Journal of Transport Economics and Policy, Volume 42, Part 1, January 2008, pp. 129–154

Why Have Traffic Fatalities Declined in Industrialised Countries?

Implications for Pedestrians and Vehicle Occupants

Elizabeth Kopits and Maureen Cropper

Address for correspondence: Elizabeth Kopits, US EPA — National Center for Environmental Economics, 1200 Pennsylvania Ave., NW, MC 1809T, Washington, DC 20460 (kopits.elizabeth@epa.gov). Maureen Cropper is at University of Maryland and World Bank.

We would like to thank the World Bank Research Board for funding and the Bank's Road Safety Thematic Group for comments and encouragement. We would also like to thank the following people for their comments and suggestions: Roger Betancourt, Tony Bliss, Jonah Gelbach, Goff Jacobs, Seth Sanders, Richard Scurfield, and Jeff Smith. We appreciate the comments of seminar participants at Resources for the Future, the University of Maryland, and the Harvard Center for Risk Analysis. 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, nor do they reflect the views of the US Environmental Protection Agency. No official Agency endorsement should be inferred.

Abstract

This paper examines the relationship between traffic fatalities and income for vehicle occupants and pedestrians and investigates factors underlying the decline in fatalities per vehicle kilometre travelled (VKT) using panel data for 32 countries from 1963–2002. Results suggest the downward-sloping portion of the curve relating traffic fatalities per capita to per capita income is due primarily to improved pedestrian safety (Kopits and Cropper, 2005a). More detailed models shed light on factors influencing pedestrian fatalities/VKT but some of the long-term improvement remains unexplained. Declines in occupant fatalities/VKT are explained primarily by reductions in alcohol abuse, improved medical services, and fewer young drivers.

Date of receipt of final manuscript: May 2007

1.0 Introduction

Research suggests that the death rate due to traffic fatalities at first increases as countries develop and motorisation increases, but eventually declines as incomes grow and fatalities per vehicle decrease (Kopits and Cropper, 2005a,b). This implies that, if historic trends continue, fatality rates will continue to increase in the developing world for several decades. An important question for policy is whether the relationship between traffic fatalities and income is the same for different classes of road user — that is, for pedestrians and vehicle occupants. Pedestrians constitute the majority of traffic deaths in developing countries, but a much smaller fraction in industrialised countries (Peden *et al.*, 2004). It is of interest to know whether pedestrian fatalities decline more rapidly than occupant fatalities as incomes grow and, if so, why this occurs.

The death rate (fatalities/population) for pedestrians and vehicle occupants is, by definition, the product of fatalities per vehicle kilometre travelled (VKT) and kilometres travelled per person. Since VKTs per person rarely decrease over time, it is the decline in fatalities per VKT that must drive a reduction in the death rate due to traffic fatalities. Since 1970, most industrialised countries have experienced a sharp decline in traffic fatalities per VKT and also in the death rate due to traffic fatalities.[1] In most cases, the percentage decline has been greater for pedestrian than for occupant fatalities. We wish to examine why this has occurred and to ask what the implications are for developing countries.

We accomplish this in two stages: first, we examine how pedestrian and occupant fatalities per VKT change with income. Second, we attempt to explain *why* this occurs by developing theoretical models of pedestrian and occupant fatalities and estimating the models using a richer set of variables. In essence, we augment per capita income by the variables it proxies — better roads, safer vehicles, improved medical services. We also examine the impact of demographic trends on pedestrian and occupant fatalities. We address these issues using panel data for developed countries: specifically, we estimate models of pedestrian and occupant fatalities per VKT using data from 1963 to 2002 for thirty-two industrialised countries, most of which are members of the International Road Traffic Accident Database (IRTAD).

The paper is organised as follows. Section 2 describes the pattern of pedestrian and occupant fatalities in the IRTAD countries over the study

[1] The mean road death rate in OECD countries has fallen by half since 1970 (from 24 deaths per 100,000 persons in 1970 to approximately 12 deaths per 100,000 persons in 2000).

period. In Section 3 we develop formal models of pedestrian and vehicle occupant fatalities, following Edlin (1999). We estimate two versions of these models: one in which all variables are proxied by per capita income (Section 4); and a second using a richer set of variables to explain the behaviour of pedestrian and occupant fatalities per VKT in industrialised countries between 1964 and 2002 (Section 5). Section 6 concludes.

2.0 Traffic Fatality Patterns in Industrialised Countries

This paper focuses on a subset of high-income countries that, from the early 1970s to the present, have experienced a decline in traffic fatalities per VKT. The countries, with the exception of Chile and Israel, are all members of the OECD's IRTAD database and are listed in Table 1. Between 1970 and 1999, total traffic fatalities declined, on average, by 35 per cent in these countries while total vehicle kilometres driven increased by over 250 per cent.[2] Within each country, the decline was more dramatic for the most vulnerable road users: pedestrians and bicyclists. As shown in Table 1, the number of pedestrian and bicyclist fatalities fell on average by over 60 per cent, while occupant fatalities declined, on average, by only 21 per cent, and even increased in some countries. This corresponds to an average 86 per cent decline in pedestrian fatalities per VKT and an average 76 per cent decline in occupant fatalities per VKT.

It is likely that part of the decline in pedestrian deaths is due to more pedestrians becoming vehicle occupants. In 1970, pedestrians and bicyclists comprised approximately 37 per cent of total road deaths in the countries in Table 1, but, by 1999, the fraction of fatalities they accounted for had fallen to 26 per cent.[3] Similarly, part of the decline in occupant fatalities may reflect the movement from two- to four-wheeled vehicles, as well as improvements in vehicle crashworthiness. Policy induced behavioural changes influence both non-motorised road users and vehicle occupants, but to different degrees.

Much of the road safety literature is devoted to evaluating the effectiveness of specific safety interventions in reducing total fatalities or fatal accidents using within-country data. Less of the literature looks

[2] On average, the total number of vehicles increased by over 200 per cent during this period.

