	25.2	15.3
15-17	2010	2.3-9.1	Sweden	2.3	5.1	9.1
Late Teens	1990	18.6-61.4	Netherlands	18.6	33.4	40.8
18-20	2010	5.3-18.5	Sweden	5.3	11.6	18.5
Young Adults	1990	12.6-45.0	Norway	12.6	25.0	32.2
21-24	2010	3.9-19.0	Switzerland	3.9	9.5	19.0
Adults	1990	7.0-19.7	Norway	7.0	12.0	17.6
25-64	2010	2.8-11.6	Sweden	2.8	4.9	11.6
Seniors	1990	9.0-24.0	Norway	9.0	18.0	20.2
+65	2010	3.7-13.4	UK	3.7	7.2	13.4

Analyzing the data in this way allows us to identify the best country in each age group in absolute terms at the two time intervals, and to understand how the US compares to both the best-performing country and the average of all countries. For example, the fatality rate for Children in the US is five times that of the best-performing country (the UK) and two and a half times that of the average of all countries in 2010.

Table (3) shows which countries have performed the best in terms of their annual rate of improvement in the last two decades. This helps us to identify which countries had the most effective outcomes for particular age cohorts. For example, the UK achieved the best rates of improvement for both Children and Seniors.

TABLE 3 Best Improving Countries (Annual Rate of Improvement)

	Range of Rate	*The country with the best rate of Improvement*	*The best country*	*Average of All countries*	*The rate of improvement in the US*
Children 0-14	3.1-4.5	UK	4.5	3.9	3.1
Youngster 15-17	2.5-4.0	Japan	4.0	3.4	3.2
Late Teens 18-20	2.1-4.1	Japan	4.1	3.1	2.7
Young Adults 21-24	1.9-4.3	Switzerland	4.3	3.0	2.0
Adults 25-64	1.7-3.4	Austria	3.4	2.8	1.7
Seniors +65	1.7-3.7	UK	3.7	2.9	1.7

Adults and Seniors had the lowest rates of improvement among all age cohorts in the US (1.7%), with Seniors doing slightly worse than Adults when compared to other countries.

5.3. Comparative Panel Modeling Results

We used panel data modeling techniques to obtain an Overall Traffic Fatality Index (OTFI) for each country for three time windows: 1990-2000, 1995-2004, and 2000-2010. For each age group, this index allows us to see how the countries ranked in each time period and how they have changed relative to each other over time, in a more statistically robust manner than our earlier analysis of the raw data. The highest value means the highest relative risk of fatality in that country. Table 4 presents the results of OTFI for each age group and for all countries in the three time periods. For example, the highest (least safe) relative road fatality index in the 1990-2010 in the Children age cohort is 0.43 for the US and the lowest (safest) is -0.53 for Sweden (An OTFI value zero indicates a country with average level of fatality for a given time period and a positive value indicates a country with a higher than average level of fatality). In the third

time period (2000-2010), the OFTI for the US increased to 0.73 while the corresponding number for Sweden remained unchanged, which means that on a relative basis, the US underperformed over time—i.e. the safety performance of the US significantly diverged from that of the Sweden.

TABLE 4 Estimation of OTFI for all Three Time Intervals and for all Age Groups

	CHILDREN (0-14)			YOUNGSTERS (15-17)		
	1990-2000	1995-2004	2000-2010	1990-2000	1995-2004	2000-2010
AUS	0.19	0.21	0.35	0.01	-0.03	0.06
AUT	-0.24	0.10	-0.03	-0.19	0.22	0.29
BEL	0.32	0.14	0.16	0.17	0.08	0.13
CAN	0.22	0.11	0.10	0.22	0.22	0.27
DEN	0.16	0.11	0.12	0.13	-0.06	-0.16
FRA	0.24	0.13	0.18	0.20	0.07	0.11
GER	-0.04	-0.15	-0.12	0.07	0.05	-0.12
IRE	0.17	0.02	-0.13	-0.14	-0.14	-0.11
ITA	-0.37	-0.27	-0.15	-0.03	0.05	0.16
JAP	-0.41	-0.41	-0.34	-0.19	-0.41	-0.51
NED	-0.05	-0.08	-0.19	-0.13	-0.16	-0.33
NOR	-0.43	-0.37	-0.39	-0.14	0.03	0.03
SWE	-0.53	-0.55	-0.52	-0.71	-0.75	-0.73
SWZ	0.01	0.05	-0.03	-0.22	-0.13	-0.14
UK	-0.26	-0.29	-0.46	-0.27	-0.28	-0.27
USA	0.43	0.60	0.73	0.50	0.53	0.55

