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# National road casualties and economic development

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## Summary

*Objective*: This paper explores why traffic fatalities increase with GDP per capita in lower income countries and decrease with GDP per capita in wealthy countries.

*Methods*: Data from 41 countries for the period 1992–1996 were obtained on road transport crashes, injuries, and fatalities as well as numbers of vehicles, kilometers of roadway, oil consumption, population, and GDP. Fixed effects regression was used to control for unobservable heterogeneity among countries.

*Results*: A 10% increase in GDP in a lower income country (GDP/Capita <\$1600) is expected to raise the number of crashes by 7.9%, the number of traffic injuries by 4.7%, and the number of deaths by 3.1% through a mechanism that is independent of population size, vehicle counts, oil use, and roadway availability. Increases in GDP in richer countries appear to reduce the number of traffic deaths, but do not reduce the number of crashes or injuries, all else equal. Greater petrol use and alcohol use are related to more traffic fatalities in rich countries, all else equal.

*Conclusion*: In lower income countries a rise in traffic-related crashes, injuries, and deaths accompanies economic growth. At a threshold of around \$1500–\$8000 per capita economic growth no longer leads to additional traffic deaths, although crashes and traffic injuries continue to increase with growth. The negative association between GDP and traffic deaths in rich countries may be mediated by lower injury severity and post-injury ambulance transport and medical care. 

*JEL classification:* O57; R41; I12

**Keywords** transportation; motor vehicles; traffic safety; cross country studies

## Introduction

Expansion of road transport brings opportunity for wealth and prosperity through increased commerce. An unintended side effect of increasing the contact between people and vehicles throughout the world will be a worsening of the traffic injury pandemic. With over 1 million killed by car crashes annually, traffic injuries are projected to become the 3rd leading cause of disability adjusted life years lost by 2020 [1]. The Red Cross has dubbed the 20th century, 'The Century of Road Death' [2] and the 21st century may show little improvement. Over 30 million people have perished in traffic fatalities since the very first pedestrian casualty in 1898 [2].

Prior studies have recorded a biphasic relationship between traffic fatalities and economic development with fatalities rising for the low income countries and falling for the high income countries [3]. Environmental economists finding a similar relationship between pollution and income noted homology to Kuznets's inverted-*U* relationship

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between income inequality and development. They discuss an 'environmental Kuznets curve' [4] in which the pollution externalities of mechanized activity first rise and then fall with the economic growth that attends industrialization. For pollution to decrease while mechanized activity increases requires investments in harm reduction. The critical question is whether the investments in harm reduction will be able to keep up with growth in the scale and intensity of polluting activity.

While environmental economists have been concerned with the harms from motorized transport, they tend to focus on the exhaust pipe as the source of harm. To date, few economists have been as concerned with harms emitted from the bumper. With over 1 million deaths per year due to traffic fatalities, motor vehicles are the most lethal aspect of the modern physical environment, and it is not surprising that a country's ability to control the harms in its roadways would be similar to its ability to control other environmental hazards. Motor vehicle fatalities can be considered the greatest health hazard which rises and falls with economic development on the environmental Kuznets curve.

*Ceteris paribus*, a population that spends more time exposed to moving vehicles ought to experience more traffic harms. The crudest measure of exposure to motorized transport, vehicles/population, always increases with economic growth [5] as do other measures such as petroleum consumption per capita and kilometers per capita. Since traffic fatalities can decline at advanced stages of economic growth despite increases in traffic, we need to understand why higher income countries are able to mitigate the harm from the increased population exposure to road traffic. One scenario would be that investment in harm reduction (safer drivers, roads, and vehicles) has simply reduced the numbers of crashes. Another possibility would be that harm reduction policies have reduced the number and severity of the injuries that attend crashes so that even though crashes occur the energy is channeled away from the occupants and pedestrians. For example, this might occur with a transition away from motorized bicycles to sedans, or through occupant restraints. Finally it might be the case that improvements in emergency transport and in the medical treatment of trauma have enabled better survival despite continuing upward trends in the numbers of crashes and injuries.

The objective of this paper is to identify the relationship between economic growth and traffic fatalities, traffic injuries and crashes. We will show that although there is an inverted $U$ (an environmental Kuznets curve) for fatalities, there is no such relationship for injuries and crashes. A secondary objective of the paper is to identify some of the mechanisms by which economic growth is related to fatalities, injuries, and crashes. Because there are cross country panel data on only a limited number of variables, the relative contribution of various unmeasured determinants of traffic fatalities such as road quality, enforcement efforts, motorist attitudes, etc. cannot be assessed in this study. We control for the total contribution of time-invariant unmeasured determinants of traffic fatalities using country fixed and random effects models.

## Methods

### Theoretical framework

Since safety is a normal good, more income ought to predict more safety, yet the perplexing trend for low income countries, is that more income leads to less traffic safety and more traffic deaths [3]. The opposite is true in high income countries where more income leads to fewer traffic deaths [3]. What can account for the difference? There are several possible explanations: (1) An externalities story in which the more advanced stages of economic development are a prerequisite for the institutional capacity to successfully assign liability and to regulate externalities; (2) A competing risks story in which it is rational for road users to underinvest in road safety and bear a greater exposure to high risk transport options in order to generate an income which can be used to control infectious and nutritional health risks that are simpler to control early in the epidemiological transition. In higher income countries infectious diseases and malnutrition recede in importance relative to transport injuries and it becomes rational for motorists and governments to spend more resources on safety. (3) A vehicle mix story in which lower traffic fatality rates occur spontaneously as economic growth empowers more road users to switch to driving safer sedans instead of more dangerous transport modalities such as motorized bicycles and the rooftops of buses; (4) A medical technology story, in which a country's capacity to transport and resuscitate road trauma victims must await the development of a highly capable medical system. We will review these explanations one by one.

## Externalities

Several have identified the potential for a motorist's insurance policy to increase risk-taking [6,7]. Externalities abound in the transportation market, and are not limited to the injuries a single motorist may inflict on others in the rush from point A to point B. To the extent that car buyers and local regulators are unconcerned and uninformed about vehicle safety, manufacturers can impose safety externalities on the market. Purveyors of alcohol may impose similar safety externalities in the absence of regulation and enforcement. Roadway engineers, despite their operation in the public sector, may experience political incentives to under-invest in maintaining the safety properties of local roadways. In terms of Coase's theorem, a first best market solution to any externalities problem can be achieved if rights to injure or to be spared injury are securely assigned and then costlessly traded [8]. In Coase's terms, all externality problems are due to institutional failures to securely assign and administer externality rights and also due to high transaction costs inhibiting injurers from bearing liability and/or injury victims from making claims. Ultimately, both the generators and victims of traffic safety externalities are distributed widely in the economy. With formidable transaction barriers separating them, motorists and their victims in a less developed country may have to wait for substantial institutional development before traffic courts and regulators can successfully assign liability and officiate over claims.

## Competing risks

The competing risks account is familiar to many transport experts in developing countries who explain the low rates of investment in road safety by pointing to 'limited resources'. A competing risks explanation of the connection between economic growth and traffic casualties assumes that countries prioritize their investments in public health and safety to maximize increments in welfare per public dollar spent. Under this view, investments in traffic safety are deferred by low income countries as they work down a league table of public investments that are deemed higher priorities. With development, more of the higher yield (lower cost) public health investments will have been fully exploited. Thus, with development, investments in safer roads and greater enforcement become both more attractive and affordable. These investments would take the form of regulating and enforcing traffic codes and vehicle safety standards, as well as controlling the frequency of alcohol-impaired driving. Prior research has shown that excise taxes on alcohol are associated with lower rates of traffic deaths [9,10].