[3] Hereafter, 'pedestrian' deaths refers to both pedestrian and bicyclist fatalities. On average, bicyclist deaths accounted for approximately 18 per cent of the total 'pedestrian' fatalities in many OECD countries over the sample period. The percentage was as high as 38 per cent in Sweden, Finland, Denmark, and Belgium, however, and nearly 60 per cent in the Netherlands.

Table 1
Traffic Fatality Trends in Industrialised Countries, 1970–1999
(Per cent Change, unless otherwise indicated)

Country	*Pedestrian deaths*	*Occupant deaths*	*Pedestrian deaths, 1999 (percentage of total)*	*Total VKT*	*Pedestrian deaths/VKT*	*Occupant deaths/VKT*	*Total deaths/VKT*
Australia	−54[b]	−44[b]	19	+125	−65[b]	−57[b]	−79
Austria	−76	−47	23	+207	−92	−83	−86
Belgium	−74[a]	−40[a]	20	+204	−90[a]	−76[a]	−85
Canada	−63	−34	16	+127[d]	−58[n]	−29[n]	−37[n]
Czech Republic	−26[b]	+60[b]	33	+80[b]	−59[b]	−12[b]	−36[b]
Denmark	−71	−49	27	+94	−85	−74	−78
Finland	−73	−48	30	+177	−90	−81	−85
France	−71	−40	15	+187	−90	−79	−82
Germany	−82	−52	21	+168	−93	−82	−87
Greece	0	+150	20	+585[e]	−83[e]	−65[e]	−71[e]
Hungary	−20	−19	46	+238[f]	−75[f]	−74[f]	−75[f]
Iceland	−44[b]	0[b]	24	+159[g]	−68[b]	−42[b]	−51[b]
Ireland	−62	+16	26	+141[h]	−74[h]	−57[h]	−64[h]
Italy	−70	−22	19	+132[i]	−82[i]	−60[i]	−68[i]
Japan	−58	−48	42	+238	−87	−85	−86
Luxembourg	−95	−37	3	+116[j]	−85[j]	−66[j]	−69[j]
Netherlands	−73	−62	28	+127	−88	−83	−85
New Zealand	−43	−17	14	+199	−81	−72	−74
Norway	−79	−24	16	+178	−92	−73	−80
Poland	−2[b]	+28[b]	47	+1317	−73[b]	−64[b]	−86
Portugal	−42	+79	22	+175[k]	−95[k]	−80[k]	−89[k]
South Korea	−40[c]	+7[c]	41	+594[l]	−73	−48[o]	−62[o]
Spain	−43	+29	18	+448	−90	−77	−81
Sweden	−71	−48	23	+88	−85	−72	−76
Switzerland	−75	−59	27	+88	−87	−78	−81
Turkey	−59[c]	−18[c]	22	+716	−82[c]	−63[c]	−70[c]
UK	−69	−43	30	+130[m]	−86[m]	−75[m]	−80[m]
USA	−41	−16	14	+144	−76	−66	−68

[a]Percentage change (1973–1999); [b]percentage change (1980–1999); [c]percentage change (1988–1999); [d]percentage change (1970–2000); [e]percentage change (1971–1998); [f]percentage change (1970–1997); [g]percentage change (1971–1999); [h]percentage change (1976–1996); [i]percentage change (1970–1991); [j]percentage change (1983–1998); [k]percentage change (1965–1997); [l]percentage change (1979–1997); [m]percentage change (1970–1998); [n]percentage change (1970–1982); [o]percentage change (1988–1997).

at how policies have impacted the fatality risk of different road user groups. Studies that do distinguish among road users have focused primarily on the impact of seat-belt usage and alcohol control policies, such as alcohol taxes and minimum drinking age laws (Peltzman, 1975; Garbacz, 1990, 1992; Cohen and Einav, 2003; Ruhm, 1996; Lindgren and Stuart, 1980; Zlatoper, 1984). They have not addressed the importance of factors such as improvements in road design and medical services, or explored the differential effect that demographic trends may have across road-user types.

Studies relying on within country data — often over short time periods — are also limited in their ability to assess the contributions of different factors to the historic decline in fatality risk. For example, the effects of changes in vehicles per capita and in the composition of the vehicle fleet are difficult to capture without country-level panel data. This is also true for demographic factors: in virtually every country in the world the death rate due to traffic crashes is higher for persons 15–24 than for any other age group. Whether this reflects inexperience or low risk aversion, it suggests that demographic changes are likely to affect the crash fatality rate, an effect that can be studied using country-level panel data. Country-level panel data can also be used to examine factors such as medical services, which may well impact pedestrian and vehicle occupant accident victims differently.[4] The few studies that have used cross-country panel data have focused on explaining variation in the total number of fatalities (Noland, 2003a; Page, 2001).

To understand better how the death rate due to traffic accidents varies across road-user groups, we develop a formal model of traffic fatalities, with separate equations for pedestrian and occupant fatalities.

3.0 Models of Pedestrian and Occupant Fatalities

The expected number of accidents times the probability that an accident is fatal. In Section 3.1, we develop separate equations for the expected number of vehicle occupant accidents and pedestrian accidents occurring annually. Section 3.2 models the likelihood that an accident results in a fatality. Implications of the models are summarised in Section 3.3.

[4] A referee reminded us that analyses using country-level panel data may suffer from aggregation bias. For example, if improvements in emergency medical services (proxied by physicians per capita in our model) reduced car occupant deaths/VKT disproportionately more than two-wheeler deaths/VKT, the coefficient estimated using aggregate data reflects a mixed effect. The aggregation process may also create spurious correlation between variables of interest and fatalities, thus producing biased estimates (see dialogue following Lave, 1985). This could occur when we measure the impact of road length on fatalities. Because we cannot control for the ratio of rural to urban roads, it could be the case that countries with more miles of road have a higher ratio of rural to urban roads, causing road length to capture the effects of rural roads. Our use of panel data allows us to handle this problem to the extent that country fixed effects control for the ratio of rural to urban roads.