	YOUNG DRIVER (18-20)			YOUNG ADULTS (21-24)		
	1990-2000	1995-2004	2000-2010	1990-2000	1995-2004	2000-2010
AUS	0.17	0.11	0.16	0.00	-0.03	0.03
AUT	0.12	0.34	0.31	0.04	0.31	0.35
BEL	0.36	0.31	0.36	0.59	0.59	0.64
CAN	0.02	0.02	0.06	0.02	0.00	0.05
DEN	-0.16	-0.06	-0.16	-0.35	-0.27	-0.37
FRA	0.37	0.28	0.29	0.55	0.46	0.44
GER	0.32	0.26	0.12	0.21	0.17	0.07
IRE	-0.02	0.07	0.19	0.21	0.26	0.29
ITA	-0.09	0.01	0.08	0.09	0.26	0.32

JAP	-0.21	-0.43	-0.62	-0.35	-0.53	-0.69
NED	-0.40	-0.37	-0.34	-0.33	-0.32	-0.33
NOR	-0.22	-0.23	-0.12	-0.36	-0.26	-0.21
SWE	-0.44	-0.53	-0.53	-0.61	-0.62	-0.54
SWZ	-0.13	-0.11	-0.22	0.03	-0.07	-0.39
UK	-0.27	-0.22	-0.29	-0.63	-0.65	-0.54
USA	0.29	0.36	0.48	0.33	0.40	0.53

	ADULTS (25-64)			**SENIORS (+65)**		
	1990-2000	1995-2004	2000-2010	1990-2000	1995-2004	2000-2010
AUS	0.07	0.09	0.17	0.06	0.03	0.05
AUT	0.05	0.36	0.25	-0.07	0.18	0.20
BEL	0.45	0.35	0.43	0.10	0.19	0.28
CAN	0.09	0.06	0.10	0.05	0.03	0.07
DEN	-0.27	-0.25	-0.25	0.30	0.14	0.04
FRA	0.48	0.37	0.29	0.00	0.03	-0.03
GER	-0.01	-0.07	-0.14	-0.19	-0.31	-0.34
IRE	0.10	0.10	0.04	0.01	0.01	-0.09
ITA	0.10	0.21	0.26	0.04	0.04	0.08
JAP	-0.23	-0.28	-0.39	0.34	0.30	0.29
NED	-0.34	-0.37	-0.44	-0.02	-0.02	0.01
NOR	-0.41	-0.39	-0.26	-0.45	-0.35	-0.35
SWE	-0.39	-0.42	-0.44	-0.27	-0.25	-0.38
SWZ	-0.11	-0.22	-0.25	0.14	0.05	0.03
UK	-0.44	-0.42	-0.39	-0.40	-0.54	-0.62
USA	0.48	0.57	0.68	0.29	0.38	0.49

These results help us to understand relative performance of each country for all six age groups. For example, for the senior age group, UK has the lowest OTFI value, which means that the country safest in terms of traffic fatality. In contrast, the US had the highest OTFI values, which indicates that the US was the least safe country for children among all selected countries.

Also, the three time intervals allow us to track changes of this relative index over the course of time. Consequently, by tracking the change of this index over time, we have a better insight of the performance of each age group within a specific country from 1990 to 2010.

