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Effect of road safety interventions on traffic injuries globally

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Declaration

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Effect of road safety interventions on traffic injuries globally

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1 INTRODUCTION

The long-run trends in road traffic deaths in high-income countries (HICs) show a remarkable pattern (Figure 1). Traffic deaths were rising in all countries prior to the 1960s but began to decline shortly afterwards and have continued to decline for the five decades that have followed. At face value this suggests a remarkable achievement. The decline in traffic deaths occurred despite the fact that vehicle ownership – and, hence, exposure to the traffic environment – has steadily increased over the last century. In contrast traffic injuries in most low- and middle-income countries (LMICs) are continuing to rise or are stable at a high level. Understanding what happened in HICs that enabled them to control and reduce traffic injuries could hold important lessons for LMICs.

In this paper, we assess the long-run trends in traffic deaths in HICs. We review the literature to show that the explanation that is most commonly provided is that these trends are the result of a process of development and social maturity. Briefly, the current understanding is that during the early stages of economic development increasing motorization leads to more people being exposed to high-speed traffic, which leads to increasing traffic deaths. At this stage, society is too poor to address their traffic safety problem. However, with continued economic development, societies reach a certain development threshold, where they have an increased interest in improving health and the economic means for addressing such problems. They now invest in interventions and are successful in reducing their traffic death toll. While this theory is widely accepted, we will show that it misses a critical point. The countries shown in Figure 1 were at very different income levels during the 1960s when they succeeded in reversing the rising trend in their road traffic death rates. Therefore, we revaluate the data from these countries to show that there was something special that happened starting in the late 1960s. We show that even after controlling for income effects, traffic deaths in countries started falling in the 1960s and have continued to fall until present. We suggest that there was a paradigm shift in the 1960s after which HICs have acted together to increasingly regulate transport risk by implementing large-scale

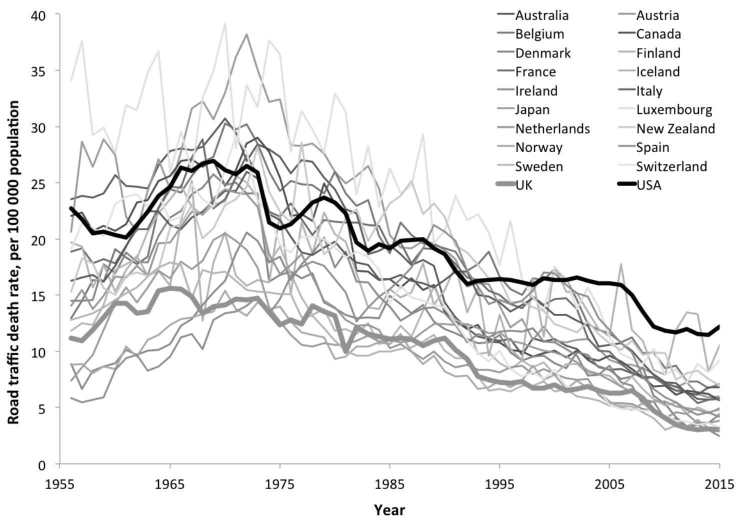

Figure 1. Road safety performance of high-income countries over six decades.

Source: Authors' calculation, see Sec 3.1.1 for details.

safety programs that have had a remarkable effect on reducing injuries. The implication for low-income countries is that they do not need to wait to be richer to address road safety. They should act now to establish national regulatory institutions with the mandate to improve safety and the resources to take an evidenced based approach to evaluating interventions and scaling-up what works. The econometric analysis presented in this paper should be read alongside papers by O'Neill et al. and Stevenson et al. in this volume, which trace the history of developments in road safety over the last century. The paper concludes by estimating the gains that selected LMICs would see from investing in proven road safety interventions.

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2 ECONOMIC DETERMINISM: ROAD SAFETY PERFORMANCE AS A DEVELOPMENTAL OUTCOME

The central question (Why did traffic deaths rise and fall as illustrated in Figure 1?) has been investigated extensively by researchers (Bishai, Quresh, James, & Ghaffar, 2005; Garg & Hyder, 2005; Grimm & Treibich, 2012; Jacobs & Cuttings, 1986; Kopits & Cropper, 2005; Law, Noland, & Evans, 2009; McManus, 2007; Nishitateno & Burke, 2014; Paulozzi, Ryan, Espitia-Hardeman, & Xi, 2007; Soderlund & Zwi, 1995; Van Beeck, Borsboom, & Mackenbach, 2000). Some of these studies are cross-sectional studies (i.e. single year data from multiple regions), while others use panel data (i.e. data for multiple years from multiple regions) of the type shown in Figure 1. Some are cross-national studies, while others focus on sub-national regions of a single country. Almost without exception these studies view the trends in road traffic death rates as a function of income growth. Typically, this involves reassessing the data in Figure 1 using per capita income as the independent variable (e.g. see

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This logic of "economic determinism" creates the impression that low-income countries may be too poor to invest in safety now and that it is appropriate for them to wait until they become richer to address road safety.

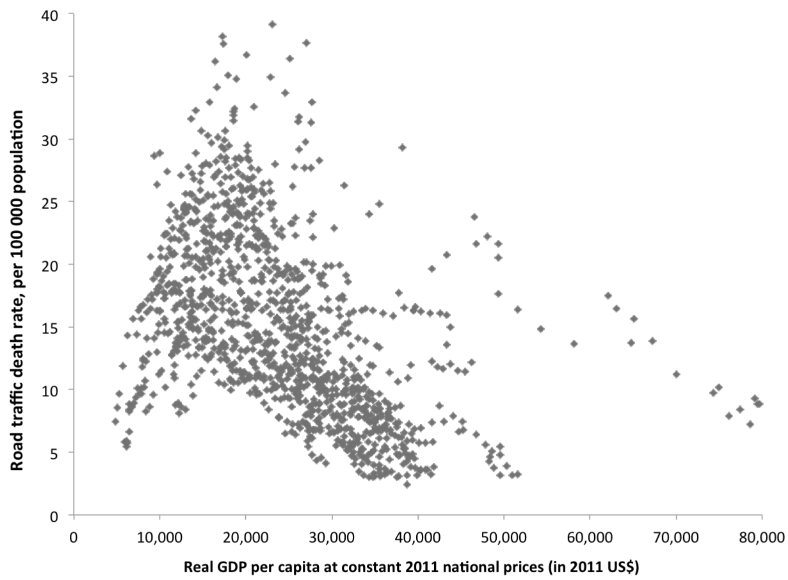

Figure 2. Road safety performance of high-income countries as a function of economic growth.

