Accident Analysis and Prevention 37 (2005) 169–178

ACCIDENT ANALYSIS & PREVENTION

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Traffic fatalities and economic growth

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Received 27 September 2003; received in revised form 26 March 2004; accepted 5 April 2004

Abstract

This paper examines the relationship between traffic fatality risk and per capita income and uses it to forecast traffic fatalities by geographic region. Equations for the road death rate (fatalities/population) and its components—the rate of motorization (vehicles/population) and fatalities per vehicle (F/V)—are estimated using panel data from 1963 to 1999 for 88 countries. The natural logarithm of F/P, V/P, and F/V are expressed as spline (piecewise linear) functions of the logarithm of real per capita GDP (measured in 1985 international prices). Region-specific time trends during the period 1963–1999 are modeled in linear and log–linear form. These models are used to project traffic fatalities and the stock of motor vehicles to 2020.

The per capita income at which traffic fatality risk (fatalities/population) begins to decline is $8600 (1985 international dollars) when separate time trends are used for each geographic region. This turning point is driven by the rate of decline in fatalities/vehicles as income rises since vehicles/population, while increasing with income at a decreasing rate, never declines with economic growth.

Projections of future traffic fatalities suggest that the global road death toll will grow by approximately 66% over the next twenty years. This number, however, reflects divergent rates of change in different parts of the world: a decline in fatalities in high-income countries of approximately 28% versus an increase in fatalities of almost 92% in China and 147% in India. The road death rate is projected to rise to approximately 2 per 10,000 persons in developing countries by 2020, while it will fall to less than 1 per 10,000 in high-income countries.
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Keywords: Traffic fatality projections; Motorization; Fatalities per vehicle

1. Introduction

As countries develop death rates usually fall, especially for diseases that affect the young and result in substantial life-years lost. Deaths due to traffic accidents are a notable exception: the growth in motor vehicles that accompanies economic growth usually brings an increase in road traffic accidents. Indeed, the World Health Organization has predicted that traffic fatalities will be the sixth leading cause of death worldwide and the second leading cause of disability-adjusted life-years lost in developing countries by the year 2020 (Murray and Lopez, 1996). Table 1 highlights the increasing importance of the problem in several developing countries. For example, between 1975 and 1998, road traffic deaths per capita increased by 44% in Malaysia, and by over 200% in Colombia and Botswana.

The situation in high-income countries is quite different. Over the same period, traffic fatalities per person decreased by 60% in Canada and Hong Kong, and by amounts ranging from 25 to 50% in most European countries. This reflects a downward trend in fatality risk (deaths/population) that began in most OECD countries in the early 1970s and has continued to the present.

These patterns are not surprising. Traffic fatality risk (fatalities/population) is the product of vehicles per person (V/P) and fatalities per vehicle (F/V). How rapidly fatality risk grows depends, by definition, on the rate of growth in motorization (V/P) and the rate of change in fatalities per vehicle

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doi:10.1016/j.aap.2004.04.006

Table 1
Change in traffic fatality risk (deaths/10,000 persons), 1975–1998

Country	% Change (1975–1998)
Canada	−63.4
Hong Kong	−61.7
Finland	−59.8
Austria	−59.1
Sweden	−58.3
Israel	−49.7
Belgium	−43.8
France	−42.6
Italy[a]	−36.7
New Zealand	−33.2
Taiwan	−32.0
United States	−27.2
Japan	−24.5
Malaysia	44.3
India[b]	79.3
Sri Lanka	84.5
Lesotho	192.8
Colombia	237.1
China	243.0
Botswana[c]	383.8

[a] % Change 1975–1997.
[b] % Change 1980–1998.
[c] % Change 1976–1998.

(F/V).[1] In most developing countries over the past 25 years, vehicle ownership grew more rapidly than fatalities per vehicle fell. The experience in industrialized countries, however, was the opposite; vehicles per person grew more slowly than fatalities per vehicle fell. From these observations, two questions emerge: Why did these patterns occur? What trends can be expected in the future?

To answer these questions this paper examines how the fatality risk (F/P) associated with traffic accidents and its components—V/P and F/V—change as countries grow. Identifying a recognizable pattern between traffic fatality risk and economic growth gives an indication of the income level at which road safety tends to improve. Understanding when this occurs can help those who would try to introduce normative measures to reduce casualty rates.

The equations relating F/P to per capita income are also used to predict traffic fatalities by region. These forecasts should alert policymakers in developing countries to what is likely to happen if measures are not enacted to reduce traffic accidents. Alternately, it indicates how long it will take to achieve the fatality risks currently experienced in high-income countries, assuming road safety policies are adopted at historical rates.

[1] The fatality risk may also be expressed as the product of fatalities per vehicle kilometers traveled (F/VKT) and distance traveled per person (VKT/P). Lack of reliable time series VKT data, especially for developing countries, prevents us from using this measure for our analysis. The correlation between VKT and the number of vehicles for countries with available data on both variables exceeds 0.975.