6. DISCUSSION

The analysis of the fatality rate allows some insight into how the US diverged from other developed countries in terms of road fatality (see Figure 4 for a comparison). The US fatality rate for the various age groups was from 2 to 2.5 times higher than the best performing country in 1990 while in 2010 these ratios jumped to between 3.5 and 5.0. The most substantial divergence occurred for Children. In 2010, the road fatality rate for Children in the US was 5.1 times that of the UK (the best performing country), compared to a ratio of 2.2 in 1990. This means that Children in the US have five times the risk of dying in a road traffic incident than their peers in the UK. Among all groups, Youngsters (15-17) in the US performed best compared to other age groups. In 1990 the rate for this age cohort was 2.5 higher than the best country and was the worst performing age cohort in relative terms. After two decades, the relative performance of this group improved comparing to other age groups.

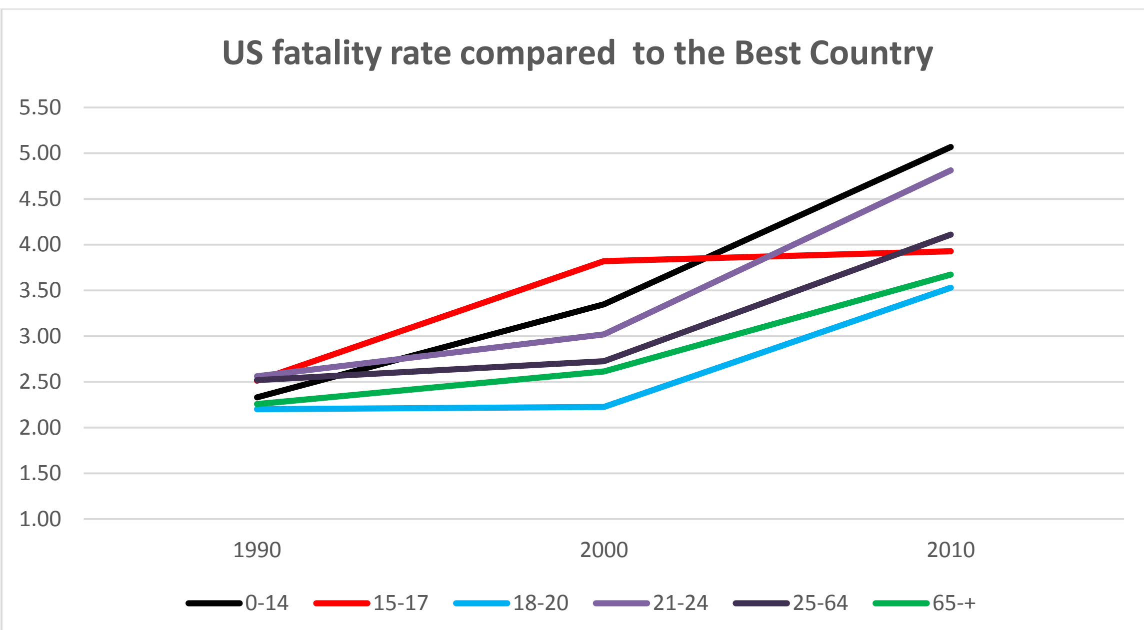


FIGURE 4 Comparing the US fatality rate with the Best Country in all age groups

Likewise we can use the findings of OTFI models to answer of which age groups contributed more on the US under-performance. Figure (5-1) depicts the OTFI index for the US and for all six age groups in all three time intervals. As the graph shows, the OTFI values for all age groups show an increasing trend except for Youngsters (15-17). This means that in 1990-2000, the relative performance of road safety in the US for all age groups was getting worse except for Youngsters. After two decades of underperforming, today the US has the highest risk of fatality among developed countries in every age group. The slope of each line shows how each groups contribute on this divergence and the results emphasizes that all age groups except Youngsters contributed to this divergence. On the other hand, we have seen that Germany had the highest overall annual rate of improvement. Figure (5-2) shows the OTFI values for the Germany for all age groups and in the three time intervals. These graphs illustrate that in Germany the OTFI values for almost all age groups decreased. This suggests that all age groups contributed the large overall progress of Germany in terms of road fatality.