Source: Authors' calculation, see Sec 3.1.1 for details.

Figure 2) and demonstrating an inverted-U relationship with income that is referred to as a "Kuznets curve". Thus, all of these studies find that there is a general relationship between income growth and road traffic injury such that when countries are poor they experience rising injuries with increasing income; and when countries are rich they experience declines with increasing income. The underlying logic of this hypothesis is that when countries are poor, growth in income is closely tied to increase in motorization, which leads to higher exposure to road traffic injuries. At this stage, it is assumed that countries are too poor to invest in harm reduction. However, after a certain level of economic development has been achieved, countries begin to invest in road safety programs and reduce their road traffic injury rates.

There is a problem with this argument that has not received attention in the road safety literature. When the data is presented as shown in Figure 2 with income as the independent variable (x-axis), it encourages thinking about national road safety performance as a process that is an outcome of economic development. This logic of "economic determinism" creates the impression that low-income countries may be too poor to invest in safety now and that it is appropriate for them to wait until they become richer to address road safety. In fact, it implies that income growth is the strategy for road safety rather than direct investment in interventions. As the public health historian Borowy has observed about a World Bank study (Kopits & Cropper, 2005) that is arguably one of the most influential publications in global road safety (Borowy, 2013):

> "Analysing vehicles per person (V/P) and fatalities per vehicle (FN) data from eighty-eight countries for the period 1963–99, they found a confirmation of the Kuznets curve with a turning point at a per capita GNP of $8600 in 1985 international dollars. On the basis of these data and of prognoses of population and income growths, they projected that it would take many years for developing countries to achieve the low RTI fatality rate of existing high-income countries. RTIs in India, for instance, which had a per capita income of only $2900 in 2000, would only begin to decline in 2042 after a peak of at least twenty-four fatalities per 100 000 persons, or thirty-four when adjusted for estimated underreporting. Brazil would 'already' peak in 2032 and would experience an RTI mortality rate of twenty-six deaths per 100 000 persons as late as 2050, compared to a rate of around eleven enjoyed by high-income countries in 2000. *Only on the last page did the text mention, almost in passing, that these projections were based on a continuity of ongoing policies, while measures such as mandatory helmet wearing or effective traffic separation might lower those numbers.*" [emphasis added]

Although criticism of this economically determined interpretation of road safety is relatively subdued in the road safety literature, it is instructive to understand the history of the concept in the broader field of economics. The "Kuznets Curve" is named after the Nobel Prize laureate Simon Kuznets, who studied long-term economic processes in the US. In 1955, he published an influential study that described an inverted U-shaped relationship between income inequality and economic growth (Kuznets, 1955) that suggested that over the long run as countries develop economically, income inequality first increases but later declines. He speculated that income inequality grew initially due to the transition from agrarian society to industrialization, but declined later as mass education created new opportunities for everybody. Kuznets cautioned against reading too much into the data saying that "*If the above summary of trends in the secular income structure of developed countries comes perilously close to pure guesswork, an attempt to explain these dimly discernible trends may surely seem foolhardy*", and "*I am acutely conscious of the meagreness of reliable information presented. The paper is perhaps 5 per cent empirical information and 95 per cent speculation, some of it possibly tainted by wishful thinking.*" Unfortunately, other researchers who have applied the Kuznets curve to other arenas have often not been similarly cautious and thoughtful.

The Kuznets curve has been fairly important to the field of environmental economics. In the early 1990s, Grossman and Krueger analyzed data on air pollution from a number of cities around the world and described an inverted-U shaped curve, which is now known as the "Environmental Kuznets Curve" (Grossman & Krueger, 1993). The concept received a large boost in popularity in

It is important to understand that in the best-case scenario, such econometric analysis can only help us understand the level of income at which rich countries began to regulate road safety. Such analysis provides no guidance to LMICs on what they should do now.

Traffic deaths in the US and UK behave almost synchronously in time, with the reversal from rising to falling mortality rates occurring in the early 1970s, even though the two countries had considerably different income levels at this time. This contradicts the Kuznets hypothesis, which suggests that the reversal in trends occurs when countries reach a certain income level

this field when it was included in the World Bank's influential 1992 World Development Report (World Bank, 1992). The logic of the environmental Kuznets curve was that in the early stages of industrialization, pollution grows rapidly because people are more interested in jobs and income than in clean air and water. Poor societies cannot afford to pay for reducing harm but the balance shifts as incomes rise. People begin to value the environment more and intervene to establish environmental regulations. There have been numerous investigations of the Kuznets curve in the literature on environmental economics and numerous critiques of the method, including those on theoretical and technical grounds. Importantly, the economic determinism of the Kuznets hypothesis has been used to argue against LMICs investing in environmentally sustainable practices. As Stern discusses, the World Bank's 1992 World Development Report, presented income growth as partly the solution to environmental damage in LMICs (Stern, 2004). The report stated "*As incomes rise, the demand for improvements in environmental quality will increase, as will the resources available for investment*." Others have made the same point but much more forcefully. Beckerman (1992) claimed that "*there is clear evidence that, although economic growth usually leads to environmental degradation in the early stages of the process, in the end the best – and probably the only – way to attain a decent environment in most countries is to become rich*." Thus, unfortunately, the Kuznets hypothesis has been used by those politically opposed to investing in protecting the environment to argue that countries should "Grow first, then clean up" (Dasgupta, Laplante, Wang, & Wheeler, 2002).

To be fair, the large and growing literature on the Kuznets curve in road safety has not yet taken a position that is as explicitly hostile to safety regulations as the environment literature. Nevertheless, it is important to understand that in the best-case scenario, such econometric analysis can only help us understand the level of income at which rich countries began to regulate road safety. Such analysis provides no guidance to LMICs on what they should do now.

3 DEVELOPING A NEW UNDERSTANDING: THE ROLE OF POLITICAL ACTION, INSTITUTIONS AND INTERVENTIONS

There are two empirical issues with Figure 2 that deserve careful consideration. First, the paper by Mohan, D. in this volume shows that the statistical estimates of national road traffic deaths by WHO do not show the U-shaped relationship with income suggested by the Kuznets hypothesis. It is possible that official statistics of traffic deaths from LMICs, which are usually used in such econometric analysis, may have high levels of underreporting. The degree of underreporting may vary by income creating a spurious relationship between the observed traffic deaths in official statistics and income.