A recent study of public investment in road safety showed that in Pakistan and Uganda rates of investment in road safety range from \$0.07 to \$0.09 per capita per year [11]. Yet the wisdom of deferring road safety investments in low income countries is subject to question since some cost–benefit calculations have shown rates of return on investments in road safety in lower income countries that approach the returns on many commonly accepted developing country health investments [12,13].

## Vehicle mix

Economic growth can alter the mix of vehicles on the road. Additional income may lead consumers to upgrade from scooters to sedans, or from sedans to sport utility vehicles (SUVs). The effects of income growth on vehicular hazards are complex and may not necessarily lead to a positive effect of economic development on safety. Personal income growth may also lead individuals to pursue convenience by substituting more hazardous personal vehicles for safer but less convenient buses and trains. For instance, bus ridership in Bogota, Colombia fell from 69% in 1972 to 52% in 1978 [14]. And more SUVs in a country may not lead to lower fatalities overall. A recent simulation study showed that an increasing prevalence of SUVs in a population of smaller vehicles could actually increase population level injury and death rates because of the much higher casualty rate during crashes between asymmetrically sized vehicles [15]. There have been no systematic cross-country studies documenting how vehicle mix changes with economic development.

## Medical technology

The medical technology explanation for the decline of traffic fatalities is supported by several strands of evidence. A case study of urban trauma outcomes in Ghana, Mexico, and the US identified the importance of investments in prehospital care in determining fatality rate – in Kumasi Ghana 51% of severely injured persons died in the field. Corresponding rates in Monterrey, Mexico and Seattle were 40 and 21%, respectively [16]. Discrete investments in trauma care and pre-hosptial care have been associated with improved trauma survival in a variety of locations [17–19].

## An economic model

In order to nest these competing hypotheses in a common economic model let us consider a model of the choices facing a driver (subscript d), an innocent bystander (e.g. a walker (subscript w), and a government policy maker (subscript g). We begin with a traffic fatality production function.

$$\pi_f = \pi_{f|i}(\mathbf{a}_d, \mathbf{a}_w, \mathbf{a}_g) \times \pi_{i|c}(\mathbf{a}_d, \mathbf{a}_w, \mathbf{a}_g) \times \pi_c(\mathbf{a}_d, \mathbf{a}_w, \mathbf{a}_g) \qquad (1)$$

where $\pi_f$ is the probability of a fatal traffic injury – which can be considered the product of the probability of a crash ($\pi_c$) and the probability of any injury conditional on a crash ($\pi_{i|c}$) and the probability of a fatal injury conditional on any injury ($\pi_{f|i}$). Each of these probabilities is produced by a vector of activities selected by the driver ($\mathbf{a}_d$), the walker ($\mathbf{a}_w$) and the government ($\mathbf{a}_g$). Activities for each agent, $\mathbf{a}_i$ (where $i \in \{d, w, g\}$) are subsets from large but finite choice sets $\mathbf{S}_i$. For instance the choice set for the driver, $\mathbf{S}_d$ includes elements such as vehicle types and vehicle maintenance, vehicle safety features, driver diligence, and a composite commodity representing the choice to invest in items other than safety. The choice set for the walker, $\mathbf{S}_w$ would include proximity to roadway, time of day, etc. The choice set for the government, $\mathbf{S}_g$ would include investments in roadway quality, guard-rails, stoplights, vehicle inspection, traffic code enforcement, traffic litigation, as well as investments in trauma care and emergency transport. The government choice set also includes a composite commodity, representing the option of investing in public goods other than safety. Associated with each agent's choice set is a price vector, $\mathbf{p}_i$. We stipulate that $\mathrm{d}\pi/\mathrm{d}a_i < 0\ \forall i \ni \{d,\ w,\ g\}$. So that the probability of injury diminishes with precautionary actions.

The objective of the driver is to minimize his/her total expected costs from accidents and accident prevention

$$C_\mathrm{D} = \mathbf{p}'_d \mathbf{a}_d + \sum_{j \ni \{f,i,c,\}} \lambda_j \pi_j(\mathbf{a}_d, \mathbf{a}_w, \mathbf{a}_g) \times (c_j) \qquad (2)$$

where $C_\mathrm{D}$ represents the expected costs of the driver, $\mathbf{p}_d$ is a vector of shadow costs for the selected action vector, $\mathbf{a}_d \subset \mathbf{S}_d$, $\lambda_i$ is the driver's share of the joint costs of property loss, health care costs, and lost life years borne by both the walker and the driver for each type of event. If $\lambda_j = 1$, the driver must pay all of both his and the pedestrian's costs.

The driver therefore chooses the $k$th element $a_{dk}$ of the action vector $\mathbf{a}_d$ from the opportunity set $\mathbf{S}_d$ as follows:

$$\frac{\mathrm{d}\pi_f}{\mathrm{d}a_{dk}}\lambda_f c_f + \frac{\mathrm{d}\pi_i}{\mathrm{d}a_{dk}}\lambda_i c_i + \frac{\mathrm{d}\pi_c}{\mathrm{d}a_{dk}}\lambda_c c_c + p_{dk} = 0 \qquad (3)$$

In Equation (3) the sum of the three partial derivatives give the marginal benefit of the driver's $k$th action choice while $p_{dk}$ gives the action's marginal cost. The notable point is that with either crash or injury insurance or in regimes where driver liability is poorly enforced $\lambda_c$ and $\lambda_i$ may be reduced and the driver perceives a marginal benefit that is distorted below its true level. Thus a government's capacity to assign and adjudicate disputes over liability for crashes and traffic injuries can lead to driver choices that can lead to event rates above the social optimum. There would also be analogous expressions guiding the pedestrian's action choices, except these expressions would contain $(1-\lambda)$ to depict the pedestrian's share of liability for outcome costs. Since pedestrian injury costs are typically much higher than motorist costs and since motorist payments cannot fully indemnify pedestrians against their pain and suffering, the model predicts that pedestrians overinvest in safety precautions, e.g. using roadways less than they would like to.

 

The choice variables for the government are $\lambda$ and $\mathbf{a}_g$. Some of the elements in the choice set, $\mathbf{S}_g$, will affect how well the liability sharing decision is enforced through the conduct of traffic and civil courts. With the presence of functioning legal institutions the government can meaningfully establish the share of liability borne by drivers ($\lambda$). The government would like to minimize the total expected costs to society of both accidents and accident prevention activities given by the following equation:

$$C_G = \mathbf{p}_d'\mathbf{a}_d + \mathbf{p}_w'\mathbf{a}_w + \mathbf{p}_g'\mathbf{a}_g + \sum_{j \ni \{f,i,c,\}} \pi_j(\mathbf{a}_d, \mathbf{a}_w, \mathbf{a}_g) \times (c_j) \quad (4)$$

Although not depicted by the model, the action choices of each party will be best response reactions to the expected best responses of the other parties. According to Coase theorem, in an economy with full information and no transaction costs between drivers and walkers the choice of $\lambda$ does not affect the choices of either party. In a second best world where information is imperfect, part of the government's strategy might be to develop institutions that make it more possible for roadway users to transact trades in injury liability by making the assignment of liability more transparent to all.

The full political economy for the government lies unspecified in this model. Various elements of $\mathbf{p}_g$ will shift downward with development in the various economic sectors. Investments in developing and maintaining judicial systems, and police systems are seldom justified by their impact on traffic safety alone. But as judicial institutions develop, they lower the opportunity cost of using litigation to improve driver behavior. Similarly emergency transport and trauma care systems are made less costly by developments in the health system such as blood banking and the availability of trained neurosurgeons as well as heart–lung bypass capabilities that would not transpire solely for the benefit of road transport victims. Some of the governments' actions serve to tax roadway user negligence through fines or to subsidize diligence by erecting pedestrian byways and maintaining rest areas. In some societies the incidence of these sanctions falls on politically organized groups who may resist these measures preferring to have higher traffic speeds, higher legal blood alcohol limits, and looser vehicular safety standards, despite the likelihood that they themselves may bear a share of the higher rate of crashes and injuries.