2. Methods

2.1. Statistical models of fatalities, vehicle ownership and economic growth

To include a broad range of countries in our empirical analysis, we proxy all factors affecting fatality risk by the economic development of a country, as measured by per capita GDP. We estimate the relationship between fatalities/population (F/P), vehicles/population (V/P), and fatalities/vehicles (F/V), and per capita income using reduced form statistical models of the general form:

$$\ln(Z)_{\mathrm{it}} = a_{\mathrm{i}} + +G[\ln(Y_{\mathrm{it}})] + H(t) + \varepsilon_{\mathrm{it}} \quad (1)$$

where Z = F/P (fatalities/10,000 persons), V/P (vehicles/10,000 persons), and F/V (fatalities/10,000 vehicles), Y= real per capita GDP (measured in 1985 international prices), a_{i} is a country-specific intercept, and G and H are functions. G is specified as a spline (piecewise linear) function of per capita income:

$$\ln(Z)_{\mathrm{it}} = a_{\mathrm{i}} + H(t) + b \ln Y_{\mathrm{it}} + \Sigma_s[c_s D_s(\ln Y_{\mathrm{it}} - \ln Y_s)] + \varepsilon_{\mathrm{it}} \quad (2)$$

where D_s is a dummy variable = 1, if Y_{it} is in income category s + 1, and Y_s is the cutoff income value between the s and s + 1 income group. Following Schmalensee et al. (2000), we divide the observations into 10 income groups with an equal number of observations in each spline segment.[2] By allowing the slope of the fatality risk-income relationship to vary by income interval, the spline offers a great deal more flexibility than a quadratic (or higher order polynomial) function.[3] In addition, although polynomials could fit the data nearly as well in sample, they result in unrealistic predictions for out-of-sample income ranges (Schmalensee et al., 2000).

The inclusion of a time trend, $H(t)$, eliminates any spurious correlation that may exist between per capita income and fatality risk over time. In addition, $H(t)$ captures the effect of any trends in technology and driver behavior that are unrelated to income. Here, we focus on two specifications of $H(t)$: (1) regional time trends that enter linearly, and (2) regional time trends that enter the equation as ln(t).[4] For purposes of

[2] We experimented with different segmentations but the results are not qualitatively different if fewer or more income segments are specified. Another issue in model specification is whether or not the same functional form applies to HD1 and HD2 countries (a categorization described below). Since few HD1 observations fall into the lowest income segments and few HD2 observations occur in the higher income ranges, it is difficult to test this statistically using the spline specification. However, for the third to the seventh spline segments, we can not reject the null hypothesis that the income elasticities are the same across the two groups of countries.

[3] Kopits and Cropper (2003) also explore a quadratic specification of income and find the results quite similar (holding the treatment of time constant) whether one uses the quadratic or spline function.

[4] The model was also estimated using a common linear and common log–linear time trend (Kopits and Cropper, 2003) but because the time trends are found to be significantly different across regions.

Table 2
Regional distribution of countries used in model estimation[a]

World Bank region	HD2	HD1
East Asia and Pacific	10 (14)	1 (1)
Eastern Europe and Central Asia	5 (5)	3 (4)
Latin America and Caribbean	5 (27)	2 (4)
Middle East and North Africa	8 (12)	1 (1)
South Asia	5 (7)	–
Sub-Saharan Africa	20 (46)	–
High-Income Countries	–	28 (35)
Total	53 (111)	35 (45)

[a] For each region, the number of countries for which predictions are made is given in parentheses.

defining the time trends, we divide countries into two groups: highly developed countries (HD1)—i.e., countries that have a Human Development Index in 1999 of 0.8 or greater—and all other countries (HD2).[5] In practice, this division of countries corresponds closely to highly-motorized countries versus other countries. All HD1 countries are treated as a single region for the purposes of computing time trends. HD2 countries, in turn, are classified according to region. Table 2 shows the number of countries in each geographic region, for both HD1 and HD2 countries.

The inclusion of country-specific intercepts in Eq. (1) implies that the impact of income on fatality risk reflects within—rather than between—country variation in ln(F/P) and ln(Y). This is desirable for two reasons. For the purposes of predicting future trends in F/P it is more desirable to rely on within-country experience rather than on cross-sectional variation in income and fatality risk. Secondly, countries differ in their definition of what constitutes a traffic death and in the percentage of deaths that are reported. (This topic is discussed more fully below.) To the extent that the degree of under-reporting remains constant over time but varies across countries it will not affect estimates of the impact of economic growth on fatality risk.[6]

2.2. Data used in the analysis

Eq. (2) is estimated using panel data for 88 countries for the period 1963–1999. To be included in the dataset a country must have at least 10 years of data on traffic fatalities.[7] Population data come from the U.S. Census Bureau's International Data Base and income data are taken from the World Bank Global Development Network Growth Database Macro Time Series. To account for differences in purchasing power across countries and allow for comparisons over time, per capita income is measured by Real Per Capita GDP, chain method (1985 international prices).[8] The data on traffic fatalities and vehicles used in this study come primarily from the International Road Federation Yearbooks, which have been supplemented by and cross-checked against various other sources. The sources of fatality and vehicle data are described more fully in the Appendix A.

2.3. Methodology for projecting vehicle usage and traffic fatalities

Future traffic fatalities can be predicted directly from Eq. (2), i.e., by predicting future fatality risk (F/P) and multiplying by estimates of future population, or by predicting vehicle ownership, V, from the V/P equation and multiplying the vehicle stock by fatalities per vehicle. The second method serves as a check on the first since more is known about vehicle ownership. In particular, one can reject models that yield unbelievably high rates of vehicle ownership, e.g., ownership significantly in excess of one vehicle per person in the year 2020.

To project future vehicle ownership and traffic fatalities assumptions must be made about income and population growth. The real per capita GDP series is projected to 2020 using the World Bank's forecasts of regional growth rates (2000–2010) (World Bank, 2002) with the assumption that the average annual 2001–2010 growth rates continue to 2020[9]. Population projections are taken from the U.S. Census International Data Base. Projections are made for 156 countries (representing 92% of total world population in 2000), including 45 highly developed countries (HD1) and 111 developing countries (HD2). Table 2 shows the distribution of countries by geographic region. To calculate the point estimates for the out-of-sample countries, assumptions must be made regarding the country-specific intercept. The coefficient on the country dummy variable for Chile is used to compute the predicted values for the 10 out-of-sample HD1 countries.[10] For the HD2 countries, the intercept is set equal to the mean of the country intercepts for the corresponding region.