Second, even in high-income settings, which have more reliable data, the preceding discussion about the role of income growth in traffic safety performance misses a vitally important characteristic of the historic data. The countries shown in Figure 1 had very different income levels during the late 1960s. Figure 3 illustrates this issue by comparing road safety performance as a function of income (Figure 3a) with time histories (Figure 3b). Note, for instance that traffic deaths in the US and UK behave almost synchronously in time, with the reversal from rising to falling mortality rates occurring in the early 1970s (Fig 3b), even though the two countries had considerably different income levels at this time (Fig 3a). This contradicts the Kuznets hypothesis, which suggests that the reversal in trends occurs when countries reach a certain income level. Instead, the data suggest that time may have been a much stronger determinant of the reversal point than income and that something special may have happened in the 1970s that transitioned HICs into a new historic period in road safety regardless of income level. Therefore, in this section, we will reassess the historic data from HICs to assess the role of time while controlling for other covariates, especially income.

3.1 Data Sources

We constructed a time-series cross-sectional (TSCS) data set of annual road traffic death rates and related covariates in OECD countries for the period 1955-2015 as follows. We extracted road traffic deaths from the World Health Organization Mortality Database March 2017 update (World Health Organization, 2017), which contains cause of death data from national vital registration systems tabulated by age and sex and cause-coded using International Classification of Disease (ICD) codes. We restricted the analysis to the 20 OECD countries that had high quality ICD data (Mathers, Fat, Inoue, Rao, & Lopez, 2005). These countries were: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, and United States of America. We estimated annual road traffic deaths in these countries following the usual

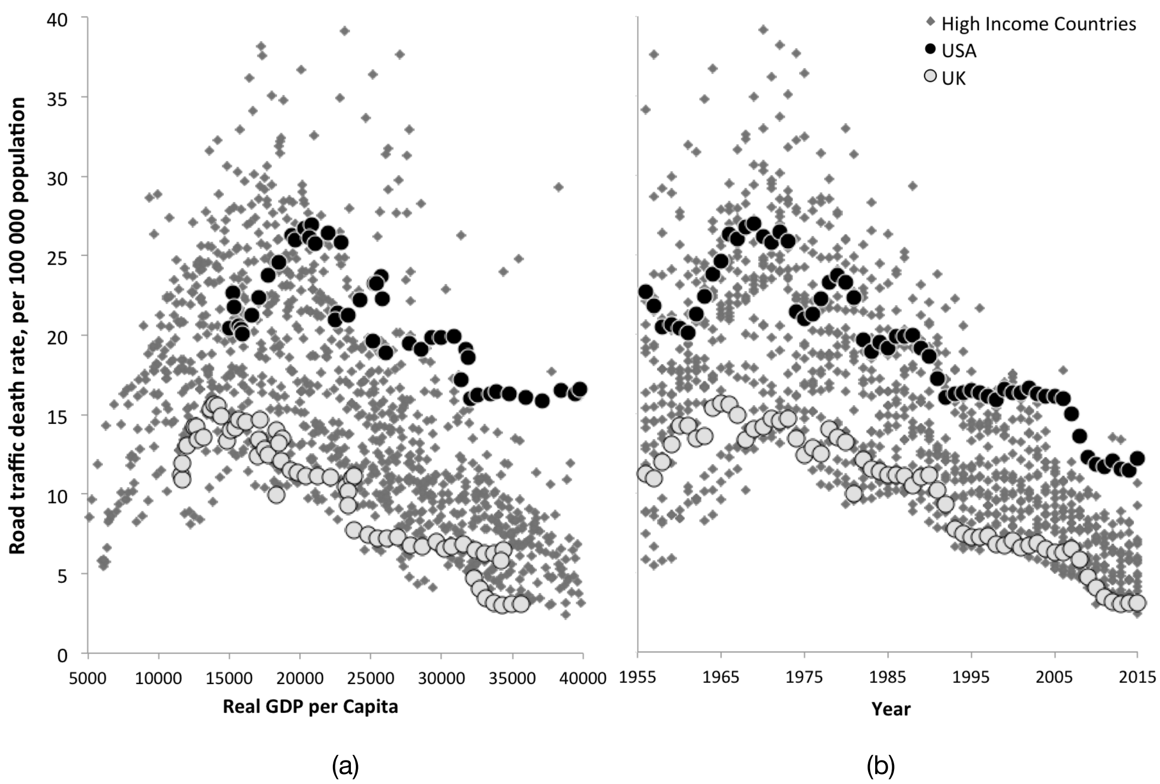

Figure 3. Comparison of road traffic deaths rates in high-income countries as a function of economic growth, (a), and time, (b).

procedure for estimating cause-specific deaths from death registration data (Bhalla & Harrison, 2015). Notably, we handled cases assigned to unspecified and ill-defined codes by proportionately distributing within the age-sex groups of the relevant specified categories. This required redistribution of cases assigned to three partially-specified causes: unspecified transport injuries, unspecified accidents, and unspecified injuries. We regrouped ages into eight categories (0-4, 5-14, 15-29, 30-44, 45-59, 60-69, 70-79, and 80+ years). We obtained age-specific population for this time period from the UN Population Division (United Nations Population Division, 2017), and annual estimates of per capita income (Real GDP Per Capita at Constant 2011 national prices in 2011 US$) for the time period 1950-2014 from the Penn World Tables 9.0 (Feenstra, Inklaar, & Timmer, 2015). We obtained data on urbanization from the UN World Urbanization Prospects Database (United Nations Population Division, 2014) in 5 year increments, from 1950 to 2014 and interpolated these to annual increments assuming exponential growth in urbanization. Data on road traffic injuries were not available for 99 country-years from the WHO Mortality Database. Since list-wise deletion of observations with any missing data can result in substantial bias (King, Honaker, Joseph, & Scheve, 2001), we used a multiple imputation program, Amelia II (Honaker, King, & Blackwell, 2017), to replace missing data and constructed a balanced TSCS dataset.

We constructed a time-series cross-sectional (TSCS) data set of annual road traffic death rates and related covariates in OECD countries for the period 1955-2015.