The model helps to organize the four complementary and competing accounts for why traffic casualties rise then fall with economic development. Development opens up multiple new options for the players as the prices of the elements in their choice sets render various choices more affordable. For walkers and drivers, economic development is accompanied by development of markets for mass-transit and/or for safer vehicles making these features of the choice sets, $\mathbf{S}_w$ and $\mathbf{S}_d$, more affordable. We refer to this possibility as '*the vehicle mix*' explanation for a reduction in traffic casualties.

For governments, when economic development enhances the quality of legal institutions it encourages governments to select actions from $\mathbf{S}_g$ that assign and regulate driver liability. We refer to this possibility as '*the externalities*' explanation for a reduction in traffic casualties. Development related improvements in the capacity of local medical systems enables governments to select elements from $\mathbf{S}_g$ that enhance emergency care. We call this the '*improved trauma care*' explanation. Finally as returns to scale are increasingly exploited in the components of $\mathbf{S}_g$ that is orthogonal to traffic safety, governments will find it optimal to substitute away from the less productive public sector activities towards traffic safety. We call this the '*competing risks*' explanation. These multiple competing explanations can be tested, because they lead to different predictions. Table 1 summarizes the predictions of the model.

With all four explanations, small increases in income in less developed countries simply increase exposure to road hazards without sufficient development to predict a reduction in casualties. The differences in the explanations occur further along in the process of development. Both the externalities and competing risks explanation involve investments in government activities that lead to more driver diligence and safer roadway environments reducing crashes, and injuries, and fatalities. The vehicle mix explanation does not predict a reduction in crashes. It predicts that the vehicles on the roads could potentially be safer, so that when a crash occurs there will be fewer injuries and fatalities. Finally the improved trauma care explanation predicts no reductions in crashes or injuries – ambulances and doctors just do a better job saving the lives of all of the victims.

 

Table 1. Predictions made by each of the 4 contending theories with respect to patterns in fatalities, injuries, and crashes as economic growth ensues. Only one theory, improved trauma care, is consistent with the data showing declines solely in fatalities

| Theory | Predicted overall pattern for plot of events vs GDP/capita | Pattern in higher income countries | Pattern in lower income countries |
|---|---|---|---|
| Improved trauma care explanation | Inverted *U* for fatalities | Fatalities decline | |
| | Monotonic non-decreasing for crashes and injuries | | |
| Vehicle mix explanation | Inverted *U* for injuries and fatalities | Injuries and fatalities decline | Rises in crashes, injuries and fatalities as vehicles per capita increase |
| | Monotonic non-decreasing for crashes | | |
| Externalities explanation | Inverted *U* for all three events | Crashes injuries and fatalities decline | |
| Competing risks explanation | Inverted *U* for all three events | Crashes, injuries and fatalities decline | |

## Data

Data were obtained from International Roadway Federation (IRF) for a 5 year period from 1992–1996. This period was chosen to coincide with the timing of cross country data on alcohol consumption which was available for a single year – 1995 [9]. The IRF data included annual road fatalities, annual injuries, annual crashes, number of registered vehicles, total road network kilometers, and kilotons of petroleum used for road vehicles [20]. Data on the proportion of buses, trucks, cars and motorcycles, were quite limited and were not used. The sources upon which IRF relies are country statistics that are of variable quality. Past authors have suspected under-reporting of road crashes in this data [21]. Under-reporting may be systematically more severe in lower income countries. Events which are most likely to be under-reported are crashes and injuries, the least severe of which are never brought to the attention of any authorities. Data on population and GDP was obtained from World Development Reports [22]. Data on alcohol consumption came from the WHO [23].

Complete data on all variables could be assembled for 46 countries for at least one year between 1992 and 1996. A maximum total of 183 country years of data could be analyzed in bivariate regressions. Multivariate regression reduced the sample size to 41 countries and 146 country-years. The availability of data from this limited set of countries means that our findings will not be representative of any particular region. Table 2 lists the countries studied. Table 3 lists the country means and standard deviations of the key variables analyzed.

## Statistical approach

We use regression to estimate a transformed version of the analysis originally conducted by Smeed in 1949 [24].

$$
\begin{aligned}
&\mathrm{Log}(\mathrm{outcomes}_{it})\\
&\quad = C + \beta_1 \log(\mathrm{vechicles}_{it}) + \beta_2 \log(\mathrm{population}_{it})\\
&\qquad + \beta_3 \log(\mathrm{oil\ \ use}_{it}) + \beta_4 \log(\mathrm{GDP}_{it})\\
&\qquad + \beta_5 \log(\mathrm{road\ \ kilometers}_{it})\\
&\qquad + \beta_6 \log(\mathrm{alcohol\ \ consumption}_{i}) + \mu_i + \varepsilon_{it} \quad (5)
\end{aligned}
$$

Here ‘outcomes’ can be crashes, injuries or accidents, and $\mu_i$ represents the combined effects of unmeasured factors associated with traffic fatalities in a country that does not rapidly change over time. These could include the degree of enforcement, cultural attitudes, the quality of roads and vehicles, the quality of medical care, etc. The other component of the error term, $\varepsilon_{it}$, is assumed to be random noise which has a normal distribution.

Table 2. Countries studied

| Country | Deaths per 100 000 vehicles (MEAN) | SD | Number of years |
|---|---|---|---|
| Austria | 33 | 4.3 | 5 |
| Bahrain | 38 | 8.5 | 5 |
| Brunei | 41 | 7.6 | 5 |
| Bulgaria | 74 | 14.8 | 5 |
| Byelarus | 225 | 48.3 | 4 |
| Cambodia | 306 | 69.3 | 5 |
| Croatia | 109 | 23 | 5 |
| Cyprus | 40 | 4 | 5 |
| Ecuador | 296 | 23 | 4 |
| El Salvador | 177 | 75.7 | 4 |
| Estonia | 74 | 18 | 5 |
| Finland | 23 | 3.4 | 5 |
| France | 29 | 2.2 | 5 |
| Georgia | 141 | 47.8 | 4 |
| Germany | 25 | 4.9 | 5 |
| Greece | 69 | 5.2 | 5 |
| Hong Kong | 64 | 11 | 5 |
| Iceland | 12 | 4.4 | 5 |
| India | 1155 | 30.8 | 2 |
| Israel | 40 | 3.5 | 5 |
| Japan | 17 | 1 | 3 |
| Kazakhstan | 232 | 45 | 4 |
| Korea, Rep. | 159 | 39.4 | 5 |
| Lithuania | 100 | 22.3 | 5 |
| Macedonia | 57 | 2.4 | 4 |
| Malaysia | 179 | 10.4 | 4 |
| Namibia | 91 | 18 | 4 |
| Netherlands | 20 | 0.4 | 4 |
| New Zealand | 32 | 2.5 | 3 |
| Nicaragua | 270 | 72 | 4 |
| Norway | 15 | 1.5 | 5 |
| Pakistan | 848 | 30.6 | 4 |
| Portugal | 67 | 12.5 | 5 |
| Romania | 122 | 16.8 | 5 |
| Saudi Arabia | 141 | 5.7 | 2 |
| Senegal | 536 | 122 | 4 |
| Serbia | 79 | 15 | 5 |
| Slovakia | 57 | 4.1 | 5 |
| Spain | 35 | 2.4 | 3 |
| Sri Lanka | 667 | 88.5 | 4 |
| Sweden | 16 | 2.2 | 4 |
| Switzerland | 21 | 2.6 | 5 |
| Taiwan | 70 | 7 | 5 |
| Turkey | 152 | 17.8 | 5 |
| UK | 17 | 1.6 | 3 |
| US | 21 | 0.1 | 5 |
| Yemen | 259 | 27 | 5 |
| Zimbabwe | 328 | 29.5 | 5 |