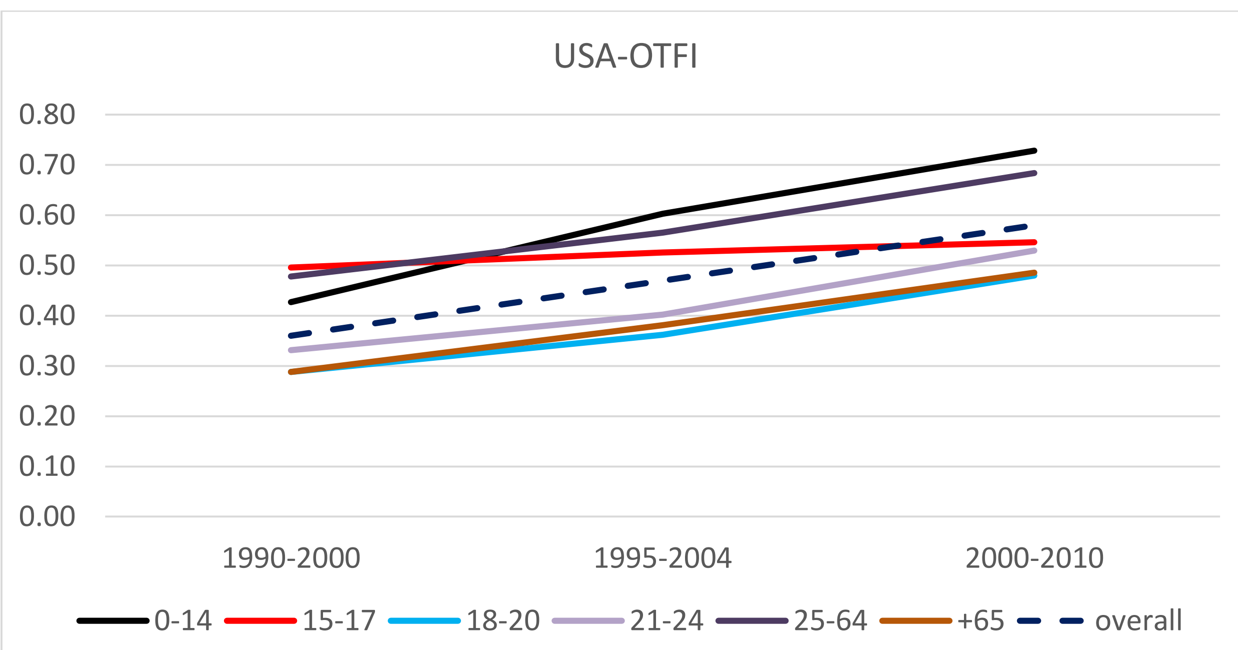


FIGURE 5-1 Comparing OTFI in the US for All age groups

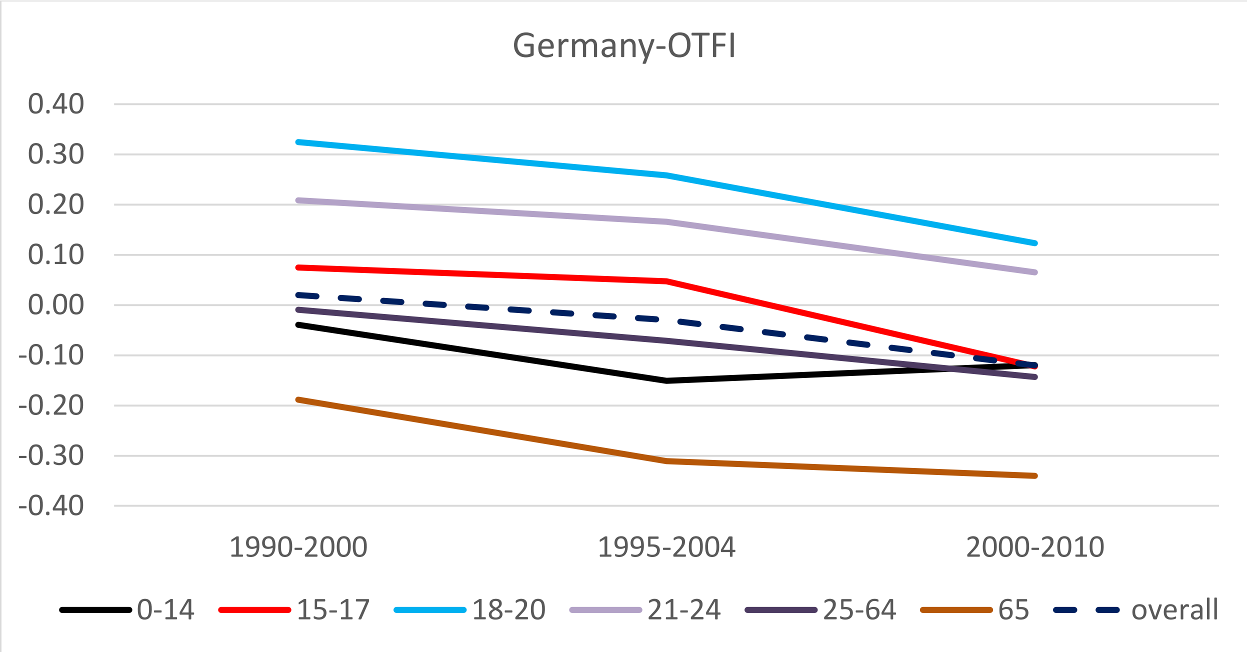


FIGURE 5-2 Comparing OTFI in the Germany for All age groups

In this paper, we have used the terminology of OECD for the grouping of different age cohorts. The implications of the grouping vary from country to country and even within states in the same country. This is because different countries have different policies for licensing, and different customs for when people start driving and for different life cycle decisions that affect driving. In addition, policies affecting the youngest age at which people can drive have changed over time. Therefore, there is no one right answer for grouping people according to age to study traffic safety outcomes. However, the OTFI results show unique patterns for all six age groups and suggest that these groups do capture some important distinctions that are worth studying. For example, the results for 15-17 and 18-20 age cohorts in the US and Germany show very distinct patterns. In the US, the fatality rate for the 15-17 age cohort was higher than for the 18-20 age cohort. But the reverse is true in Germany. This difference is probably due to variations in the starting age for driving in these two countries. Also, the improvement in the fatality rate for this

15-17 age cohort in the US is much higher than that for the 18-20 age cohort, possibly reflecting the impact of the GDL policies.

7. CONCLUSION

Our research findings illustrate tremendous variations in road fatality rates (both in terms of the absolute values and the rates of improvement over time) among different age cohorts in all of the 16 countries we studied. The conceptual framework that we have sketched out explains why road traffic fatality rates may vary by age, and how policies may shape these patterns. Accordingly, it is important to monitor road safety performance for different age cohorts to understand how these age cohorts contribute to data for the population as a whole.