3. Results

3.1. Plots of dependent variables v. income

Figs. 1–3 plot each of our three dependent variables against per capita income, pooling data for all countries and

[5] The United Nations Human Development Index measures per capita income, life expectancy and educational achievement.

[6] To illustrate, when Eq. (2) is estimated using country-specific intercepts, the coefficients b and c reflect within-country variation in fatalities and income. Multiplying country i's fatality risk by a constant to reflect under-reporting would not change the estimates of b and c.

[7] Table A.1 in Kopits and Cropper (2003) lists the countries used to estimate the models and the number of years of data available for each country.

[8] This series was created from the Penn World Tables 5.6 RGDPCH variable for 1960–1992 and the 1992–1999 data were estimated using the 1985 GDP per capita and GDP per capita growth rates from the Global Development Finance and World Development Indicators.

[9] A list of the growth rates is provided in Table A.3 in Kopits and Cropper (2003).

[10] The choice of Chile is motivated by the fact that the most populous out-of-sample HD1 countries for which predictions must be made are Argentina and Uruguay.

Table 3
Regression results from fatalities/population, vehicles/population, and fatalities/vehicles models

	Fatalities/population		Vehicles/population		Fatalities/vehicles	
	1	2	1	2	1	2
ln *Y*						
$1–$938	1.444*** (0.346)	1.253*** (0.328)	0.478 (0.401)	0.248 (0.495)	1.518*** (0.471)	1.138* (0.658)
$938–$1,395	1.119*** (0.307)	1.060*** (0.282)	0.756 (0.576)	1.537** (0.769)	0.017 (0.697)	− 0.673 (0.971)
$1,395–$2,043	0.512* (0.268)	0.326 (0.283)	0.946*** (0.266)	1.407*** (0.320)	− 0.145 (0.334)	− 0.988** (0.411)
$2,043–$3,045	0.976** (0.386)	0.765* (0.413)	0.597** (0.259)	0.783** (0.348)	0.612 (0.402)	− 0.006 (0.553)
$3,045–$4,065	0.960*** (0.327)	0.701** (0.347)	1.349*** (0.357)	1.699*** (0.381)	− 0.403 (0.427)	− 1.169** (0.496)
$4,065–$6,095	0.602** (0.277)	0.390 (0.248)	0.828*** (0.292)	1.214*** (0.302)	− 0.190 (0.281)	− 0.864*** (0.307)
$6,095–$8,592	0.258 (0.284)	0.075 (0.274)	0.840*** (0.274)	1.034*** (0.327)	− 0.500 (0.361)	− 0.953** (0.408)
$8,592-$10,894	−0.207 (0.265)	−0.542** (0.267)	− 0.060 (0.211)	0.288 (0.285)	− 0.085 (0.259)	− 0.917** (0.399)
$10,894-$13,234	−0.668* (0.384)	−1.338*** (0.332)	− 0.605* (0.326)	0.364* (0.222)	0.110 (0.354)	− 1.689*** (0.403)
>$13,234	−0.522* (0.274)	−0.996*** (0.242)	− 0.492*** (0.246)	0.228 (0.166)	− 0.013 (0.335)	− 1.306*** (0.275)
Turning point (1985$int'l)	$8,592	$8,592	$8,592	–	$1,395	$938
Regional t						
East Asia and Pacific	0.006 (0.007)	0.257*** (0.096)	0.058*** (0.014)	0.593*** (0.221)	− 0.057*** (0.016)	− 0.302 (0.251)
Eastern Europe and Central Asia	−0.013** (0.006)	−0.031 (0.087)	0.056*** (0.005)	0.509*** (0.081)	− 0.070*** (0.010)	− 0.478*** (0.161)
India	0.022*** (0.005)	0.319*** (0.046)	0.076*** (0.008)	0.741*** (0.091)	− 0.052*** (0.009)	− 0.413*** (0.118)
Latin American and Caribbean	0.012 (0.007)	0.264 (0.168)	0.022*** (0.007)	0.185** (0.075)	− 0.013*** (0.006)	− 0.030 (0.106)
Middle East and North Africa	−0.007 (0.010)	0.011 (0.127)	0.019*** (0.006)	0.030 (0.070)	− 0.025*** (0.008)	0.034 (0.109)
South Asia (excluding India)	0.004 (0.004)	0.096** (0.041)	0.041*** (0.008)	0.254** (0.103)	− 0.038*** (0.008)	− 0.140 (0.120)
Sub-Saharan Africa	0.011** (0.005)	0.161** (0.068)	0.030*** (0.009)	0.349*** (0.118)	− 0.032*** (0.007)	− 0.288*** (0.096)
High-income (HD1)	−0.015*** (0.005)	−0.057 (0.043)	0.029*** (0.005)	0.198*** (0.058)	− 0.047*** (0.005)	− 0.251*** (0.067)
F-statistic on regional ts:	$F(7, 87) = 8.67^{***}$	$F(7, 87) = 9.28^{***}$	$F(7, 74) = 19.22^{***}$	$F(7, 74) = 23.44^{***}$	$F(7, 69) = 10.42^{***}$	$F(7, 69) = 6.83^{***}$
Constant	−11.360*** (2.290)	−10.463*** (2.141)	−0.437 (2.661)	0.445 (3.265)	− 12.357*** (3.132)	− 9.575** (4.338)
DW statistic	0.841	0.816	0.192	0.196	0.605	0.472
Adjusted R^2	0.8695	0.8656	0.9850	0.9799	0.9589	0.9391
Countries; obs	88; 2200		75; 1876		70; 1695	