Multivariate regression can estimate all of the $\beta$ parameters. Because inspection of the raw data showed a biphasic relationship, the sample was stratified into an upper tertile with GDP/capita

Table 3. Descriptive data from the sample

| Variables | Mean across country-years | SD |
|---|---|---|
| Petrol consumption (in kilotons used for road transport) | 1.5 | 5.8 |
| Crashes (annual count) | 104 777 | 342 547 |
| Injuries (annual count) | 138 166 | 510 431 |
| Deaths (annual count) | 3655 | 8556 |
| Total road network (kilometers) | 275 878 | 860 115 |
| Four Wheel Vehicles (count in millions) includes Passenger cars, buses, coaches, lorries, and vans | 9.3 | 3 |
| Population (in millions) | 48.22 | 142.8 |
| GDP per capita $ adjusted for purchasing power parity | $ 11 364.5 | 7894 |
| Alcohol (liters per person per year) | 6.78 | 4.5 |

Number of countries with complete data for all variables = 41.

$\geqslant$\$1600 and a sample including the lower two tertiles of low income countries with GDP/capita $\leqslant$\$1600. Models were run to test the robustness of the findings to alternative cut points. Ordinary least squares (OLS), fixed effects (FE), and random effects (RE) models were estimated. Both the outcomes and the inputs in the production models are log-transformed to both normalize the variables and to ease interpretation.

Rather than conduct regressions on outcomes per capita as a function of inputs per capita, we enter both outcomes and inputs unadjusted per capita. Note that if $Y$ and $X$ are completely uncorrelated, it is elementary to show that $Y/P$ and $X/P$ can still show a spurious correlation. Consequently, we do not regress events/population against GDP/population or other factors/population because the regression would be biased by correlation caused by the common population denominator on both sides of the regression equation. All multivariate models include log population as a separate independent variable, this permits the same 'per capita' interpretation without creating spurious correlation. In a regression of $Y = \beta_0 + \beta_1 X + \beta_2 P$, one can interpret $\beta_1$ as the effect of $X$ on $Y$ holding population fixed. Alternatively, after estimation is complete, one can divide through by $P$ to show that $(Y/P) = (\beta_0/P) + (\beta_1)(X/P) + \beta_2$ and $\beta_1$ is the effect of per capita $X$ on per capita $Y$.

Hausman tests are used to test model specification [25]. The Hausman test is used to test the null that two estimators are consistent where one is a conditional maximum likelihood estimator and therefore inefficient and the other is efficient under the null hypothesis. We first test the null that fixed effects models are consistent relative to OLS, and then the null that random effects models are consistent relative to fixed effects models. Because the Hausman test relies on an estimate of $\mathrm{Var}(b-\beta)$ as $\mathrm{Var}(b)-\mathrm{Var}(\beta)$ it can sometimes lead to negative Chi squared statistics suggesting that the data do not conform to the model assumptions. Whenever this occurred we used the 'suest' command in Stata 8.0 [26] to implement a robust Hausman test which estimates $\mathrm{Var}(b-\beta)$ as $\mathrm{Var}(b)-\mathrm{cov}(b,\beta)-\mathrm{cov}(\beta,b)+\mathrm{Var}(\beta)$ which is always well-defined [27]. We also implemented a Breusch–Pagan test of the null that all random effects are zero. Using a combination of the Breusch–Pagan and Hausman tests we were able to establish preferred statistical models in each instance. To enable readers to judge the importance of specification, we present all three models and note the preferred specification.

## Results

Figure 1 displays a scatter plot of Log(Deaths/Person) vs Log(GDP/Person) and confirms an inverted $U$ relationship with an inflection point in the range between per capita GDPs of \$1500 to \$8000 per person. Countries poised at this inflection point include: Malaysia, Republic of Korea, Saudi Arabia, Greece, and Portugal. Figures 2 and 3 show a rise in both traffic crashes and traffic injuries, which levels off, but never declines as GDP/capita rises. The three figures together suggest that the drop in traffic fatality rates for wealthier countries might reflect phenomena re-

 

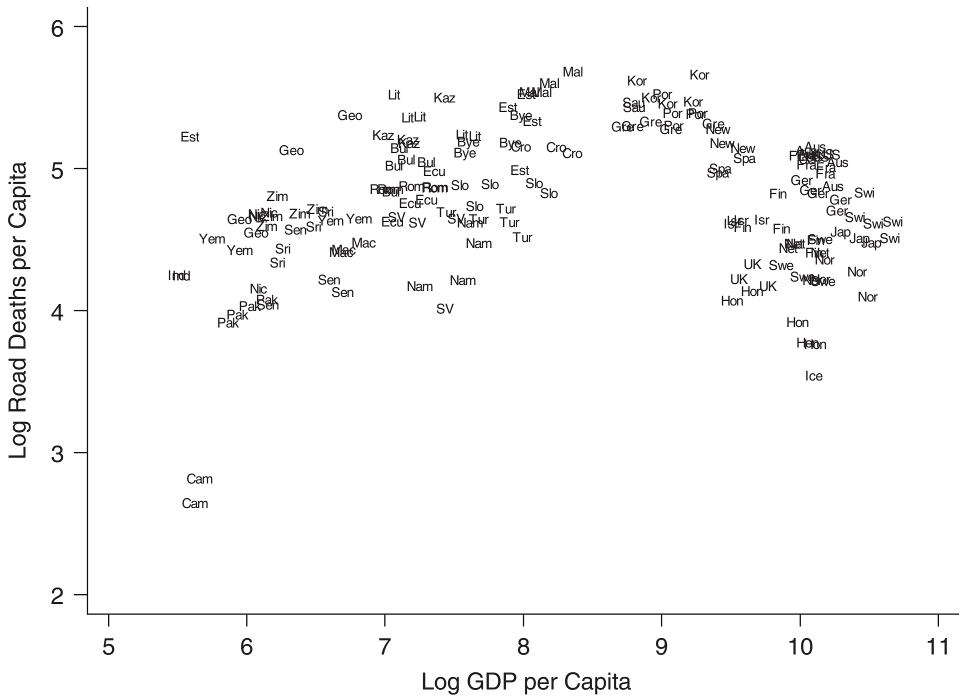


Figure 1. Scatterplot of Log Road Deaths per capita vs Log GDP per capita 1992–1996. KEY: Country abbreviations are initial letters from the list below with exceptions noted in (): Austria, Bulgaria, Byelarus, Cambodia, Croatia, Ecuador, El Salvador (SV), Estonia, Finland, France, Georgia, Germany, Greece, Hong-Kong, India, Israel, Kazakhstan, Lithuania, Macedonia, Malaysia, Namibia, Netherlands, Nicaragua, Norway, Pakistan, Portugal, Republic of Korea (Kor), Romania, Saudi Arabia, Senegal, Slovakia, Sri Lanka, Sweden, Switzerland, United Kingdom (UK) United States (US), Yemen, Zimbabwe

lated to better survival of injuries rather than fewer injuries and crashes.

Table 4 indicates the results of bivariate models to predict counts of crashes, injuries, and fatalities. This table shows unadjusted regression coefficients from a model of log outcomes against a single logged independent variable: Log(Outcome) $= \beta$ Log(Factor) $+ \varepsilon$. In the unadjusted models GDP, Population, Vehicle Counts, Oil Use and Roadway Availability appear to be positively correlated with all of the outcomes in both low and high income countries. Alcohol use has its strongest association with injury counts in high income countries. Since each of these factors is correlated with the others it is impossible to infer the relative contributions without turning to multivariate methods.