The benchmarking analysis, the results of which were verified by robust statistical method of panel modeling, reveals that in both the Children and the Seniors age groups, the UK not only has the lowest fatality rate but also had the highest rate of improvement. This suggests the need to conduct in-depth analyses into why the UK has had such good outcomes for these age groups in order to identify and assess potential changes in policies targeted towards these age cohorts that could be replicated by other countries.

Likewise, having achieved the biggest improvement from 1990 to 2010 for Young Adults, Switzerland became the safest place for this age group. This suggests further investigation to determine what led to these improvements to determine if there were any age-specific policies that other countries could replicate. Similarly, for Youngsters and Late Teens, Sweden (with the lowest fatality rate) and Japan (with the highest rate of improvement) warrant further investigation. For Adults, the two countries to investigate are again Sweden (because it has the lowest fatality rate) and Austria (because it achieved the highest rate of improvement).

Looking specifically at the US, our analysis shows that safety improvements for Youngsters was much higher than other age groups, and closely tracked peer countries. This strong performance for this age group may stem from earlier research from Sivak (1983) and Loeb (1987), which inspired the adoption of GDL programs. In sharp contrast, Children and Seniors in the US compare very poorly to peer countries. For example, in 2010, a Child in the US was a stunning five times more likely to experience a road traffic fatality than a Child in the UK. This startling statistic suggests an immediate need to explore further the causes and potential solutions to these disparities. This is especially important if the US is to achieve the ambitious goals set out in Zero Vision initiatives.