Heteroskedasticity-corrected standard errors, clustered on country to allow for within panel autocorrelation, are given in parentheses. The constant term reflects the intercept term for India. Country fixed effects were included in all regressions but are not displayed here. Model specifications: (1) regional linear time trends; (2) regional, log–linear time trends.
*** Indicates 1% level of significance.
** Indicates 5% level of significance.
* Indicates 10% level of significance.

years in the dataset. Although these plots reflect both cross-sectional and time series variation in the data (whereas the estimates of (1) reflect only time series variation) they foreshadow the results in Table 3.

The cross-sectional variation in motorization rates in Fig. 1 is striking. In 1999, vehicles per capita ranged from a high of 780 per 1000 persons in the United States to fewer than 30 per 1000 persons in countries such as Pakistan and Nigeria. High-income countries tend to have more vehicles per capita than lower income countries, but there are important exceptions. Low motorization rates in Hong Kong, Singapore, Chile, and Costa Rica are notable outliers[11]. In

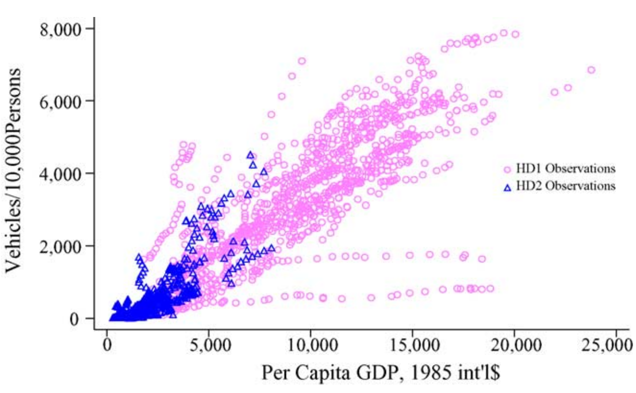

Fig. 1. Motorization rate vs. income: all countries and years.

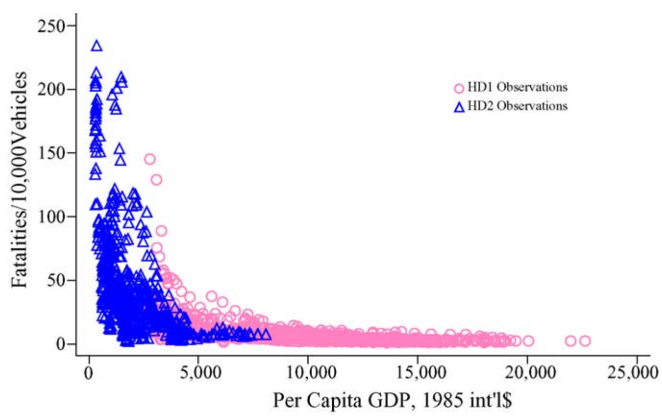

Fig. 2. Fatalities/vehicle vs. income: all countries and years.

[11] The low motorization level in these countries could reflect physical limitations in the case of Hong Kong and Singapore and highly mountainous topography in the case of Chile and Costa Rica. These country characteristics will be accounted for in the fixed effects estimation.

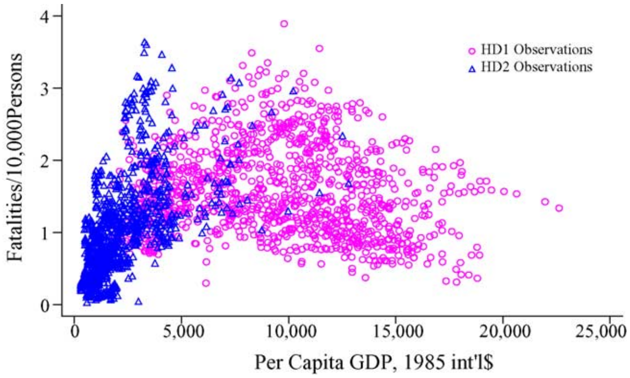

Fig. 3. Traffic fatality risk vs. income: all countries and years.

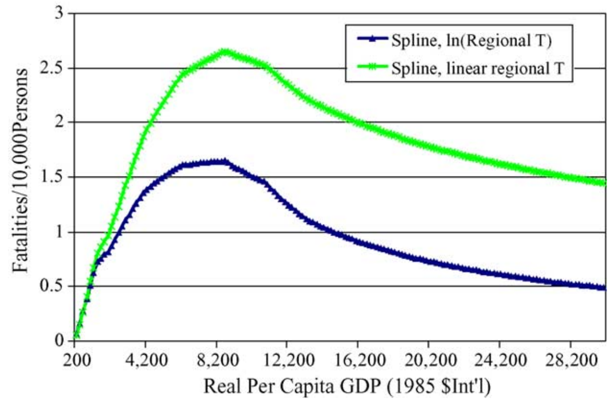

Fig. 4. Fatalities/population regression results.

addition, Fig. 1 suggests that motorization is strongly correlated with income. The within-group (time series) variation in motorization, however, varies from country to country. Growth in vehicle ownership appears to have slowed down (but not declined) in many high-income countries such as Norway, Australia, Hong Kong, and the United States. In countries experiencing lower levels of per capita GDP such as Greece, Malaysia, and Thailand, however, vehicle fleets have continued to expand rapidly with income.[12]

Fatalities per vehicle, by contrast, appear to decline rapidly with income, at least after some low level of income, and then continue to decline at a slower rate at higher income levels. Fig. 2, which plots fatalities per vehicle (F/V) against income using data for all countries and years, attests to this fact.[13] In part, the sharp decline in F/V with income reflects the fact that, as income rises, a higher percentage of travelers are vehicle passengers rather than pedestrians, and thus, are less likely to die in the event of a crash.[14] It also may reflect the move to safer vehicles (e.g., from two-wheelers to four-wheelers), safer roads, and/or changing attitudes toward risk as incomes grow.