Tables 5–7 show multivariate results for crashes, injuries, and deaths. The structure of each table includes 3 sets of 3 columns each. The first set uses data on the subsample of lower income countries, the second uses data on the wealthier countries, and the final uses all of the available data. The first model of each set is an ordinary least squares (OLS). Since alcohol is only available for one year during the period, alcohol is omitted from the fixed effects (FE) and random effects (RE) models. The Breusch–Pagan test results decisively indicate the presence of non-zero unmeasured country level effects, which violate the assumption of the OLS specification. The Hausman tests results shown at the bottom of each table show a preference for the FE specification most of the time. The overall pattern of significance and coefficient magnitudes are similar between RE and FE models.

Due to the log–log structure of the regression equation, the regression coefficients can be interpreted as elasticities. In other words the coefficient of 0.788 on log GDP model 2 in Table 5 suggests that holding all other factors constant, a 10% rise in GDP in this sample would be correlated with a 7.88% rise in crashes in the sample of low income

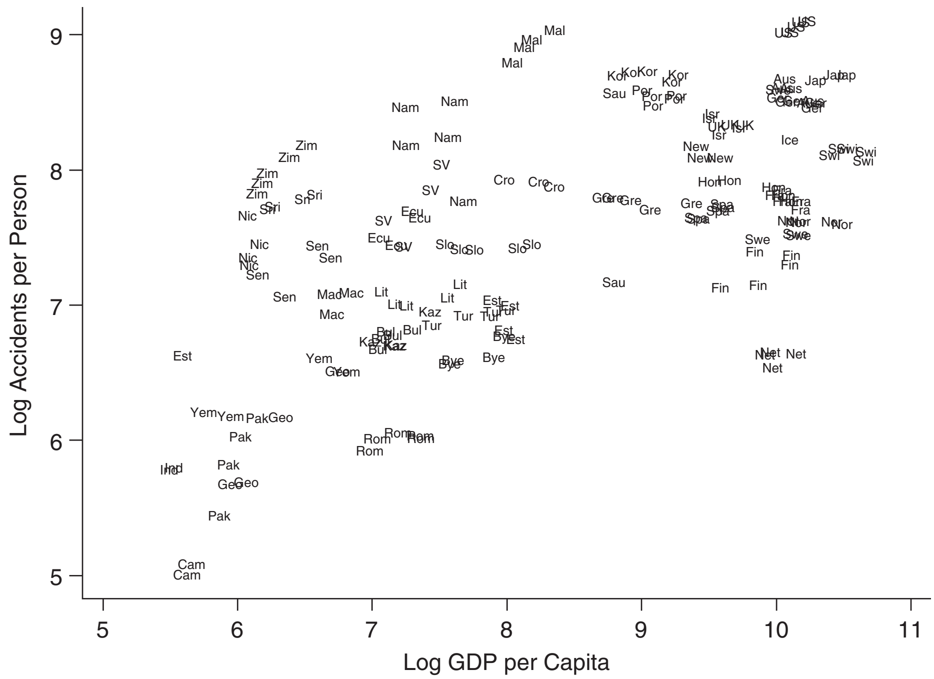


Figure 2. Scatterplot of Log Traffic Crashes per capita vs Log GDP per capita 1992–1996. Key as per Figure 1

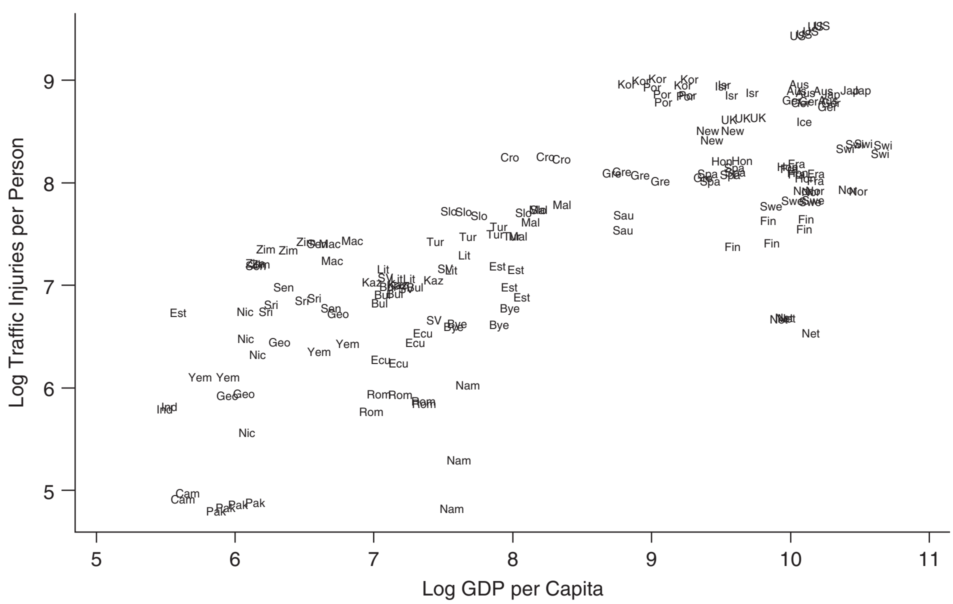


Figure 3. Scatterplot of Log Traffic Injuries per capita vs Log GDP per capita: 1992–1996. Key: as per Figure 1

countries. Note that in Table 5 the positive relationship between crashes and GDP is stronger and more significant in low income countries, and the results in the full sample are attributable to the effects in the low income subset. Alcohol use appears to increase traffic deaths (Table 7) with

 

Table 4. Bivariate log–log regressions of accidents, injuries, and deaths

| | Poor countries | | | Rich countries | | | All countries | | |
|---|---|---|---|---|---|---|---|---|---|
| | Acc | Inj | Deaths | Acc | Inj | Deaths | Acc | Inj | Deaths |
| Log GDP | 0.724 | 0.681 | 0.939 | 0.775 | 0.904 | 0.598 | 0.629 | 0.758 | 0.452 |
| | (5.15)*** | (4.53)*** | (8.66)*** | (9.83)*** | (11.75)*** | (8.81)*** | (9.15)*** | (11.83)*** | (7.63)*** |
| Log population | 0.702 | 0.658 | 0.889 | 1.11 | 1.193 | 1.034 | 1.002 | 1.05 | 0.996 |
| | (9.33)*** | (5.05)*** | (15.34)*** | (13.08)*** | (12.20)*** | (24.31)*** | (8.90)*** | (7.45)*** | (22.73)*** |
| Log vehicles | 0.32 | 0.49 | 0.848 | 0.94 | 1.043 | 0.854 | 0.799 | 0.945 | 0.732 |
| | (1.310) | (1.97)* | (4.25)*** | (17.32)*** | (16.62)*** | (12.32)*** | (10.54)*** | (13.41)*** | (10.30)*** |
| Log alcohol consumption | −0.237 | −0.107 | 0.033 | 0.551 | 0.958 | 0.557 | 0.283 | 0.585 | 0.277 |
| | (−1.460) | (−0.90) | (0.220) | (1.380) | (2.57)** | (1.79)* | (1.30) | (2.59)** | (1.50) |
| Log roads | 0.557 | 0.509 | 0.698 | 0.818 | 0.863 | 0.752 | 0.781 | 0.82 | 0.738 |
| | (3.47)*** | (2.89)** | (3.84)*** | (5.67)*** | (6.50)*** | (9.45)*** | (6.35)*** | (6.67)*** | (10.46)*** |
| Log oil | 0.426 | 0.327 | 0.595 | 0.924 | 0.994 | 0.853 | 0.836 | 0.922 | 0.768 |
| | (2.68)** | (1.450) | (2.06)* | (14.71)*** | (12.48)*** | (10.05)*** | (11.21)*** | (10.25)*** | (9.39)*** |

Poor countries defined as GDP/capita < \$1600/person. All regressions include only the logged annual count of outcomes vs one logged independent variable and a constant. Acc = Log (Accident count); Inj = Log (Injury count); Deaths = Log (Death count). Robust *t*-statistics in brackets.
*Significant at 10%; **Significant at 5%; ***Significant at 1%.

most of its contribution occurring in rich countries. Note that alcohol use does not predict an increase in the number of crashes (Table 5) or injuries (Table 6). It is unusual that alcohol effects are seen for deaths, but not for crashes and injuries. This is counterintuitive and may reflect the inability of ecological models to fully reflect factors that increase risk on an individual basis [28].