3.1 Models of motor-vehicle accidents

To model the number of motor-vehicle accidents, we derive the probability that vehicle i is involved in an accident with another vehicle, p_i, and the probability that vehicle i is involved in a one-vehicle accident (for example, hitting a tree), r_i.[5] The expected number of occupant accidents occurring annually is the sum over all vehicles of $p_i + r_i$.

Following Edlin (1999), the probability that vehicle i has an accident with vehicle j is the probability that both vehicles are in the same location at the same time, and that neither driver avoids an accident. Formally,

$$P\,(i \text{ has an accident with } j) = f_i f_j L^{-1} q_i q_j, \tag{1}$$

where f_i = probability that vehicle i is on the road; L = number of locations at which an accident may occur; q_i = probability that the driver of vehicle i does not avoid an accident. $f_i f_j L^{-1}$ is thus the probability that vehicle j is in the same location as vehicle i,[6] and $q_i q_j$ the probability that neither driver avoids an accident.[7] Following Edlin, we assume that f_i is proportional to the number of kilometres that vehicle i is driven annually, m_i, (that is, $f_i = \rho m_i$) and that L is proportional to the length of the road network, R.

The probability that vehicle i is involved in an accident with any other vehicle is

$$p_i = \rho m_i q_i L^{-1} \left[\sum_{j \neq i} \rho m_j q_j \right]. \tag{2}$$

Assuming for simplicity that all drivers are identical, that is, $q_i = q_j = q$, the probability that vehicle i is involved in a two-vehicle accident is given by

$$p_i \approx \rho^2 q^2 m_i L^{-1} M, \tag{3}$$

where M = total kilometres travelled by all vehicles annually.

The probability that vehicle i is involved in a one-vehicle accident is the probability that vehicle i is in a given location (f_i/L), that an event occurs to precipitate an accident (such as an unforeseen bend in the road), and that the driver of vehicle i does not avoid the accident. Denote the probability

[5] Single-vehicle crashes account for a substantial portion of fatal crashes. In the USA, over 50 per cent of fatal crashes result from single-vehicle accidents (US DOT, http://www-fars.nhtsa.dot.gov/report.cfm?stateid=0&year=2000&title=Trends), which account for approximately a third of US highway fatalities (Lee and Mannering, 2002).

[6] L is not squared in this expression since it does not matter where on the road the two vehicles meet. The probability that vehicle i is in *any* location on the road is f_i. The probability that vehicle j is in the same location as i equals the probability that vehicle j is on the road, f_j, times the probability that j is at the *same* location as vehicle i, $1/L$.

[7] This specification assumes that accident rates and vehicle locations are uniform.

of the event that precipitates the accident e. Then the probability that vehicle i is involved in a one-vehicle accident is

$$r_i = \rho q m_i L^{-1} e. \tag{4}$$

The probability of a pedestrian accident may be derived analogously to the probability of a two-vehicle accident.[8] It is the probability of pedestrian j and vehicle i being in the same place at the same time and neither avoiding the accident:

$$\begin{aligned} P\,(\text{pedestrian } j \text{ in an accident with vehicle } i) &= f_i f_j L^{-1} q_i q_j \\ &= \rho m_i \rho' w_j L^{-1} q e', \end{aligned} \tag{5}$$

where f_j is assumed proportional to the number of kilometres pedestrian j walks each year, w_j, and e' is the probability that the pedestrian does not avoid the accident. The probability of vehicle i being involved in a pedestrian accident is the sum across all pedestrians of (5),

$$P\,(\text{vehicle } i \text{ has an accident with a pedestrian}) = \rho m_i \rho' W L^{-1} q e', \tag{6}$$

where W is the number of kilometres walked by all pedestrians in a year.

The number of pedestrian accidents occurring annually is the sum across all vehicles of (6). Assuming $m_i = m$, the average number of kilometres driven per vehicle and noting that $M = mV$, where V is the number of vehicles in the country,

$$\text{pedestrian accidents} = \rho M \rho' W L^{-1} q e'. \tag{7}$$

The number of accidents involving vehicle occupants is the sum across all vehicles of (3) and (4):

$$\text{occupant accidents} = \rho^2 q^2 M^2 L^{-1} + \rho q M L^{-1} e. \tag{8}$$

3.2 Models of accident fatalities

The expected number of deaths that occur each year as a result of motor vehicle accidents equals the sum across all vehicles of the probability that an accident occurs times the probability of a fatality, given that an accident occurs. Letting $\gamma = P\,(\text{pedestrian is killed} \mid \text{accident})$ and $\lambda = P\,(\text{occupant is killed} \mid \text{accident})$,

$$\text{occupant fatalities} = (\rho^2 q M^2 L^{-1} + \rho q M L^{-1} e)\lambda, \tag{9}$$

$$\text{pedestrian fatalities} = \rho M \rho' W L^{-1} q e' \gamma. \tag{10}$$

[8] For ease of notation, the probability that a driver is unable to avoid a one-vehicle accident or an accident with a pedestrian is assumed the same as the probability that the driver is unable to avoid a two-vehicle accident, q_i.

Expressing equations (9) and (10) in terms of fatalities per distance travelled by all motor vehicles (where distance travelled $= M$),

$$\text{occupant fatalities/distance travelled} = \rho^2 q^2 M L^{-1}\lambda + \rho q L^{-1} e\lambda, \qquad (9')$$

$$\text{pedestrian fatalities/distance travelled} = \rho\rho' W L^{-1} q e'\gamma. \qquad (10')$$

3.3 Implications of the models

Equation (10′) says that pedestrian fatalities per VKT should decline, the more likely it is that a driver can avoid an accident (the smaller is q), the more extensive the road network (the larger is L), the less likely a pedestrian is to precipitate the accident (the smaller is We'), and the less likely the pedestrian is to die if an accident occurs (the smaller is γ). The number of occupant fatalities per VKT (equation (9′)) should also decline with decreases in q and with increases in L. In addition, the occupant fatality rate should decline the less likely an event occurs to precipitate a one-vehicle accident (the smaller is e) and the less likely an occupant is to die given that an accident occurred (the smaller is λ). Finally, increases in total VKTs will increase the probability of any two vehicles meeting on the road and, hence, increase the occupant fatality rate.