The foregoing data suggest that one would expect to see motor vehicle fatality risk (F/P) first increase and then decrease with income. Fig. 3, which plots F/P versus income for all years and countries in our dataset, supports this inverted U-shaped pattern. As incomes grow and vehicle fleets increase during initial stages of development, traffic fatality risk tends to worsen. At higher income levels, however, as growth in motorization slows and governments and individuals invest more in road safety, the decline in F/V drives the death rate (F/P) down.

3.2. Results of the statistical models

Table 3 summarizes the results of estimating the spline model for traffic fatality risk (F/P), V/P and F/V, with the two treatments of time trends, the linear (labeled 1 in the table) and the log–linear (labeled 2). The table shows the income elasticities for each spline interval as well as the regional time coefficients for each model. The Durbin–Watson statistics indicate the need to correct for autocorrelation in all three equations.[15] The standard errors have been adjusted to account for serial correlation in disturbances within countries over time, as well as for heteroskedasticity.[16]

It should be noted that the income groups shown in Table 3 are based on the number of observations in the F/P equation. Because the number of countries and observations varies slightly across the three equations, the income elasticities of V/P and F/V do not sum exactly to the coefficient in the corresponding spline group in the F/P model. There is no qualitative difference in the results if all equations are estimated with the same observations. To give a more complete picture of the model results, Figs. 4–6 plot each dependent variable as a function of per capita income. In each figure, the results are displayed using the country intercept for India with the time trend set equal to 1999.

Several results are worth emphasizing. The income level at which traffic fatality risk (F/P) first declines is $8600 (1985 international prices), regardless of how the time trends are specified. This is the approximate income level attained by countries such as Belgium, the United Kingdom, and Austria in the early 1970s, South Korea in 1994, and New Zealand in 1968. However, the income elasticity for per capita incomes

[12] Fig 2 of Kopits and Cropper (2003) shows how motorization rates have grown with income over time for a sample of countries.

[13] Fig. 4 of Kopits and Cropper (2003) shows the within-country variation in fatalities per vehicle for a sample of countries. Note that the fatality numbers used in Figs. 1 and 3 have not been adjusted for underreporting of road deaths. Thus, F/V levels in developing countries may be underestimated.

[14] This point was first publicized by Smeed (1949), who demonstrated that F/V declines as V/P increases.

[15] The DW statistic is less than the lower bound critical value of 1.576 (for $k = 18$ and N large) in all regressions, indicating the presence of positive within-panel serial correlation in the disturbances.

[16] This procedure is theoretically justified when the number of panels is large (Liang and Zeger, 1986). Recent studies of finite sample properties of robust variance matrix estimators find that this fully robust variance estimator works reasonably well in the context of fixed effects estimation and panel data even when the number of panels is not especially large relative to the length of each panel (Wooldridge, 2003).

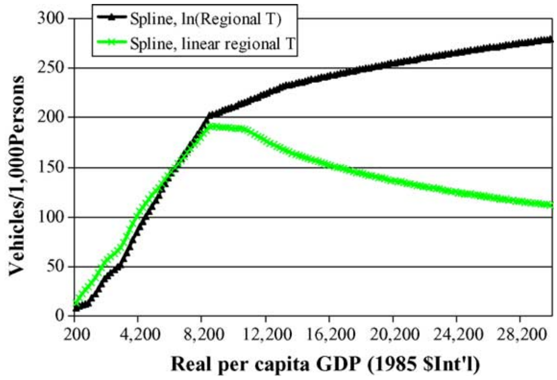

Fig. 5. Vehicles/population regression results.

up to $8600 is larger when the time trends enter in linear form. Thus, the maximum fatality risk is over 60% higher than the level reached if the time trends enter the model in log–linear form.

Whether the time trends enter the models linearly or in log–linear form, the differences in trends across regions are generally similar. Over the estimation period (1963–1999) fatality risk grew fastest in India and in Latin America (holding income constant), and almost as fast in Sub-Saharan Africa as in Latin America. Fatalities per capita also increased nearly as fast in the East Asia and Pacific region as in Latin America when log–linear time trends are specified. By contrast, (holding income constant) F/P declined in high-income countries. Results for other regions are statistically insignificant in at least some specifications.

Whether the time trend enters (2) linearly or log–linearly greatly alters predictions of future traffic fatalities. To help distinguish between the two specifications of the time trend, we examine the corresponding models for vehicles per person (V/P) and fatalities per vehicle (F/V).

Of the two models of the motorization rate (V/P), only the model with the log–linear time trend gives reasonable results. When the time trend enters the motorization equation linearly, vehicles per capita peak at a value of income observed in the data, and begin to decline with income for per capita GDP exceeding $8600. In contrast, the log–linear regional time trends yield non-negative income elasticities of V/P for all levels of income. Another reason for focusing on the log–linear specification is that projections of V/P based on linear regional time trends produce unreasonable forecasts of vehicle growth over the next two decades.