Table 6 suggests that like crashes, injuries are more strongly positively related to GDP among lower income than higher income countries. Note further that according to the OLS models in Table 6 holding the number of vehicles and persons constant, low income countries that consume *more* oil have *fewer* injuries. In the OLS model it is likely that oil usage is reflecting factors related to the type of vehicles used in a country. If a country used more motor fuel, but held the number of vehicles and people constant, one would suspect that such a country would have larger vehicles. Fixed effects and random effects models eliminate this type of 'vehicle mix' confounding and in models 2,3,5,6,8, and 9 of Table 6, the protective effect of oil is absent. In wealthier countries, the preferred models reveal that additional oil use is, all other things equal, associated with more injuries (Table 6, Column 5) and deaths (Table 7, Column 5), but not more crashes (Table 5, Column 6). This gives a suggestion that the pure effect of additional oil use, e.g. absent fixed effects such as vehicle mix, is to increase the 'energy' associated with each crash leading to more injuries and deaths.

Table 7 recovers evidence for the biphasic relationship between GDP/capita and traffic deaths per capita with a positive relationship in low income countries and a negative or zero effect in higher income countries. Table 7 also points out that for lower income countries holding GDP fixed, growth in the number of vehicles and in population are both stronger contributors to traffic deaths than GDP itself.

The fixed effects models in Table 7 show that unobservable country effects always bias the effects of GDP negatively. In lower income countries where GDP increases traffic mortality these harmful effects are underestimated by OLS models, suggesting that the unobservable factors confounded with GDP are protective. In higher income countries where GDP decreases mortality, the protective effects of GDP are overestimated, again suggesting that the unobservable factors

Table 5. Multivariate regressions of crashes

| | Lower income | | | Higher income | | | All | | |
|---|---|---|---|---|---|---|---|---|---|
| | OLS | FE[a] | RE | OLS | FE | RE[a] | OLS | FE[a] | RE |
| Column: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Log GDP | 0.694 | 0.788 | 0.591 | 0.112 | 0.085 | 0.077 | 0.352 | 0.166 | 0.184 |
| | (2.33)** | (4.84)*** | (4.78)*** | (0.530) | (0.710) | (0.78) | (2.36)** | (2.72)*** | (3.42)*** |
| Log population | 0.324 | 2.627 | 0.288 | 0.743 | −0.691 | 0.857 | 0.735 | 0.708 | 0.56 |
| | (0.720) | (2.55)** | (1.55) | (3.17)*** | (−0.650) | (5.14)*** | (4.23)*** | (1.140) | (5.37)*** |
| Log vehicles | −0.379 | −0.458 | −0.159 | 0.483 | −0.009 | 0.129 | −0.028 | 0.204 | 0.15 |
| | (−0.920) | (−0.770) | (−0.73) | (1.380) | (−0.040) | (0.82) | (−0.10) | (1.10) | (0.12) |
| Log oil | 0.055 | 0.054 | 0.155 | −0.038 | 0.08 | 0.056 | 0.06 | 0.113 | 0.110 |
| | (0.820) | (0.280) | (1.04) | (−0.180) | (1.10) | (0.82) | (0.610) | (1.520) | (0.10)* |
| Log roads | 0.029 | 0.027 | 0.003 | −0.155 | −0.016 | −0.0137 | −0.046 | 0.014 | 0.011 |
| | (0.280) | (0.920) | (0.09) | (−1.080) | (−0.470) | (−0.40) | (−0.440) | (0.550) | (0.65) |
| Log alcohol consumption | −0.005 | | | −0.104 | | | −0.039 | | |
| | (0.020) | | | (−0.450) | | | (−0.240) | | |
| Constant | 6.242 | 0.856 | 3.47 | 2.314 | 10.397 | 4.76 | 4.565 | 1.889 | 2.99 |
| | (1.080) | (0.140) | (1.350) | (0.810) | (2.93)*** | (2.81)*** | (2.05)** | (0.750) | (2.90)*** |
| Observations | 41 | 47 | 47 | 94 | 99 | 99 | 135 | 146 | 146 |
| *R*-squared | 0.63 | 0.64 | 0.62 | 0.88 | 0.77 | 0.87 | 0.84 | 0.82 | 0.82 |
| Hausman test OLS vs FE | | 24.12*** | | | 50.64*** | | | 11.00* | |
| Hausman test FE vs RE | | 10.04* | | | 7.25 | | | 1.05 | |
| Breusch–Pagan test | | | 29.54*** | | | 115.56*** | | | 145.87*** |

Robust *t*-statistics in brackets.
[*]Significant at 10%; [**]Significant at 5%; [***]Significant at 1%.
[a] Denotes preferred model according to specification tests.

Table 6. Multivariate regressions of injuries

| | Lower income | | | Higher income | | | All | | |
|---|---|---|---|---|---|---|---|---|---|
| | OLS | FE | RE[a] | OLS | FE[a] | RE | OLS | FE[a] | RE |
| Column: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Log GDP | 0.63 | 0.677 | 0.473 | 0.175 | 0.057 | 0.031 | 0.386 | 0.168 | 0.186 |
| | (3.41)*** | (2.62)** | (2.78)*** | (0.850) | (0.830) | (0.480) | (3.17)*** | (2.90)*** | (3.55)*** |
| Log population | 0.285 | 2.922 | 0.302 | 0.708 | −0.755 | 0.717 | 0.639 | 0.821 | 0.466 |
| | (1.070) | (1.79)* | (1.69)* | (3.23)*** | (−1.240) | (5.050)*** | (4.10)*** | (1.390) | (4.93)*** |
| Log vehicles | 0.182 | −0.758 | 0.133 | 0.46 | 0.214 | 0.296 | 0.315 | −0.014 | 0.320 |
| | (0.780) | (−0.80) | (0.71) | (1.370) | (1.74)* | (2.70)*** | (1.79)* | (−0.080) | (3.50)*** |
| Log oil | −0.201 | 0.136 | −0.027 | −0.027 | 0.078 | 0.065 | −0.14 | 0.069 | 0.078 |
| | (−3.20)*** | (0.440) | (−0.17) | (−0.130) | (1.87)* | (1.540) | (−2.07)** | (0.970) | (1.240) |
| Log roads | −0.016 | 0.022 | −0.002 | −0.146 | −0.011 | −0.008 | −0.07 | 0.011 | 0.007 |
| | (−0.250) | (0.470) | (−0.04) | (−0.770) | (−0.570) | (−0.380) | (−0.670) | (−0.460) | (0.290) |
| Log alcohol consumption | −0.056 | | | −0.003 | | | −0.015 | | |
| | (−0.410) | | | (−0.010) | | | (−0.120) | | |
| Constant | 2.756 | 3.431 | 2.46 | 1.777 | 7.719 | 3.141 | 2.279 | 5.322 | 1.144 |
| | (0.850) | (0.350) | (1.15) | (0.650) | (3.80)*** | (2.410) | (1.340) | (2.22)** | (1.210)*** |
| Observations | 41 | 45 | 45 | 94 | 99 | 99 | 135 | 144 | 146 |
| $R$-squared | 0.77 | 0.57 | 0.69 | 0.88 | 0.55 | 0.87 | 0.89 | 0.76 | 0.86 |
| Hausman test OLS vs FE | | 18.47*** | | | 59.68*** | | | 42.93*** | |
| Hausman test FE vs RE | | 6.35 | | | 29*** | | | 13.07** | |
| Breusch–Pagan test | | | 20.72*** | | | 139.76*** | | | 164.43*** |

Robust $t$-statistics in brackets.
*Significant at 10%; **Significant at 5%; ***Significant at 1%.
[a] Preferred model by specification tests.