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Chapter 5.Conclusion

In most developed countries, the total number of road fatalities peaked in the 1970s, and decreased at a relatively steady pace thereafter. Extensive effort has been made by many researchers in various transportation fields to address how fatality traffic or accident occurs, which factors are affecting it and what factors have contributed to the overall declining trend. However, there has been a lack of attention to the conceptual relationship between all the determinants of road traffic fatalities including the macroeconomics factors, demographic indicators, transportation characteristics, and health conditions. The result is that, most existing studies do not offer a holistic structure to study road safety. In response to this crucial need, and as the basis for our empirical effort, in this study, we developed a comprehensive conceptual framework for understanding the full range of factors affecting traffic fatality. This conceptual framework is in essence a synthesized of the research literature on this topic.

The analysis of overall road fatality trend revealed that after 1970, there are two main patterns in the road fatality rate in all selected countries: an overall declining trend and a secondary cyclical pattern. The second chapter of this study provided a better understanding of the underlying causes of periodic variations in road fatalities. It illustrated that gasoline prices and unemployment rate are inversely related to road fatality rate. Accordingly, the study indicates that fluctuations in gasoline prices and unemployment rate are two of the main underlying cause of the cyclical patterns in the road fatality rate. Furthermore, the impact of these factors is not just dues to the fact that they contribute to lower rate or driving but it also seems that they lower the traffic fatality rate by changing how people drive. This is an important finding because it suggests that policy makers need to be cognizant of these factors in interpreting short range changes in traffic fatality.

This model from Chapter 2 also shows that improvements in health conditions in different countries have had the largest impact on the decline in traffic fatality rate over time. Many casual observers contribute long term decreases in traffic fatality to improvements in infrastructure without adequately accounting for factors such as improvements in health conditions and emergency services.

The third Chapter of the study examined road the rate of changes (improvement rate) of road fatality in developed countries. In this work we have created two different indices for comparing how well countries are doing with regards to traffic fatality at different points in time. By comparing these two sets of road fatality indices, we captured the effect and the role of country specific factors such as differences in infrastructure, policy, enforcement, mode share, and driving habits on the road safety changes. The results suggested that the USA has made limited progress relative to other countries in terms of addressing these important factors. In comparison, countries like Sweden and the Netherlands have performed much better in terms of these country specific factors. However, more research is needed to better identify the specific policies and infrastructural changes have been made in these countries that have contributed to their significant progress in reducing traffic fatality.

Our findings in chapter 4 illustrated tremendous variations in road fatality rates (both in terms of the absolute values and the rates of improvement over time) among different age cohorts in all of the 16 countries. Benchmarking analysis revealed that it is not just the so-called SUN (Switzerland, the UK and the Netherlands) countries that are doing well. These SUN countries have frequently been identified has having superior performance in terms of traffic safety. However, our more detailed analysis looking at different age groups show pockets of

superior performance in other countries including Switzerland, Germany and Japan for specific age groups.

Among all the countries we studied the US stands out as being different. First the US started with a relatively good traffic fatality record in 1970 but has gotten consistently worse since then in comparison to it peers. Our findings in different chapters shed lights on different aspects of this divergence of the US from the other counties. Our first study showed that the fluctuations in gasoline prices have an inverse relationship with road safety. The US is at a disadvantage in that gasoline prices are much lower than other countries and has such has not had the moderating effect on traffic fatality that we see in other countries. The difference between gasoline prices in the US and other countries is affected by the rate of taxation, which is very low in the US, and has not seen any significant changes over the last several decades.

The third Chapter illustrated the fact that country specific factors, which likely includes factors such as infrastructural design, urban form, and transportation polices have had an adverse impact on the US performance. While, the last Chapter showed that safety improvements in the US for Youngsters (15-17 years old) was much better than for other age groups, and closely tracked peer countries. In contrast, Children (0-14 years old) and Seniors (+65 years old) in the US, fared very poorly relative to their peers in other countries. In 2010, a Child in the US was a stunning five times more likely to experience a road traffic fatality than a Child in the UK while this ratio in 1990 was just two times higher. This startling statistic suggests an immediate need to explore further the causes and potential solutions to these disparities. This is especially important if the US is to achieve the ambitious goals set out in Zero Vision initiatives.

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