4.0 How Do Pedestrian and Occupant Fatalities per VKT Vary with Income?

Virtually all factors causing pedestrian fatalities per VKT (equation (10′)) to fall should increase with income; hence pedestrian fatalities per VKT should decline with economic growth. In contrast, fatalities per VKT associated with two-vehicle crashes (the second term in equation (9′)) should increase with total VKTs. This suggests that occupant fatalities per VKT need not decline monotonically with economic growth, nor should they decline as rapidly with per capita income as pedestrian fatalities per VKT.

Table 2 and Figure 1 bear this out. The table and figure present fixed-effects models of ln (pedestrian fatalities/VKT) and ln (occupant fatalities/VKT) estimated using data for 1963–2002 for thirty-two high-income countries.[9]

[9]The sample includes all OECD countries listed in Table 1, along with Chile, Israel, Slovenia, and Slovak Republic. See Kopits and Cropper (2005b) for a breakdown of observations by country. Data sources are described in the Appendix. Descriptive statistics for individual variables in the sample can be found in Kopits and Cropper (2005b) (http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2005/08/04/000016406_20050804141259/Rendered/PDF/wps3678.pdf) or are available upon request.

Table 2

Pedestrian and Occupant Fatalities/VKT as a Function of Income and Time[a]

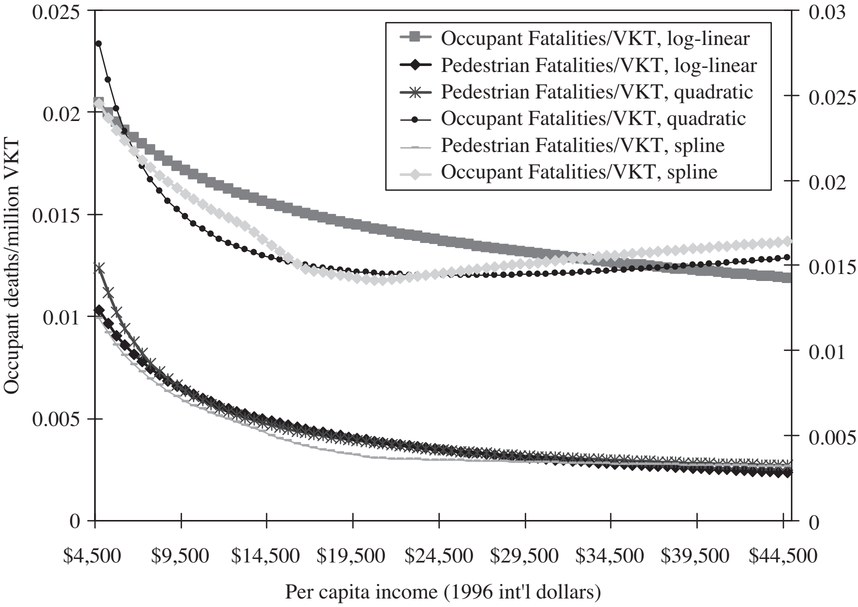
	ln (pedestrian fatalities/VKT)			ln (pedestrian fatalities/ population)	ln (occupant fatalities/VKT)			ln (occupant fatalities/ population)
	1	2	3	4	1	2	3	4
ln (per capita GDP)	−0.643***	−3.494			−0.237	−4.503**		
	(0.146)	(3.633)			(0.188)	(1.952)		
(ln (per capita GDP))^2		0.148				0.222**		
		(0.189)				(0.100)		
ln (per capita GDP) for:								
$4,552–13,165			−0.706***	0.653***			−0.328	1.030***
			(0.270)	(0.187)			(0.233)	(0.293)
$13,165–16,565			−1.073***	−0.680*			−0.675**	−0.283
			(0.339)	(0.370)			(0.293)	(0.401)
$16,565–20,700			−0.776**	−0.847*			−0.210	−0.281
			(0.390)	(0.488)			(0.364)	(0.539)
$20,700–44,227			−0.180	−0.488**			0.198	−0.109
			(0.339)	(0.239)			(0.195)	(0.268)
Common t	−0.060***	−0.060***	−0.059***	−0.033***	−0.044***	−0.044***	−0.043***	−0.017**
	(0.004)	(0.004)	(0.005)	(0.006)	(0.004)	(0.004)	(0.005)	(0.008)
Constant (Austria)	3.056**	16.748	3.692	−15.253***	−0.267	20.222**	0.642	−18.387***
	(1.360)	(17.451)	(2.533)	(1.705)	(1.741)	(9.591)	(2.158)	(2.683)
Turning point (1996 int'l $)		$129,500				$25,384		
Adjusted R^2	0.9543	0.9547	0.9560	0.8585	0.9468	0.9485	0.9502	0.8204
Countries	32	32	32	32	32	32	32	32
Observations	830	830	830	830	830	830	830	830

***Indicates 1 per cent level of significance; **Indicates 5 per cent level of significance; *Indicates 10 per cent level of significance.

[a]Heteroskedasticity-corrected standard errors, clustered on country to allow for within-panel autocorrelation, are given in parentheses. Country-fixed effects were included in all regressions but are not displayed here.

Figure 1

*Occupant and Pedestrian Fatalities/VKT as a Function of Income Only**



*Based on results shown in Table 2, evaluated at the country intercept estimate for Austria in 1999.

Model 1 contains only the log of per capita income (measured in 1996 International \$) and a time trend. The log of income enters model 2 in a piecewise-linear fashion, with each spline segment containing an equal number of observations, while model 3 specifies a quadratic function of log income.[10]

The models for pedestrian fatalities per VKT suggest that fatality risk to pedestrians declines with per capita income, until a per capita income of \$20,700 (1996 int'l \$).[11] In contrast, the table suggests that there is no monotonic relationship between per capita income and occupant fatality risk over the range of incomes in the data. For pedestrians, fatality risk declines with income for per capita incomes between \$4,552 and \$20,700 (1996 int'l \$), with an elasticity ranging from –0.71 to –1.1. The only

[10]In all specifications, Durbin–Watson statistics (calculated for fixed effects panel data models (Nunziata, 2002) indicate the presence of positive within-panel serial correlation in the disturbances. Therefore, standard errors have been adjusted to account for serial correlation in disturbances within countries over time, as well as for heteroskedasticity. This procedure is theoretically justified when the number of panels is large (Liang and Zeger, 1986). Recent studies find this estimator works reasonably well in fixed effects estimation even when the number of panels is not especially large relative to the length of each panel (Wooldridge, 2003).