Table 7. Multivariate regressions of deaths

| | Lower income | | | Higher income | | | All | | |
|---|---|---|---|---|---|---|---|---|---|
| | OLS | FE | RE[a] | OLS | FE[a] | RE | OLS | FE[a] | RE |
| Column: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Log GDP | 0.196 | 0.621 | 0.313 | −0.394 | −0.145 | −0.323 | −0.288 | 0.069 | −0.057 |
| | (1.83)* | (3.62)*** | (2.81)*** | (−3.46)*** | (−1.430) | (−4.16)*** | (−3.42)*** | (1.190) | (−1.140) |
| Log population | 0.398 | 2.339 | 0.408 | 1.205 | −0.495 | 1.182 | 1.01 | 0.941 | 0.857 |
| | (2.22)*** | (2.16)*** | (3.80)*** | (10.77)*** | (−0.550) | (10.25)*** | (9.69)*** | (1.60) | (12.51)*** |
| Log vehicles | 0.487 | −0.142 | 0.434 | 0.109 | 0.006 | 0.113 | 0.287 | −0.284 | 0.120 |
| | (2.69)*** | (−0.230) | (3.89)*** | (0.530) | (0.030) | (0.950) | (1.71)* | (−1.60) | (1.550) |
| Log oil | 0.012 | −0.022 | 0.040 | 0.126 | 0.135 | 0.131 | 0.073 | 0.105 | 0.126 |
| | (0.360) | (−0.110) | (0.390) | (0.770) | (2.20)*** | (2.30)** | (1.430) | (1.490) | (2.13)** |
| Log roads | 0.032 | 0.023 | 0.002 | 0.021 | 0.006 | 0.004 | −0.018 | 0.025 | 0.021 |
| | (0.80) | (0.730) | (0.080) | (0.220) | (0.210) | (0.140) | (−0.290) | (1.090) | (0.890) |
| Log alcohol consumption | −0.057 | | | 0.244 | | | 0.153 | | |
| | (−0.77) | | | (1.68) | | | (1.84)* | | |
| Constant | −2.473 | −2.456 | −2.96 | 4.919 | 8.409 | 4.666 | 2.767 | 6.593 | 2.11 |
| | (−1.050) | (−0.370) | (−2.330) | (3.77)*** | (2.82)*** | (3.86)*** | (2.14)*** | (2.77)*** | (2.98)*** |
| Observations | 41 | 46 | 46 | 93 | 98 | 98 | 134 | 144 | 144 |
| $R$-squared | 0.91 | 0.78 | 0.92 | 0.95 | 0.79 | 0.93 | 0.92 | 0.83 | 0.88 |
| Hausman test OLS vs FE | | 17.30*** | | | 21.41*** | | | 56.23*** | |
| Hausman test FE vs RE | | 8.79 | | | 10.00* | | | 31.32*** | |
| Breusch–Pagan test | | | 9.17** | | | 83.09*** | | | 72.99*** |

Robust $t$-statistics in brackets.
*Significant at 10%; **Significant at 5%; ***Significant at 1%.
[a]Model preferred by specification tests.

 

confounded with GDP are protective. In other words, under the assumption that GDP is confounded with unmeasured co-factors in OLS models – these confounders work to reduce deaths in both lower and higher income countries.

All of the independent variables in the analysis are highly correlated. Raw correlation coefficients ranged from a low of 0.6722 for Cor (Log GDP, Log Pop) to a high of 0.8957 for Cor (Log Vehicles, Log Oil). Comparing the bivariate results to the multivariate results indicates that the significant effects of roads and vehicles in the bivariate regressions are often lost in multivariate specifications because of this colinearity. Oil use is also collinear with GDP, vehicles, and roads. It has positive effects on crashes, injuries, and deaths in the bivariate specification, but, as discussed above, oil use has protective effects in the multivariate models because it may proxy for vehicle type.

## Discussion

Prior analysis of longitudinal cross country data on traffic deaths has found an early positive effect of GDP/capita on fatalities followed decades later by a protective negative effect [3]. This study offers some clues about what makes GDP growth protective in rich countries and hazardous in low income countries. Much of the complexity stems from using GDP as a proxy measure for a host of relevant, hard-to-measure factors including urbanization, vehicle mix, road quality, and health services. Although these factors tend to correlate with GDP – they remain largely unidentified. By comparing the OLS models to FE models, we develop insight that these unidentified factors appear to reduce fatalities in both rich and poor countries, and may be related to institutional capacity of the legal and medical systems.

Prior speculation on the reason for the rise of traffic deaths with GDP growth in low income countries held that it was due to mobility growth – more commodities being produced leads to more vehicles to deliver them, and more kilometers traveled. The results here suggest a modification of that hypothesis, because GDP growth, holding population fixed, appears to increase deaths, injuries, and crashes independently of vehicle counts or oil consumption, or – in fixed effects models – other unmeasured confounders. In low income countries GDP growth appear to increase the inherent hazardousness of driving, not just the mobility of the population. One mechanism for this could be an increase in pedestrian and cyclist activity (holding motorized vehicles fixed) that could accompany GDP growth in low income countries holding oil use and motor vehicle counts fixed. The latest data from Uganda show that the majority of traffic injuries involved cyclists [29].

Our theoretical framework supported four alternative explanations linking rising GDP in higher income countries to reductions in traffic casualties: (1) The institutional capacity to control externalities; (2) An accumulation of investments in controlling competing risks rendering traffic control investments the next best use of funds; (3) A correlation of GDP with a transition away from motorized bicycles towards sedans; (4) The availability of improved trauma care. Of these four mechanisms, improvements in pre-hospital and emergency medical care would reduce death rates only, while the other three explanations predict fewer crashes and/or fewer injuries as well. Since the observed patterns in Figures 1–3 show only a decline in deaths, but no decline of crashes or injuries, our findings lend the most support for the theory that improvements in the survival of trauma victims is the leading factor behind the successful control of traffic casualties in higher income countries. Both improved emergency trauma care and occupant protection devices could improve death rates without reducing crashes or injuries. All of the other theories that connect economic growth to traffic safety predict declines in crash or injury rates as high income countries develop that have not (as of 1996) been observed in the data.

Prior authors have suspected that both improvements in traffic infrastructure and in effective post-injury ambulance transport and medical care could mediate the effect of GDP/capita on traffic casualties [3]. Because GDP/capita growth in high income countries was not associated with reductions in injuries or crashes, we find it difficult to credit a major role for GDP related improvements in traffic infrastructure that prevent crashes. It is conceivable that improvements in occupant protection and reductions in crash severity somehow reduce fatalities without reducing the number of nonfatal injuries. It may also be that injuries, but not deaths are systematically over-reported in higher income countries. The presence of motorist insurance systems in higher income countries could provide an incentive for growing numbers of minimally injured motorists to seek medical care in order to be indemnified. Until injury surveillance systems improve their tracking of injury severity in more countries it will be difficult to know whether there are cross-country trends towards lower injury severity that one would expect if occupant protection and vehicle design factors were playing an important role.