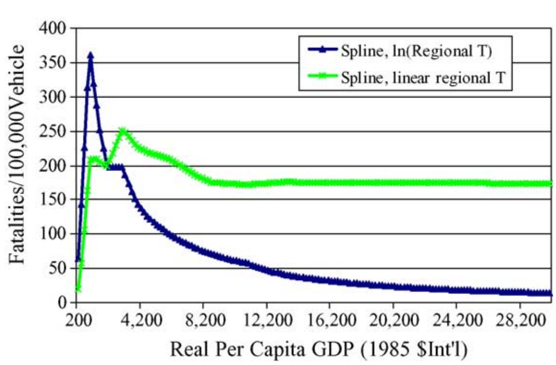

Fig. 6. Fatalities/vehicle regression results.

Of the two models for fatalities per vehicle, the model with the log–linear time trend fits better. Fig. 6, which plots both models for India (t = 1999), indicates exactly how fast F/V declines as income grows. In the log–linear time trend specification, fatalities per vehicle begin to decline with income for per capita GDP in excess of $1000 (1985 international prices), the per capita income of Mozambique, Ghana, and Cameroon in 1999 and India in the mid-1980s. Fatalities per vehicle fall by a factor of 3 (e.g., from 360 to 120 per 100,000 vehicles for India) as per capita income grows from $1200 to $4400. After reaching a per capita income of $15,200 (1985 international dollars), the approximate income of the United States in the early 1980s and Switzerland in 1986, however, F/V declines slowly in absolute terms: from 25 per 100,000 vehicles at an income of $20,000 to 15 per 100,000 vehicles at an income of $30,000. By contrast, with linear time trends, the estimated income elasticity of fatalities per vehicle is smaller in magnitude and statistically insignificant in most spline segments.

Combining the results of the models for F/V and for V/P explains the results for deaths per capita observed in Fig. 4. The elasticity of V/P with respect to income exceeds in absolute value the elasticity of F/V with respect to income for incomes up to $6100–$8600, when the two elasticities are approximately equal—the condition for (F/V) × (V/P) to peak. This is the income range reached by countries such as Austria, Finland, Norway, and the United Kingdom in the early 1970s and Malaysia and Greece in the late 1990s. At higher incomes, the elasticity of fatalities per vehicle with respect to income exceeds the elasticity of motorization with respect to income. This is consistent with the coefficients reported in Table 3, which show the income elasticity of the death rate decreasing from 1.253 at the lowest levels of income to −0.996 once per capita income exceeds $13,500.

3.3. Predictions of future traffic fatalities and motorization

One reason for estimating the preceding models is to predict what will happen to traffic fatalities if historic trends continue. We begin by examining the implications of the V/P models in Table 3 for future growth in vehicle ownership. The spline model with linear regional time trends yields unbelievably large estimates of the world motor vehicle stock in 2020, as well as estimates of vehicle ownership per capita for certain groups of countries that are well over 1. For this reason we focus on the model with region-specific log–linear time trends, which projects the world vehicle stock to reach 1.47 billion by 2020.

Using the spline model for F/P with log–linear regional time trends, we project that total road traffic fatalities will increase from 539,000 in 2000 to over 864,000 by

2020.[17] Ninety-five percent confidence intervals for these forecasts are (459,000, 640,000) and (706,000, 1,070,000), respectively.[18] Note these projections assume that the income elasticity estimated for the observations in the highest spline interval also apply at higher income levels.

We emphasize that these predictions represent traffic fatalities unadjusted for under-reporting. To compare these figures with fatality risks from other causes of death, it is necessary to adjust for the fact that (a) the definition of what constitutes a traffic fatality differs across countries and (b) the percentage of traffic fatalities reported by the police also varies across countries.

Our under-reporting adjustments follow the conservative factors used by Jacobs, Aeron-Thomas and Astrop (2000).[19] To update all point estimates to the 30-day traffic fatality definition, a correction factor of 1.15 was applied in the developing countries and the standard ECMT correction factors were used for the high-income countries.[20] Then the estimates were adjusted to account for general under-reporting of traffic fatalities, by 25% in developing countries and by 2% in highly developed countries.[21] With these adjustments, global road deaths are projected to climb to over 1.2 million by 2020 (a 40% adjustment over the base estimate of 864,000). Although this represents a 66% increase over the 2000 world estimate, the trend varies considerably across different regions of the world. Table 4 and Fig. 7 indicate that, between 2000 and 2020, fatalities are projected to increase by over 80% in developing countries, but decrease by nearly 30% in high-income countries. Within the developing world, the greatest percentage increases in traffic deaths between 2000 and 2020 will occur in South Asia (144% increase), followed by East Asia and Sub-Saharan Africa (both showing an 80% increase). It is also interesting to note that the number of traffic fatalities per 100,000 persons is predicted to diverge considerably by 2020. By 2020, the fatality risk is predicted to be less than 8 in 100,000 in high-income countries but nearly 20 in 100,000 in low-income countries.

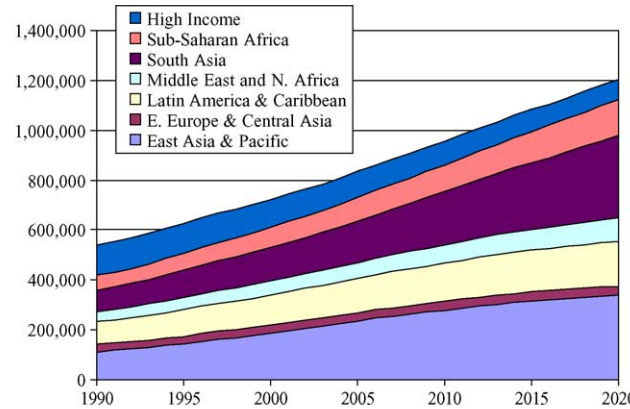

Fig. 7. Global traffic fatalities, adjusted for under-reporting, 1990–2020. (Projections are displayed according to World Bank regional classifications.)