[11]This corresponds to the per capita income of Sweden in 1990 and the USA in 1980.

income range in which occupant fatality risk declines with income is \$13,165 to \$16,565 (1996 int'l \$), and, the quadratic function suggests that occupant fatality risk rises for incomes in excess of \$25,500, although the function is fairly flat.[12]

These results suggest that the decline in the death rate (fatalities/population) due to traffic fatalities at high-income levels (Kopits and Cropper, 2005a) is dominated by a decline in the pedestrian death rate. This is borne out in the spline specifications of income in Table 2 (Model 4). The elasticity of the pedestrian death rate with respect to income is positive for incomes below \$13,165 (1996 int'l \$) and negative and significant for incomes in excess of this amount, a result similar to Kopits and Cropper (2005a).[13] In contrast, the elasticity of the occupant death rate with respect to income, which is also positive for incomes below \$13,165, shows no statistically significant relationship with income for incomes above this level.

5.0 What Other Factors Explain Variation in Pedestrian and Occupant Fatality Risk?

Given the multiplicative nature of equations ($9'$) and ($10'$), models of occupant fatalities/VKT (OccF/VKT) and pedestrian fatalities/VKT (PedF/VKT) may be approximated with flexible, reduced-form log–log functions, where L, q, e, e', W, γ, and λ are proxied by the variables described below.

5.1 Specification of occupant fatalities per VKT

The Base Model for occupant fatalities (see Table 3) includes three sets of variables in addition to per capita income (Y) and a time trend (t): demographic variables (Youth, Elderly, and Urban), motorisation variables (Vehicle fleet, Vehicle fleet$^*t$, and the growth rate of the vehicle fleet) and road infrastructure (Road length and Road length$^*t$).

The percentage of the driving age population between 15 and 24 (Youth), and the percentage of the population over 64 (Elderly) may influence the probability that a driver avoids an accident (q) as well as

[12] This coincides with the incomes of Switzerland and the USA in the early 1960s.

[13] Kopits and Cropper (2005a) measure per capita income in 1985 international dollars. They find that the death rate declines after incomes of about \$8,600 (1985 int'l \$). A per capita income of \$13,165 (1996 int'l \$) is approximately equal to \$8,600 (1985 int'l \$), the income of Denmark and Luxembourg in 1965.

Table 3

Results for Vehicle Occupant Fatalities/VKT Models[a]

	1 (Base Model)	*2*	*3*	*4*
Coefficient estimates				
ln (per capita GDP)	−2.158***	−2.515***	−2.713***	−2.078***
	(0.642)	(0.737)	(0.734)	(0.708)
ln (per cent driving age population aged 15–24[b] (Youth))	13.279***	15.219***	15.833***	12.851***
	(3.558)	(4.058)	(4.019)	(3.862)
ln (Youth)*ln (per capita GDP)	−1.304***	−1.492***	−1.540***	−1.245***
	(0.359)	(0.409)	(0.406)	(0.395)
ln (vehicle fleet[c])	0.382**	0.477***	0.232	0.386*
	(0.167)	(0.177)	(0.229)	(0.226)
ln (road length)	−0.388**	−0.258	−0.719**	−0.416**
	(0.156)	(0.167)	(0.308)	(0.175)
ln (vehicle fleet)* t	−0.012***	−0.012***	−0.010***	−0.011***
	(0.002)	(0.003)	(0.003)	(0.002)
ln (road length)* t	0.013***	0.013***	0.011***	0.012***
	(0.002)	(0.002)	(0.004)	(0.002)
t	−0.014	−0.009	−0.017	−0.019
	(0.015)	(0.021)	(0.023)	(0.015)
Percentage change in vehicle stock from the previous year	0.587**	0.231	1.059***	0.479*
	(0.278)	(0.268)	(0.388)	(0.271)
ln (per cent driving age population aged 65+ (Elderly))	0.061	−0.090	0.290	−0.112
	(0.220)	(0.245)	(0.385)	(0.226)
ln (per cent population living in urbanised areas (Urban))	−0.091	−0.080	0.137	−0.064
	(0.346)	(0.352)	(0.783)	(0.392)
ln (licensed physicians/10,000 persons (Physician))		−0.303*		
		(0.170)		
ln (deaths due to cirrhosis of liver/100,000 driving age persons (Liver))			0.099**	
			(0.050)	
Motorised two-wheelers (percentage of total vehicle stock)				0.001
				(0.004)

Constant		18.345***	19.433***	29.392***	17.516***
		(5.913)	(6.793)	(10.489)	(6.167)
Adjusted R^2		0.9601	0.9629	0.9542	0.9624
Observations		680	537	515	613
Countries		32	29	30	31
Estimated elasticities with respect to interacted variables					
per capita GDP[d]		−0.011	−0.059	−0.179	−0.028
		(0.130)	(0.112)	(0.136)	(0.132)
Youth[d]		0.608**	0.718***	0.870***	0.749***
		(0.258)	(0.254)	(0.299)	(0.229)
Vehicle fleet:	1965	0.347**	0.441**	0.203	0.354
		(0.165)	(0.173)	(0.226)	(0.222)
	1995	−0.006	0.078	−0.095	0.034
		(0.147)	(0.149)	(0.218)	(0.189)
Road length (kms):	1965	−0.351**	−0.218	−0.686**	−0.380**
		(0.153)	(0.163)	(0.313)	(0.171)
	1995	0.028	0.181	−0.353	−0.023
		(0.134)	(0.142)	(0.374)	(0.142)
Time[e]		−0.046***	−0.037***	−0.038***	−0.042***
		(0.005)	(0.006)	(0.007)	(0.006)