There were several limitations of this study. The set of countries with available data are unlikely to be representative of any particular region or stage of development. Countries with missing years of data contribute less than other countries, further impairing any representativeness of the dataset. Where they are measured, data on casualties from lower income countries could be measured with error which would bias our results towards zero. Data on crashes may be systematically more complete where police resources and GDP are higher lending an upward reporting bias to estimates of traffic events per change in GDP. One could also conjecture that the very availability of traffic casualty data from a low income country may be correlated with greater investment of government resources in traffic issues. Thus sample selection bias could create a downward bias in our findings. A selection bias in government statistics would allow for the appearance of fewer incremental casualties per increment of GDP Despite these limitations, the major qualitative differences in the time course of fatalities (inverted-*U*), vs injuries and crashes (monotonic growth) (Figures 1–3) should be immune to sample selection bias.

## Conclusion

According to Red Cross estimates, the costs of road transport crashes in developing countries, at more than $50 billion annually, exceeds the total world expenditure on foreign aid [2]. In low income countries, it appears that GDP/capita growth is associated with a rise in traffic deaths. The mechanism is independent of oil use, population and vehicle ownership, and may be related to increases in pedestrian or cyclist activity required to transact the exchanges that are necessary for GDP/capita to grow holding vehicle counts and oil use fixed. In rich countries GDP growth lowers traffic fatalities. Because GDP does not lower the numbers of crashes or injuries in rich countries, the mediating factor there may indeed be occupant protection as well as post-injury ambulance transport and trauma care which can reduce deaths.

Low income countries interested in a development path that softens the link between GDP growth and traffic fatalities, urgently need to collect basic data on the patterns of traffic fatalities. Cost-effective measures to protect pedestrians and cyclists do exist for countries that identify these groups as having a heightened risk [30–32].

In higher income countries, petroleum and alcohol both appear to contribute to the problem of traffic deaths. Both of these liquids are heavily regulated and taxed, although seldom with the express intent of controlling traffic fatalities. More complete assessment of the economic effects of higher fuel prices and higher alcohol prices should include estimates of the savings due to traffic fatalities that are averted.

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## References

1. Murray C, Lopez A. *The Global Burden of Disease*. Harvard Press: Cambridge, MA, 1996.
2. International Federation of Red Cross and Red Crescent Societies. Must Millions More Die from Traffic Accidents? In *World Disasters Report*, Societies IFoRCaRC (ed.). Oxford University Press: New York, 1998.
3. van Beeck EF, Borsboom GJ, Mackenbach JP. Economic development and traffic accident mortality in the industrialized world, 1962–1990. *Int J Epidemiol* 2000; **29**(3): 503–509.
4. Dasgupta S, Laplante B, Wang H, Wheeler D. Confronting the environmental Kuznets curve. *J Econ Perspect* 2002; **16**(1): 147–168.
5. Kopits E, Cropper M. Traffic fatalities and economic growth. *Accid Anal Prev* 2005; **37**(1): 169–178.
6. Vickrey W. Automobile accidents, Tort law, externalities, and insurance: an economist's critique. *Law Contemp Problems* 1968; **33**: 464–487.

 

7. Calabresi G. *The Costs of Accidents: A Legal and Economic Analysis*. Yale University Press: New Haven, 1970.
8. Coase R. The problem of social cost. *J Law Econ* 1960; **3**(October): 1–44.
9. Ruhm CJ. Alcohol policies and highway vehicle fatalities. *J Health Econ* 1996; **15**(4): 435–454.
10. Chaloupka FJ, Grossman M, Saffer H. The effects of price on the consequences of alcohol use and abuse. *Recent Dev Alcohol* 1998; **14**: 331–346.
11. Bishai D, Hyder AA, Ghaffar A, Morrow RH, Kobusingye O. Rates of public investment for road safety in developing countries: case studies of Uganda and Pakistan. *Health Policy Plan* 2003; **18**(2): 232–235.
12. Jacobs G. *The inclusion of accident savings in highway cost-benefit analyses*. Mimeo. Transport Research Laboratory: Crowthorne, Berkshire, UK, 1989.
13. Norton R, Hyder A, Bishai D, Peden M. Unintentional Injuries. In *Disease Control Priorities-2*, Jamison DT, Musgrove P, Meachem A (eds). National Institutes of Health: Washington, DC, 2005.
14. Mohan R. *Understanding the Developing Metropolis Lessons from the City Study of Bogotá and Cali, Colombia*. World Bank: Washington, DC, 1994.
15. Tay R. Marginal effects of changing the vehicle mix on fatal crashes. *J Transport Econ Policy* 2003; **37**(3): 439–450.
16. Mock CN, Jurkovich GJ, nii-Amon-Kotei D, Arreola-Risa C, Maier RV. Trauma mortality patterns in three nations at different economic levels: implications for global trauma system development. *J Trauma* 1998; **44**(5): 804–812 (discussion 812–4).
17. Adam R, Stedman M, Winn J, Howard M, Williams JI, Ali J. Improving trauma care in Trinidad and Tobago. *West Indian Med J* 1994; **43**(2): 36–38.
18. Arreola-Risa C, Mock CN, Lojero-Wheatly L *et al.* Low-cost improvements in prehospital trauma care in a Latin American city. *J Trauma* 2000; **48**(1): 119–124.
19. Husum H, Gilbert M, Wisborg T, Van Heng Y, Murad M. Rural prehospital trauma systems improve trauma outcome in low-income countries: a prospective study from North Iraq and Cambodia. *J Trauma* 2003; **54**(6): 1188–1196.
20. International Road Federation. *IRF World Road Statistics – 1998 Edition*. International Road Federation: Washington, DC, 1998.
21. Ghaffar A. *Measuring the Burden of Injuries in Pakistan*. Johns Hopkins University: Baltimore, MD; 2000.
22. World Bank. *The World Development Report*. Oxford University Press: New York, 1993–1997.
23. WHO. *Global Status Report on Alcohol*. Geneva, 1999.
24. Smeed RJ. Some statistical aspects of road safety research. *J Roy Stat Soc Ser A* 1949; **112**: 1–23.
25. Hausman JA. Specification tests in econometrics. *Econometrica* 1978; **46**(6): 1251–1271.
26. Stata Corporation. *Stata Reference Manual Release 8*. Stata Press: College Station, TX, 2003.
27. Weesie J. Seemingly unrelated estimation and the cluster-adjusted sandwich estimator. *Stata Tech Bull* 1999; **52**: 34–47.
28. Piantadosi S, Byar DP, Green SB. The ecological fallacy. *Am J Epidemiol* 1988; **127**(5): 893–904.
29. Kobusingye O, Guwatudde D, Lett R. Injury patterns in rural and urban Uganda. *Inj Prev* 2001; **7**(1): 46–50.
30. Malek M, Guyer B, Lescohier I. The epidemiology and prevention of child pedestrian injury. *Accid Anal Prev* 1990; **22**(4): 301–313.
31. Chiu WT, Kuo CY, Hung CC, Chen M. The effect of the Taiwan motorcycle helmet use law on head injuries. *Am J Public Health* 2000; **90**(5): 793–796.
32. Bishai D, Hyder AA. Modeling the cost effectiveness of injury counter measures in lower and middle income countries. DCPP Working Paper 2004; http://www.fic.nih.gov/dcpp/wps/WP29.pdf.