3.2 Econometric model

TSCS methods have been used extensively in econometrics, political science and global health for retrospective analysis of the impacts of policies or programs. There is a substantial literature that recommends appropriate ways for dealing with various pitfalls associated with TSCS methods (Beck & katz, 2001; Beck & Katz, 2011; Judson & Owen, 1999). We summarize the issues as they relate to our analysis and point the reader to a review article (Beck & Katz, 2011) for a detailed discussion:

- The use of panel corrected standard errors is recommended in TSCS analysis to correct ordinary least square (OLS) standard errors for problems of groupwise heteroscedasticity and contemporaneous correlation of errors.
- Failure to use unit (country) fixed effects can lead to potentially severe omitted variables bias.
- The use of a lagged dependent variable is recommended to account for serial auto-correlation of errors.

In addition, a lagged dependent variable outperforms other TSCS methods (including simple OLS, and generalized least squares estimators), especially when the coefficient on the lagged dependent variable is low (Obermeyer & Murray, 2008).

Thus, we used OLS regression models with panel corrected standard errors to study the time history of road traffic mortality rates in OECD countries. We fit sixteen separate models, one for each age-sex group, using the natural log of the road traffic mortality rate (dr) as the independent variable and income (gdp),

Consistent with the Kuznets Hypothesis, the coefficients of income were positive and the coefficients of income-squared were negative (i.e. downward opening parabola relative to income) in most of the 16 age-sex specific models. However, these effects were not statistically significant. This was the case for both model specifications that included and did not include lagged dependent variables.

income-squared, urbanization and population density as dependent variables. We used fixed effects (modeled as dummy variables) for country, ICD revision of cause of death coding, and year. The analysis follows the following general form:

$$\left[\ln(dr_{it}) = \alpha + \beta_1 \cdot gdp_{it} + \beta_2 \cdot gdp_{it}^2 + \beta_3 \cdot urb_{it} + \beta_4 \cdot popdensity_{it} + u_i + v_t + \varepsilon_{it}\right]_{age-sex-gps}$$

….(1)

where u_i and v_t are country and year fixed effects, β_1, β_2, β_3 and β_4, are constants, and ε_{it} is the error term. As is expected with time series regression analysis, examining the error terms in the models revealed the presence of serial auto-correlation. Thus, we included a one-year lag of the dependent variable in the right hand side of Equation (1). We present results for models that included a lagged dependent variable but also describe the effect of excluding it. All analysis was conducted in Stata Version 15.

3.3 Results

Consistent with the Kuznets Hypothesis, the coefficients of income were positive and the coefficients of income-squared were negative (i.e. downward opening parabola relative to income) in most of the 16 age-sex specific models. However, these effects were not statistically significant. This was the case for both model specifications that included and did not include lagged dependent variables.

The coefficients of the year dummies (i.e. the magnitude of the time fixed effect) showed a pattern that was remarkably consistent for all age-sex specific models and persisted regardless of whether a lagged dependent variable was included in the model specification. Prior to the late 1960s, the time coefficients are relatively stable or have a rising trend but they decline steadily for all age-sex groups starting around 1970. Figure 4 illustrates the coefficient of the year dummies along with 95th CI for one of these models (boys, 5-14 years old) and Fig. 5 illustrates the trends in these coefficients for all age-sex groups. The coefficient of the lagged dependent variable in the models ranged between 0.37 and 0.63 and exceeded the recommended threshold of 0.6 (Obermeyer & Murray, 2008) for only one age-sex group (men, 15-29 years).

In general, the decline is higher among the elderly (men and women >80 years) and children (boys and girls <5 years). The trends for young women show a large increase pre-1970 relative to other groups followed by a decline that is similar to those for other groups. This is likely because gains in safety for young women have been counteracted by increases in exposure due to increased travel. The increase in exposure is likely much larger for young women than other age-sex groups. For instance, between 1950 and 2000 the increase in US labour force participation of women was more than twice the increase for men, which would result in much higher use of transportation services (Brownson, Boehmer, & Luke, 2005).

3.4 Interpretation of Results

We believe that the persistence of these time effects in the models after controlling for income is evidence of a transition to a road safety policy era in developed countries. The results suggest that the reversal in trend in road deaths in HICs during the 1960s is not because the countries reached a certain income threshold. In fact, in 1965 the richest of these countries had a per capita income that was more than double that of the poorest. Instead, our results suggest that the late 1960s were likely a special moment in history when countries at different income levels were able to reduce their traffic death toll. These results are consistent with past work by (Brüde & Elvik, 2015), who analysed traffic growth and fatality in six countries and concluded that traffic death rates decreased after the 1970s due to policy interventions.

By the 1960s, a paradigmatic change had already occurred in public health where focus shifted from blaming individuals for their illnesses to looking at interventions with stress on