***Indicates 1 per cent level of significance; **5 per cent level of significance; *10 per cent level of significance. Heteroskedasticity-corrected standard errors, clustered on country to allow for within panel autocorrelation, are given in parentheses. Country fixed effects were included in all regressions.
[a]Vehicle occupant fatalities include drivers and passengers killed in any motorised vehicle (cars, buses, trucks, motorised two-wheelers).
[b]Driving-age population is defined as ages 15 and up.
[c]Includes cars, buses, trucks, and motorised two-wheelers.
[d]Elasticities are evaluated at mean ln (per capita GDP) and ln (Youth) of Base Model sample: per capita GDP = \$16,630 (1996 int'l \$), Youth = 0.1928. For example, in Model 1, the income elasticity of the occupant fatality rate $= \partial \ln(\text{occupant fatalities/VKT})/\partial \ln(\text{per capita GDP}) = -2.158 - 1.304^{*}(\ln(0.192781)) = -0.011$.
[e]Elasticity is evaluated at the mean value of ln (Vehicle fleet) and ln (Road length) of the Base Model sample.

the likelihood that an occupant survives a crash (λ). In practice, q reflects driver skill, attitudes towards risk/safety, education, and driving experience, all of which may vary with age. Because attitudes towards risk and level of education may vary with per capita income, we interact Youth and Y. The effect on fatality rates of having a larger percentage of drivers over 65 is unclear: although older drivers may have more experience and drive at slower speeds, they may a have a slower reaction time to an imminent collision (thus affecting q). Older drivers may also be less likely to survive a crash (thus decreasing λ). The percentage of the population living in urban areas (Urban) may proxy average speeds, which are likely to be lower in urban than in rural areas, other things being equal.

The size of the vehicle fleet is included in models of occupant fatalities since an increase in the fleet, other things being equal, should increase the chance of multiple-vehicle crashes. In addition we have interacted ln (vehicle fleet) with a linear time trend. This is equivalent to allowing the coefficient on ln (vehicle fleet) to depend linearly on time, in order to capture the effects of (for example) changes in the quality of cars over time.[14] The condition of the vehicle fleet will affect the likelihood that a driver avoids an accident (q). We proxy safer vehicles with the vehicle fleet–time interaction on the grounds that as older vehicles go out of service, the vehicle mix is tilted toward more recent models, which are equipped with better safety features. Holding the size of the vehicle fleet constant, increases in the vehicle–time interaction indicates an increase in the average safety level of the vehicle stock. The rate of growth in the vehicle fleet is a measure of driver experience. The faster the fleet grows, the greater is the proportion of less-experienced drivers on the road; hence the average driver's inability to avoid collisions (q) should increase with growth in the vehicle fleet.

The model of Section 3 suggests that there should be fewer accidents, other things being equal, the longer is the road network. We therefore include the total number of route-kilometres of roads in our models.[15] Since road designs have improved over time, a road length–time trend interaction captures safer road conditions.[16] If improvements in road

[14]To determine whether the coefficient should be linear in time, we also estimated the model using more flexible functional forms. Results from a four-segment linear spline specification suggest that the magnitude and significance of the ln vehicles–time interaction diminishes only slightly in later decades. In a quadratic specification, the coefficient on the squared term is small and insignificant, suggesting that the linear time trend is reasonable.

[15]Although the number of lane-miles would be a better measure of road infrastructure, data limitations prevent us from using it.

[16]As with the vehicle fleet, we tested more flexible functional forms of the interaction of time with roads to proxy the effect of safer roads. The trends in the road-time coefficients are similar to the vehicle-time coefficients using these specifications, suggesting that the linear time trend is a reasonable assumption.

design allow drivers more reaction time, this should increase a driver's ability to avoid an imminent accident. However, any beneficial effect of improved road and vehicle conditions could be offset by increased speeds or other risky driving behaviour, a point to which we return below.

Subsequent models in Table 3 add three additional factors that may affect occupant fatalities: physicians per capita, a measure of alcohol abuse, and the percentage of two-wheelers in the vehicle fleet. The probability of a vehicle occupant dying given that an accident occurs, λ, clearly depends on the quality of emergency medical services. Since indicators of emergency medical services are limited, we proxy medical quality by the number of licensed physicians per person (Physicians). A driver's ability to avoid an accident is clearly influenced by alcohol consumption/abuse. One measure of the amount of abusive drinking in the country is the death rate due to cirrhosis of the liver (Liver).[17] The percentage of two-wheelers in the vehicle fleet provides some measure of the heterogeneity of the vehicle mix and/or variance of speed on the road.

5.2 Specification of pedestrian fatalities per VKT

The Base Model for pedestrian fatalities per VKT in Table 4 contains variables identical to those in the model of occupant fatalities, but adds total population. Population is included because total kilometres walked by pedestrians (W) should increase with population size. The rationale for including the size of the vehicle fleet in the pedestrian equation is that, holding population constant, it should vary inversely with W. In addition, since estimation with more flexible functional forms of the time trend suggests that the linear specification is too restrictive, the vehicle fleet and road length coefficients are allowed to be quadratic in time. Urban is included to capture the fact that people are more likely to walk in urban areas.

5.3 Reduced-form estimates

Tables 3 and 4 provide coefficient estimates and summarise the elasticity estimates resulting from four specifications of occupant and pedestrian fatalities per VKT (equations ($9'$) and ($10'$)). They exclude seat-belt variables, which should affect λ but drastically reduce our sample size (see Kopits and Cropper, 2005b).

[17] The cruder proxy for the amount of drunk driving that has been used in other studies is the adult (18 years old and over) per capita alcohol consumption in the country.