4. Discussion

4.1. Models of vehicle ownership

Our model of vehicle ownership, which together with models of fatalities per vehicle provide a check on the validity of our fatality results, accord with results in the literature. Elasticities based on the model with log–linear time trends are consistent with previous studies of motorization, which find that the income elasticity of demand for motor vehicles declines with income (Ingram and Liu (1998), Dargay and Gately (1999), Button et al. (1993)). We find the income elasticity of vehicle ownership decreases from a value of 1.54 in the second spline segment ($938–$1395 (1985 international dollars)) to a low of 0.23 in the highest income category, with significantly higher estimates for spline segments 2 through 5 than 7–10.[22] Fig. 5, which plots the V/P results using the country intercept for India with the time trend set equal to 1999, suggests that the rate of increase in motorization slows down considerably after reaching a per capita income of $9400 (1985 international dollars), the level of income attained by Norway and the United Kingdom in 1974.

Vehicle projections based on our model agree fairly well with other estimates of vehicle growth in the literature. Dargay and Gately (1999) project that the total vehicle fleet in OECD countries will reach 705 million by 2015 (a 62% increase from 1992 values). Our model yields a 2015 estimate of 687 million vehicles for the same group of countries.

Other studies have made projections of vehicle growth for the automobile fleet only for passenger cars and commercial vehicles. Since our motor vehicle counts include all buses and two-wheelers, direct comparisons with these studies is difficult. However, vehicle fleet estimates based on the V/P results do exceed their automobile forecasts under all specifications.

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[17] Projections based on the ln(F/V) and ln(V/P) equations yield similar estimates. That is, if future fatalities are calculated by first predicting the vehicle stock, V, from the ln(V/P) equation and then multiplying V by fatalities per vehicle (predicted from the ln(F/V) equation), the global road death toll is expected to increase from over 510,000 in 2000 to 790,000 by 2020.

[18] The model generates point estimates of the log of the fatality risk (ln(fatalities/10,000 people)). The confidence intervals for the predicted values of ln(fatalities/10,000 people) are symmetric, but the forecast intervals for the total number of fatalities are not. These intervals are computed as the predicted value ± 1.96 times the estimated standard error.

[19] Jacobs et al. (2000) reviewed numerous underreporting studies and found evidence of underreporting rates ranging from 0 to 26% in high motorized countries and as high as 351% in less motorized countries. Fatalities in China, for example, were 42% higher in 1994 than reported in official statistics (Liren, 1996).

[20] High-income countries with ECMT correction factors greater than 1 include: France: 1.057, Italy: 1.07, Portugal: 1.3, Japan: 1.3 (ECMT, 1998, 2000, 2001).

[21] The 25% under-reporting adjustment is applied to 111 HD2 countries and the 2% adjustment is used for 45 HD1 countries. See Table 2 for a regional breakdown of countries.

[22] Income elasticity estimates generated from a two-segment spline model are statistically different from each other, decreasing from 1.32 (0.240) to 0.719 (0.219) once per capita income exceeds $4682 (1985 international dollars).

Table 4
Predicted road traffic fatalities by region (000s), adjusted for under-reporting, 1990–2020

World Bank region	No. of countries	1990	2000	2010	2020	% Change 2000–2020	Fatality risk (deaths/100,000 persons)	
							2000	2020
East Asia and Pacific	15	112	188	278	337	79.8%	10.9	16.8
E. Europe and Central Asia	9	30	32	36	38	18.2%	19.0	21.2
Latin America and Caribbean	31	90	122	154	180	48.1%	26.1	31.0
Middle East and N. Africa	13	41	56	73	94	67.5%	19.2	22.3
South Asia	7	87	135	212	330	143.9%	10.2	18.9
Sub-Saharan Africa	46	59	80	109	144	79.8%	12.3	14.9
Subtotal	121	419	613	862	1,124	83.3%	13.3	19.0
High-income countries	35	123	110	95	80	−27.8%	11.8	7.8
World total	156	542	723	957	1,204	66.4%	13.0	17.4

Under Schafer's (1998) results, the global automobile fleet would more than double from 470 million in 1990 to 1.0–1.2 billion automobiles in 2020. This amounts to a 113–155% increase in automobiles. The model with log–linear regional time trends generates a 140% increase in the total vehicle fleet during the same period (from 609 million to 1.47 billion total vehicles).

4.2. *Implications of our fatality projections*

The forecasts presented here are significantly lower than the 1990–2020 estimates of road traffic fatalities presented by the World Health Organization in *The Global Burden of Disease* (GBD) (Murray and Lopez, 1996). WHO estimated that 1.39 million people would die in road traffic accidents in 2000 and that 2.34 million would die in 2020. The reason for the higher figures is that WHO started from a higher base (999,000 deaths in 1990). In part, the high GBD base estimate for 1990 may be due to severe data limitations in developing regions. For example, 1990 estimates for the entire Sub-Saharan Africa (SSA) region were based only on data from South Africa (Cooper et al., 1998; Jacobs et al., 2000). South Africa has by far the highest reported fatality risk (F/P) of nearly 20 SSA countries for which we have 1990 data. Even after adjusting predicted values for non-reporting and under-reporting of fatalities, our SSA estimate is 59,150 deaths for 1990 whereas the GBD baseline is 155,000 for the same year. Despite such large differences between our base estimates and theirs, Murray and Lopez predict that global traffic fatalities will grow at approximately the same rate as the present projections. (Fatalities grow by 62% between 2000 and 2020 according to WHO and by 66% according to our estimates (see Table 4).)