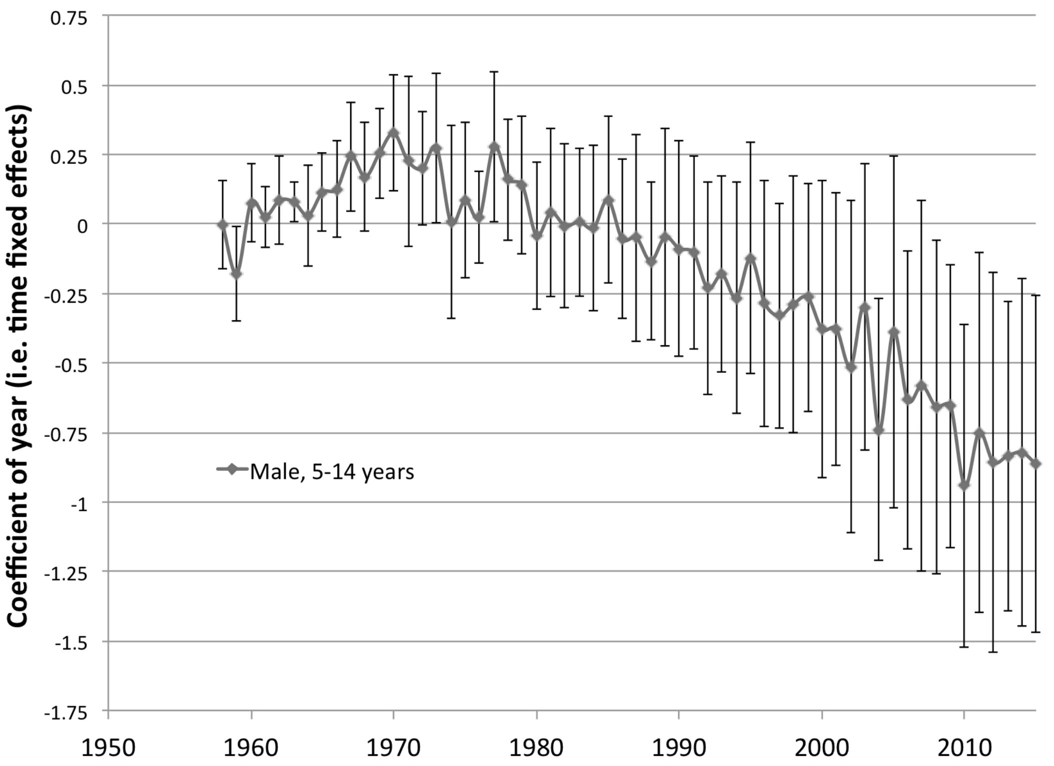

Figure 4. Magnitude of the time-fixed effect for boys 5-14 years old and 95th CI. Models include a lagged dependent variable to account for serial autocorrelation.

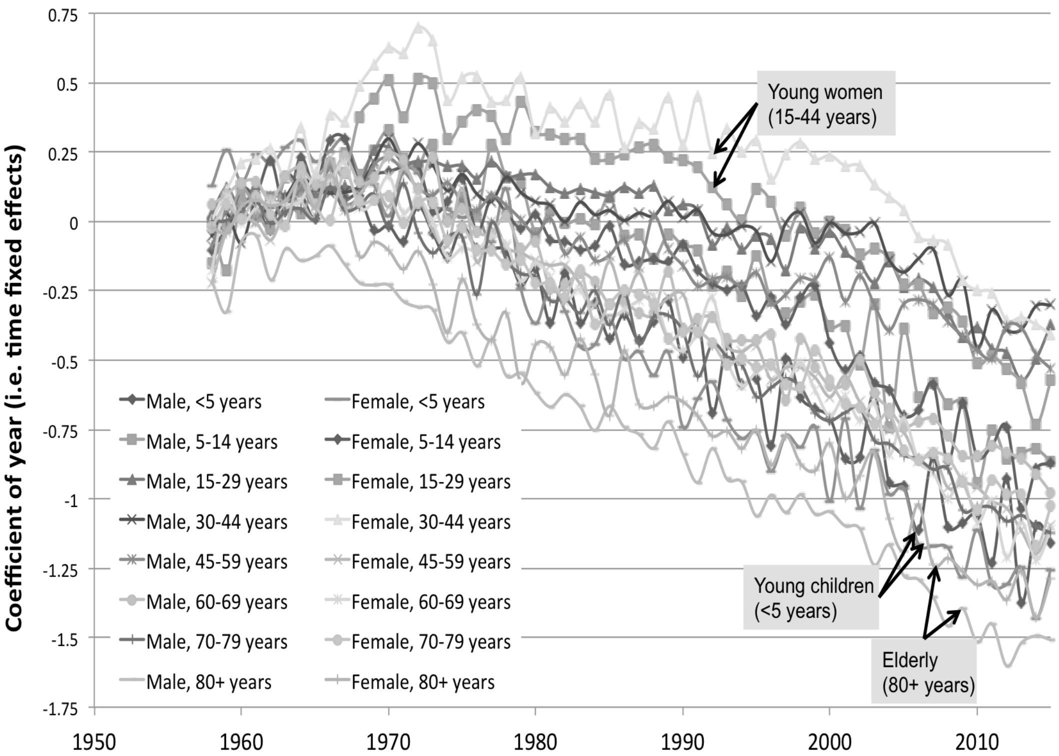

Figure 5. Magnitude of the time-fixed effect for all age-sex groups. Models include a lagged dependent variable to account for serial autocorrelation.

environmental improvement and control of the agent and vector involved in the disease process. One of the earliest to raise the issue for injuries was Gibson (1961):

> "The term "accident" it seems to me, refers to a makeshift concept with a hodgepodge of legal, medical, and statistical overtones. Two of its meanings are incompatible. Defined as a harmful encounter with the environment, a danger not averted, an accident is a psychological phenomenon, subject to prediction and control. But defined as an unpredictable event, it is by definition uncontrollable. The two meanings are hopelessly entangled in the common usage. There is no hope of defining it for research purposes. Hence I suggest that the word be discarded in scientific discussion."

Gibson's approach to thinking of all injuries being produced by some energy interchange and in principal etiologically similar to any other disease was shared by many other researchers of the time. Dr. William Haddon was one of the first public health professionals to formalise this approach and promote the idea that road traffic injuries be considered a serious public health problem (Haddon, 1968). This understanding that road traffic injuries result from a complex interaction of sociological, psychological, physical and technological phenomena helped in design of safer products, environments, roads and traffic management systems. Once it was accepted that injury control is a public health problem, the responsibility for road safety started shifting from individuals to the state and society. This, in turn, made it possible to initiate a scientific policy for injury control and safety promotion.

The papers by O'Neill et al. and Stevenson et al. in this volume provide an accounting of the history of road safety in the US and high-income countries more generally. Briefly, the 1960s were a period of paradigmatic change in thinking about road safety in many HICs. In the US, for instance, this period was one in which the definition (and hence the solution space) of the road safety problem shifted from being driver oriented to a more balanced approach that included interventions that focused on vehicles, road infrastructure, and post-crash care, in a broad view of the environment in which crashes happen (Gangloff, 2006; Haddon, 1972; MacLennan, 1988). The movement was led by a group of engineers (such as Hugh DeHaven and John Stapp), physicians (such as William Haddon), lawyers (such as Ralph Nader), and politicians (such as Daniel Patrick Moynihan). Acting at a time of increasing state power and the rising consumer movement, they successfully lobbied the US congress to pass two key pieces of legislation in 1966 – the National Traffic and Motor Vehicle Safety Act and the Highway Safety Act, which for the first time authorized the US government to play a key role in vehicle and highway safety. This in turn led to the establishment of the National Highway Safety Bureau (later National Highway Traffic Safety Agency (NHTSA)). NHTSA together with the Federal Highway Administration (FHWA) had mandates to regulate safety standards for vehicles and highways, and these two agencies played an important role in pushing the development, implementation and enforcement of many safety interventions, such as air bags, seat belts, energy absorbing steering wheels, breakaway sign and utility poles on roadways, deformable median barriers, and guard rails among many others.