Table 4
Results for Pedestrian Fatalities/VKT Models[a]

	1 (Base Model)	*2*	*3*	*4*
Coefficient estimates				
ln (per capita GDP)	−0.6031	−0.9121	−1.6673*	−1.4635**
	(0.7639)	(0.8102)	(0.9249)	(0.6655)
ln (per cent driving age population aged 15–24[b] (Youth))	2.7960	4.4026	9.7941*	8.3427**
	(4.5392)	(4.6562)	(5.3484)	(3.6941)
ln (Youth)*ln (per capita GDP)	−0.2098	−0.3853	−0.9034*	−0.7737**
	(0.4576)	(0.4774)	(0.5398)	(0.3763)
ln (vehicle fleet[c])	−0.2254	−0.2253	−0.1454	−0.1062
	(0.2243)	(0.2053)	(0.3018)	(0.2100)
ln (road length)	−0.7469**	−0.8042***	−1.1330***	−0.8358***
	(0.3114)	(0.3085)	(0.3174)	(0.2754)
ln (vehicle fleet)* t	−0.0261**	−0.0201*	−0.0275	−0.0285**
	(0.0122)	(0.0119)	(0.0208)	(0.0111)
ln (road length)* t	0.0334***	0.0317***	0.0326*	0.0396***
	(0.0122)	(0.0099)	(0.0182)	(0.0112)
ln (vehicle fleet)* t^2	0.0004	0.0004	0.0005	0.0005*
	(0.0003)	(0.0002)	(0.0005)	(0.0002)
ln (road length)* t^2	−0.0005*	−0.0005**	−0.0005	−0.0006**
	(0.0003)	(0.0002)	(0.0004)	(0.0002)
t	−0.0569	−0.1066	−0.0285	−0.1032
	(0.0775)	(0.0889)	(0.1600)	(0.0782)
t^2	−0.0004	0.0001	−0.0012	0.0002
	(0.0015)	(0.0017)	(0.0036)	(0.0015)
Percentage change in vehicle stock from the previous year	0.9007**	0.7408	0.9158***	0.9007***
	(0.3992)	(0.4711)	(0.3384)	(0.3345)
ln (per cent driving age population aged 65+ (Elderly))	0.7193***	0.3822*	0.6313*	0.5743**
	(0.2437)	(0.2145)	(0.3471)	(0.2307)
ln (per cent population living in urbanised areas (Urban))	1.0021**	1.0861**	0.9248	0.9085***
	(0.4322)	(0.4561)	(0.8846)	(0.3446)
ln (total midyear population)	0.0502	−0.7622	0.7544	0.1913
	(0.6343)	(0.6428)	(0.5359)	(0.4373)

ln (licensed physicians/10,000 persons (Physician))			−0.2278		
			(0.2786)		
ln (deaths due to cirrhosis of liver/100,000 driving age persons (Liver))				0.2294***	
				(0.0690)	
Motorised two-wheelers (percentage of total vehicle stock)					−0.0079**
					(0.0038)
Constant		12.1810	28.1055**	14.3682	17.9860*
		(11.0200)	(12.0363)	(12.3544)	(9.4744)
Adjusted R^2		0.9617	0.9633	0.9611	0.9645
Observations		680	537	515	613
Countries		32	29	30	31
Estimated elasticities with respect to interacted variables					
per capita GDP[d]		−0.258*	−0.278*	−0.180	−0.190
		(0.147)	(0.147)	(0.202)	(0.159)
Youth[d]		0.757**	0.657	1.014***	0.823**
		(0.318)	(0.413)	(0.326)	(0.334)
Vehicle fleet:	1965	−0.300	−0.282	−0.224	−0.187
		(0.213)	(0.197)	(0.272)	(0.199)
	1995	−0.630***	−0.476**	−0.540**	−0.545***
		(0.202)	(0.200)	(0.232)	(0.178)
Road length (kms):	1965	−0.651**	−0.714**	−1.040***	−0.722***
		(0.290)	(0.298)	(0.297)	(0.262)
	1995	−0.180	−0.299	−0.589**	−0.173
		(0.210)	(0.287)	(0.279)	(0.230)
Time[e]		−0.050***	−0.039***	−0.050***	−0.056***
		(0.007)	(0.010)	(0.007)	(0.006)

***Indicates 1 per cent level of significance; **5 per cent level of significance; *10 per cent level of significance. Heteroskedasticity-corrected standard errors, clustered on country to allow for within panel autocorrelation, are given in parentheses. Country fixed effects were included in all regressions.

[a]Pedestrian fatalities include bicyclist deaths.

[b]Driving age population is defined as ages 15 and up.

[c]Includes cars, buses, trucks, and motorised two-wheelers.

[d]Elasticities are evaluated at mean ln (per capita GDP) and ln (Youth) of Base Model sample: per capita GDP = \$16,630 (1996 int'l \$), Youth = 0.1928.

[e]Elasticity is evaluated at the mean value of ln (Vehicle fleet) and ln (Road length) of the Base Model sample.

5.3.1 Factors affecting occupant fatality risk

In Table 3, several results stand out. Consistent with Table 2, per capita income is insignificant in explaining the decline in occupant fatalities/VKT.[18] What is significant in explaining the decline in occupant fatalities are demographic trends, reductions in alcohol abuse, growth in the road network, improvements in motor vehicles, and in the availability of medical services.

Demographic trends. A striking result of Table 3 is the importance of demographic trends. An increase in the percentage of driving age population aged 15–24 (Youth) has a large, positive effect on the occupant fatality rate. Evaluated at the Base Model sample mean income, the elasticity with respect to Youth is statistically significant in all specifications, ranging in magnitude from 0.608 (0.258) to 0.870 (0.291). Given that Youth fell by 20–40 per cent in many countries over the period 1970–2000, this demographic trend alone could account for nearly 30 per cent of the decline in occupant fatalities per VKT during this period.

The positive relationship between Youth and fatalities per VKT finding agrees with results in the literature, including Peltzman (1975), Noland (2003a) and Page (2001). However, the importance of demographics is more pronounced here than in most within-country studies that are limited to shorter periods of analysis. Using country-level data for 1970 and 1980, Keeler (1994), for example, finds increases in the young population to increase traffic fatalities but the result is not significant.