We believe that Murray and Lopez (1996) have overestimated road traffic fatalities and stand behind the estimates presented here. One reason for this is that our estimate of fatalities in 2000 (723,439) agrees with the TRL estimate of global road deaths for 1999 (Jacobs et al., 2000), i.e., 745,769 fatalities worldwide (low under-reporting adjustment case). The TRL 1999 estimate is based on published 1996 data from 142 countries updated to 1999 levels and adjusted for non-reporting and under-reporting of fatalities. Since this seems to be the most comprehensive, bottom-up approach to estimating the global road death toll to date, we feel that it is the most appropriate estimate against which to compare our projections. Our prediction of traffic fatalities in 2020 (1.2 million deaths worldwide) also lies within the range suggested by TRL for 2020 (1–1.3 million deaths), although the latter is not based on a statistical model.

5. Conclusions

The results presented above suggest that, if developing countries follow historic trends, it will take many years for them to achieve the motor vehicle fatality risks of high-income countries. Provided that present policies continue into the future, the road death rate in India, for example, will not begin to decline until 2042.[23] (The projected peak corresponds to approximately 24 fatalities per 100,000 persons prior to any adjustment for underreporting but becomes 34 fatalities per 100,000 persons if we maintain the underreporting adjustment factors chosen above.) This is primarily due to the fact that India's per capita income (in 1985 international dollars) was only $2900 in 2000, whereas F/P peaks at a per capita income of approximately $8600. Similarly, in Brazil F/P will not peak until 2032, and the model projects over 26 deaths per 100,000 persons as far out as 2050.

In other developing countries, the traffic fatality risk will begin to decline before 2020 but F/P risks will still exceed the levels experienced in high-income countries today (which average about 11 fatalities per 100,000 persons). Malaysia, for example, is estimated to have over 20 fatalities per 100,000 persons (after adjusting for underreporting) in 2020. If 5.1% growth continues beyond 2020, F/P will reach 11.1 by 2033 (using the same under-reporting adjustment as above); however, if the growth rate decreases to 2.5% after 2020, F/P will reach 11.0 only in 2049.

[23] This assumes the annual real per capita GDP growth rate of 3.87% and India's log–linear time trend (from the last column in Table 3) will continue into the future.

The predictions in this paper, and the estimates of the income level at which traffic fatality risk begins to decline, assume the policies that were in place from 1963 through 1999 will continue in the future and that, as they continue to grow, developing economies will adopt road safety policies at the same rate as high-income countries did. Clearly, this may not be the case. In many developing countries fatalities per vehicle could be reduced significantly through interventions that are not reflected in our data. For example, drivers of two-wheelers could be required to wear white helmets, traffic calming measures could be instituted in towns, and measures could be taken to separate pedestrian traffic from vehicular traffic. The central question for policy in low-income countries is to identify the factors that underlie the decline in fatalities per vehicle (or per VKT) and to implement policies that are cost-effective.

Acknowledgements

We would like to thank the World Bank Research Board for funding and the Bank's Road Safety Thematic Group for comments and encouragement. Paulus Guitink and Hua Wang generously provided data. We would also like to thank the following people for their comments and suggestions: Amy Aeron-Thomas, Roger Betancourt, Tony Bliss, Bill Evans, Jagadish Guria, Goff Jacobs, Matthijs Koornstra, Seth Sanders, Richard Scurfield, Zmarak Shalizi, Jeff Smith, and V. Kerry Smith. We appreciate the comments of seminar participants at Resources for the Future, the University of Maryland, Camp Resources, and the International Conference on Vehicle Safety and Reliability in Keszthely, Hungary. The findings, interpretation, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the World Bank, its Executive Directors, or the countries they represent. The views expressed in this paper are those of the authors and do not necessarily represent those of the U.S. Environmental Protection Agency. No official Agency endorsement should be inferred.

Appendix A. Data sources

Data on traffic fatalities and vehicle fleet composition (including all passenger cars, buses, trucks, and motorized two-wheelers) were taken from various editions of the International Road Federation's (IRF) World Road Statistics (WRS) annual yearbooks, 1968–2000.

Prior to 1990, the WRS were published annually, each edition containing data from the previous 5 years. After digitizing, the 1963–1989 yearbooks, each series was compared across editions to check for accuracy and to ensure that all revisions were properly recorded. The WRS data for 1990–1999 were provided by IRF in electronic form.

Selected IRF data were also compared to and supplemented by numerous regional and country-specific road safety studies. Supplementary data was added from several sources where appropriate, including studies published by the: Inter-American Development Bank (1998), Denmark Ministry of Transport (1998), Transportation Research Laboratory (Jacobs et al., 2000), United Nations Economic and Social Commission for Asia and the Pacific (1997), Statistical Bureau of the People's Republic of China (China Statistical Yearbook (various years)), Israel National Road Safety Authority (2000), European Conference of Ministers of Transport (ECMT) (1998, 2000, 2001), Global Road Safety Partnership, OECD's International Road Traffic Accident Database (IRTAD), Cross-National Time Series Database (CNTS), Statistical Economic and Social Research and Training Center for Islamic Countries (SESRTCIC), Bangladesh Bureau of Statistics, and the American Automobile Manufacturers Association (1993).

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