NHTSA also had authority to address road user issues, including, for example, motorcycle helmet laws, but this authority was weakened in the early 1970s, returning issues such as helmet and seatbelt laws back to individual states (see discussion papers by O'Neill et al. in this volume). Simultaneous with the efforts in the US, many European countries, plus Australia and Canada, adopted similar safety regulations for vehicles. In addition, these countries also followed the lead of Australia and passed laws requiring use of vehicle seat belts and motorcycle helmets. The safety innovations of this period did not end there, traffic engineers and road designers (who had earlier focussed almost entirely on improving traffic flow) increasingly recognized the need to address safety, leading to, for example, the removal of roadside hazards and innovative designs such as modern roundabouts. Traffic law enforcement also began to change its focus from catching offenders to creating deterrence. Although not all of these countermeasures were adopted at the same time, in the late 1960s and 1970s there was a widespread and fundamental paradigm shift in the approach to vehicle and highway safety in motorized countries. For the first-time effective countermeasures were being adopted.

Thus, our reframing of the Kuznets analysis to show a policy effect starting in the late 1960s helps to explain the importance of concerted action by individuals and agencies in improving road safety. Nevertheless, it is important to understand that such econometric analysis is poorly suited for making strong claims of cause and effect. In fact, constructing a long-run panel dataset makes it difficult to control for potentially important variables for which country-level annual data is not readily available for the entire period. Such variables include, for instance, fuel prices, alcohol consumption, the amount of traffic exposure, among others. In addition, there may be other explanations for the synchronicity in time besides collective policy action. In particular, the diffusion of new vehicle and medical technologies likely plays an important role. As discussed above, regulations in the US resulted in auto manufacturers developing and deploying new safety technologies for vehicles sold in the US. It is likely that this would have resulted in beneficial spillover effects in other countries – i.e. other countries would likely see

safer cars even without introducing new regulations. Finally, there are other possible explanations for the inverted-U shaped pattern in historic safety data. As we have shown before (Bhalla, Ezzati, Mahal, Salomon, & Reich, 2007), as a society motorizes individual risk profiles shift (pedestrians face a high risk but impose low risks on others; car occupants face low risk but impose high risks on others). This shift in individual risk manifests as an inverted-U shaped risk profile at the societal level. Assessing such effects is likely not possible with the historic time series data. However, we recommend that there should be continued exploration of the history of road safety in industrialized countries using a multitude of quantitative and qualitative methods.

4 HOW MUCH WOULD DEVELOPING COUNTRIES BENEFIT FROM A SIMILAR APPROACH

As discussed above, the key lesson for developing countries is that they need to stop focusing solely on interventions aimed at changing behaviours of road users and take a systematic approach that includes legislation, enforcement and engineering to address the key risk factors. In this section, we develop an estimate of the effect of selected interventions on traffic deaths in selected LMICs.

4.1 Estimation method

We pick six interventions that have been widely deployed in HICs and whose effects are well understood. These interventions aim to increase helmet use, increase seatbelt use, reduce traffic speed, reduce drink driving, and improve the crashworthiness of cars for occupants and pedestrians. We assess the effect of these interventions on six countries (China, Colombia, Ethiopia, India, Iran, and Russia), one from each of the major WHO regions.

We use a comparative risk assessment (CRA) framework to estimate the effect of modifying risk factors on traffic injuries. CRA relies on the epidemiological concept of attributable risk, which is the difference in rate of a condition between an exposed population and an unexposed population. Briefly, CRA estimates the burden of injuries due to risk factors using a counterfactual approach. The population attributable fraction (PAF) of a risk factor is estimated as the expected proportional reduction in mortality if risk factor exposure were reduced to an alternative (counterfactual) distribution. Thus, for a continuous variable,

$$PAF = \frac{\int_{x=0}^{m} RR(x)P(x)\,dx - \int_{x=0}^{m} RR(x)P'(x)\,dx}{\int_{x=0}^{m} RR(x)P(x)\,dx} \qquad \text{.....(2)}$$

where x is exposure level, $P(x)$ is actual population distribution of exposure, $P'(x)$ is counterfactual (alternative) population distribution of exposure, $RR(x)$ is relative risk of mortality at exposure level x, and m is maximum exposure level.

And, for a categorical exposure,

$$PAF = \frac{\sum_{i=1}^{n} P_i\, RR_i - \sum_{i=1}^{n} P'_i\, RR_i}{\sum_{i=1}^{n} P_i\, RR_i} \qquad \text{.....(3)}$$

where n is number of exposure categories, P_i is proportion of population currently in the i^{th} exposure category, P'_i is proportion of population in the i^{th} exposure category in the counterfactual (alternative) scenario, and RR_i: relative risk of disease-specific mortality for the i^{th} exposure category.

We use estimates of the 2015 Global Burden of Disease Study (Global Burden of Disease Study 2013 Collaborators, 2015) as our baseline data on road traffic deaths and injuries in the six countries. Table 1 describes the sources of information used for modeling the effects of

Table 1: Sources of information used for modeling effect of interventions

Intervention	Baseline & Target Exposure	Effectiveness of intervention
Helmet: Legislation and enforcement to increase helmet use	Baseline helmet use based on WHO GSRRS 2015*; Target: Increase to 100% helmet use	RR@ of death of helmeted vs unhelmeted = 0.58; RR of non-fatal = 0.31. Source: Cochrane Review.(Thompson, 2009)
Seatbelt: Legislation and enforcement to increase seatbelt use	Baseline seatbelt use based on WHO GSRRS 2015; Target: Increase to 100% seatbelt use	RR of death of belted vs unbelted = 0.5; RR of non-fatal = 0.55. Source: Handbook of Road Safety Measures.(Elvik, Vaa, Erke, & Sorensen, 2009)
Speed Control: Implementation of speed control	Baseline impact speed 55 km/h; Target: Reduce impact speed by 5%.	Non-linear relationship between speed and probability of crash (Nilsson, 2004) and probability of death in event of crash.(Elvik, 2012)
Drink Driving: Legislation and enforcement to reduce drink driving	Avertable mortality based on GBD-2015# estimate of % deaths involving alcohol	Based on a review of effectiveness of drink driving programs, (Shults, 2001) (Chisholm, Naci, Hyder, Tran, & Peden, 2012) combined effect of legislation and enforcement is to reduce avertable mortality by 25% and non-fatal injuries by 15%.
Car Design: Occupant Improving crashworthiness of vehicles for occupants	Baseline availability of high quality cars is based on status of regulations (Source: WHO GSRRS) and active NCAP program	Based on studies (Farmer & Lund, 2015; Glassbrenner, 2012; Kahane, 2015) that compare reduction in occupant risk in newer US cars, RR of driver death in newer vs older vehicle is 0.6.
Car Design: Pedestrian Improving crashworthiness of vehicles for pedestrians	Baseline availability of high quality cars is based on status of regulations (Source: WHO GSRRS) and active NCAP program	Based on studies evaluating effect of EU regulations (Pastor, 2013; Strandroth, Sternlund, & Lie, 2014) that compare reduction in pedestrian risk, RR of pedestrian death in newer vs older vehicle is 0.65

** WHO GSRRS: Global Status Report on Road Safety (World Health Organization, 2015)*

 # GBD: Institute of Health Metrics and Evaluations Global Burden of Disease Project (Global Burden of Disease Study 2013 Collaborators, 2015)

@ RR: Relative Risk

intervention on traffic injuries. Information on baseline exposures to risk factors in LMICs is unreliable.

For helmet use and seatbelt use, we use data compiled by the 2015 WHO Global Status Report on Road Safety (GSRRS) with the following exceptions. For India, the values reported by the GSRRS (60% helmet use, 26% seatbelt use) are too high because they are based on measurements in a large city (Bangalore) with regular enforcement campaigns. Therefore, we reduced these baseline exposure estimates to 20% helmet use and 10% seatbelt use. The GSRRS also reports estimates of the proportion of traffic deaths that involved alcohol use. However, these are based on official statistics and usually had unrealistically low values. Therefore, we used GBD-2015 estimates for traffic deaths attributed to alcohol use in each country. Our analysis of the effect of vehicle design relies on evaluation of changes in risk of occupant deaths in the US and pedestrian deaths in the EU where regulations and market mechanisms (consumer information from new car assessment programs) has driven changes in crashworthiness design. In countries where there are no vehicle design regulations (Colombia, Ethiopia, India, and Iran for occupants; China, Colombia, Ethiopia, India, and Iran for pedestrians), we assume that none of the vehicles in these countries are designed with crashworthiness features. China has regulations that require complying with national standards for frontal, side, and rear impacts, and roof strength, and a small NCAP program. The net effect of these on the safety of vehicles in China is not known. We assume that 20% of vehicles in China relative to the US have crashworthiness features. Similarly, Russia requires vehicles to comply with UNECE WP29 regulations for occupant and pedestrian, and we assume that 50% of vehicles in Russia have crashworthiness features. Finally, car design regulations and NCAP testing for pedestrian safety do not apply to all vehicles (notably, they do not apply to buses and trucks). The proportion of pedestrian deaths that are due to impacts with cars, vans, and SUVs is 23% in India (Bhalla et al., 2017), where motorcycles, buses, and trucks pose the highest threat to pedestrian. This proportion is 66% in Western Europe (Koornstra et al., 2002). We assumed the proportion in Ethiopia was the same as that for India. For the remaining countries, which are all middle-income, we assumed the proportion was 44.5%, the average of India and Western Europe.

4.2 Results

Figure 6 illustrates the effects of these interventions. Reducing speed has the highest effect on reducing traffic deaths (25%-27% reduction) in all countries (see also the paper on speed by Hyden et al. in this volume). The effects of other interventions are strongly affected by the types of road users that are killed in each country and the baseline exposure to the risk factor. In countries where motorcycle riders are a large proportion of the victims and helmet use is relatively low (India and China), increasing helmet use has a relatively large effect on reducing overall traffic deaths (6% and 10% reduction, respectively). Although Colombia has a relatively large proportion of motorcycle deaths, expected gains from increasing helmet use are small (2% reduction) because baseline helmet use is already high (89%). Interventions to reduce drink driving will have the highest gains in Russia, which has the highest percentage (46%) of traffic deaths attributable to alcohol. Increasing seatbelt use has the highest benefits in Ethiopia (21% reduction), and Iran (18% reduction), where vehicle occupants are a relatively large proportion of deaths and/or seatbelt use is relatively low. Similarly, vehicle design for occupant protection will bring the highest benefits to Iran (21% reduction) and Ethiopia (17% reduction). Vehicle design for pedestrian protection will provide the biggest benefit to China (13% reduction), where pedestrians form a large proportion of victims. Notably, the gains are smaller in India (6%) and Ethiopia (5%) primarily because we estimate that a relatively small proportion (23%) of pedestrian deaths are due to impacts with cars, vans, and SUVs that are the focus of pedestrian crashworthiness regulations and NCAP testing. Motorcycles, buses and trucks, which are commonly involved in pedestrian collisions in LMICs, are not covered by vehicle regulations for pedestrian protection.

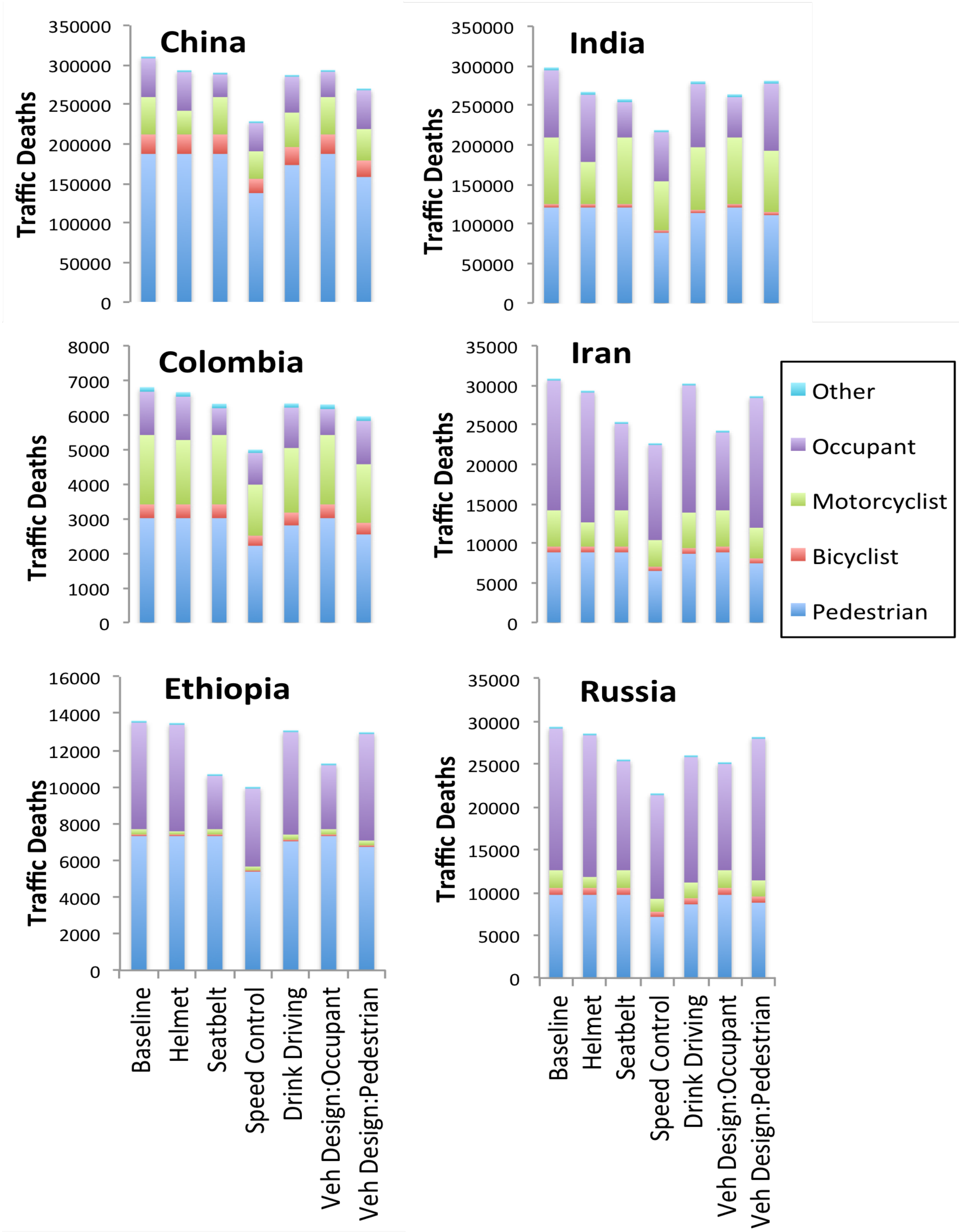

Figure 6. Potential effect of six road safety interventions on traffic deaths in six low- and middle-income countries.

4.3 Interpretation of Results

The estimates presented here are not intended to be accurate predictions of the effect of interventions but a crude assessment of the amount that LMICs will benefit if they shifted their road safety focus from ineffectual means like educating road users and towards addressing specific risk factors. Our findings suggest that the gains would be large as discussed by Hyden et al. in this volume, even small reductions in speed will result in relatively large reductions in traffic deaths because speed has a large effect on the probability of being involved in a crash as well as the probability of death in the event of a crash. Policy makers have a wide range of methods to control speeds, building traffic calming infrastructure, lowering speed limits, conducting highly visible enforcement blitzes, use of automated speed enforcement technologies, requiring speed limiters on taxis and public transport vehicles, among others.

Countries that deploy multiple interventions will see large safety benefits.

Besides speed**,** each of the other interventions can help reduce deaths by 5% to 15% depending on who is at most risk in each country. We have not modeled the effect of multiple interventions deployed simultaneously. Note that simply adding the estimates of benefits from individual interventions will likely overestimate the total lives saved. However, clearly countries that deploy multiple interventions will see large safety benefits.

This section has focused on a small list of interventions for the purpose of illustration from amongst the numerous effective ways of addressing road safety. For instance, although, we do not model the effect of medical interventions, (Noland, 2003, 2004) assessed that improvement in medical care and technology between 1970 and 2000 was responsible for between 5% and 25% of the reductions in fatalities in that period.

LMICs are not doomed to walk a pre-determined path of economic development that leads to increasing road traffic deaths until they become rich enough to invest in interventions.

5 CONCLUSION

The new understanding of the history of road safety performance of HICs holds important lessons for LMICs. Perhaps, most importantly, our analysis suggests that LMICs are not doomed to walk a pre-determined path of economic development that leads to increasing road traffic deaths until they become rich enough to invest in interventions. Instead, the history of HICs suggests that as a new understanding emerged these countries stopped blaming the victims and enacted a new approach to road safety that brought substantial success in controlling traffic deaths. LMICs should act now with an enlightened approach to road safety as HICs did in the 1960s.It is vitally important for LMICs to understand what this enlightened approach looks like. The papers by O'Neill describe how HICs transitioned from a focus primarily on the behavior of road users to a more comprehensive approach that target the key risks posed by vehicles, roads and road users, at different times (i.e. prior to crash, during the crash phase, and post-crash). Unlike the past, the new approach also included a systematic approach to identifying the most important risk factors and evaluation of empirical evidence on the effectiveness of interventions. Most LMICs continue to focus on blaming road

Most LMICs continue to focus on blaming road users and a host of driver education and behaviour change interventions that are known to be ineffective. LMICs need to take a comprehensive and evidence-based approach to road safety interventions.

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users and a host of driver education and behavior change interventions that are known to be ineffective. LMICs need to take a comprehensive and evidence-based approach to road safety interventions.

Finally, note that HICs did not achieve success because of any single or a few effective interventions. In fact, over time a large number of interventions were deployed that tended to start with the most important risk factors and increasingly became more stringent and targeted a wider population of road users. Thus, the history of HICs is better understood as one of increasing regulation of the road environment. Achieving this required establishing national agencies and giving them legislative authority and the financial resources needed to maintain a trained technical work force, develop interventions, evaluate their effects, and scale-up interventions that work as part of an ongoing process of continuing improvement. This is a long-term process and if LMICs are to achieve success similar to that of HICs, they need to prioritize the development of appropriate institutional arrangements. Traffic death rates in HICs today are about one-fifth of what they were at their peak in the mid 1960s. This provides a benchmark for what could be achieved if LMICs walked a similar path.

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