The negative coefficient on the income–Youth interaction term (see Table 3) indicates that the importance of young drivers diminishes as incomes increase. The elasticity with respect to Youth exceeds 2.0 (0.50) for per capita incomes less than \$5,900 (1996 int'l \$)[19] but falls to 0.08 (0.26) once per capita income reaches \$25,000.[20] This result could reflect changes in young people's attitudes toward risk or an increase in the education of young drivers with economic prosperity.

---

[18]Note that a linear combination of significant coefficients can be statistically insignificant, and vice versa. In Table 3, for example, although the coefficients on income and the income–Youth interaction terms are statistically significant, the variance of the income coefficient estimate and the covariance between the income and Youth coefficients are such that, when evaluated at the sample mean of Youth, the elasticity of the occupant fatality rate with respect to income is no longer significant.

[19]This is the approximate per capita income (1996 int'l \$) of Portugal and Hungary in the late 1960s to early 1970s and Turkey in the early 1990s. International dollars account for differences in purchasing power across countries and allows for comparisons of income over time. See the Appendix for more detail on this income series.

[20]This is approximately the income of the USA around 1990 and Denmark and Norway in the late 1990s.

In contrast to the effects of Youth, the percentage of driving-age population aged 65 and over (Elderly) has a small, positive but insignificant effect on occupant fatalities per VKT. Likewise, the percentage of population living in urban areas (Urban) has an insignificant effect on the occupant fatality rate.

Motorisation. Our results suggest that occupant fatalities per VKT increase with the size of the motor vehicle fleet, as the formal model suggests, although this finding is less robust as the sample size falls in Models 3 and 4. Moreover, the negative coefficient on the vehicle–time trend interaction indicates that the effect diminishes over time, with the elasticity falling to approximately zero by the mid-1990s. This result is consistent with newer, safer vehicles providing additional protection to vehicle occupants. The finding that the percentage of motorised two-wheelers in the vehicle stock has no effect on the occupant fatality rate (Model 4) is somewhat surprising given the increased vulnerability of motorcycle accident victims to bodily injury. Lastly, occupant fatality risk increases with a country's rate of motorisation; however, the magnitude of this effect is not large. Considering that the growth rate of the vehicle fleet fell from approximately 0.06 to 0.02 in several countries over the sample period,[21] decreases in the rate of motorisation contributed to less than a 3 or 4 per cent decline in occupant fatalities/VKT.

Road infrastructure. Road building reduces occupant fatality risk, as suggested by the formal models, but trends in road conditions (proxied by the road length–time trend interaction) offset this effect. The elasticity of occupant fatalities with respect to the road network decreases from about −0.35 (0.15) in 1965 to approximately zero by the mid-1990s.[22]

Since total route length does not decrease over time, increases in the road–time interaction could reflect an ageing or deterioration of the existing road network. Or, if the building of new roads is positively correlated with road maintenance and improvements on existing routes, then the positive coefficient on the road length–time trend interaction suggests that trends in road improvements may have led to an increase in risk-taking behaviour on the part of drivers in response to safer road conditions.

[21] For example, the annual growth rate of the vehicle fleet fell from 5.9 per cent in 1965 to 1.9 per cent in 2002 in Austria, from 6.0 to 1.1 per cent in Denmark, and from 5.0 to 2.0 per cent in the USA.

[22] The magnitude of the coefficient on total route length (and, hence, the overall elasticity) approximately doubles in magnitude when Liver is included in the estimation (Model 3 in Table 3). This reflects the change in the sample of countries and years when Liver is included in the model. If the Base Model is estimated using the same observations used to estimate Model 3, the Road elasticity is approximately the same as in Model 3.

This result is consistent with Noland's (2003b) finding that road infrastructure improvements — additional lane-miles, lane widening, and changes in geometric design — may lead to increases in traffic fatalities. Since the interpretation of the route length–time trend interaction is not clear, measuring the net effect of trends in road conditions on traffic deaths per VKT requires more detailed data on road maintenance.

Alcohol. The number of deaths due to cirrhosis of the liver (Liver) has a positive and significant effect on occupant deaths per VKT (Model 3),[23] reflecting an increase in the probability of a drunk driver being unable to avoid an imminent accident.

Trends in liver cirrhosis death rates varied across high-income countries over the 1970–2000 period. The death rate decreased substantially in the USA and many European countries (by 30 to 50 per cent, and by nearly 60 per cent in France), although some countries (such as Finland, Hungary, and the UK) experienced increases during this time. An elasticity estimate of 0.10 (0.05) suggests that reductions in alcohol use contributed to less than a 6 per cent decline in the occupant fatality rate in most high-income countries between 1970 and 2000.

Medical treatment indicators. Increases in the availability of medical services (proxied by the number of physicians per capita) have a significant, negative effect on the occupant fatality rate. This is consistent with Noland's (2003a) finding that more physicians per capita led to reductions in total fatalities in a similar set of countries during 1970–1996, although he did not control for the length of the road network.[24]

To summarise our results: decreases in the percentage of young drivers are significant in explaining the decline in occupant fatality rates over the 1970–2000 period. Trends in road building are associated with declines in occupant fatalities per VKT, especially in the early years of the sample period. The growth in vehicle fleets, on the other hand, increased occupant fatality rates, but this effect was gradually offset by improvements in vehicle

[23]The coefficient remains significant and of the same magnitude when other controls (such as the availability of medical services) are added to the model (Kopits, 2004). Replacing Liver with per capita alcohol consumption has the expected positive sign (increasing fatalities per VKT) but is small in magnitude and statistically insignificant (see Kopits, 2004). The imprecision of this coefficient could be a result of measurement error since per capita alcohol consumption is a crude measure of drunk driving.

[24]Kopits (2004) also explored the effects of an alternate measure of the quality of emergency medical care: the heart attack survival rate, since it is less correlated with the other explanatory variables, and thus less affected by multicollinearity than Physicians. However, sample size shrinks significantly with the inclusion of this variable.

safety features over time. Finally, reductions in alcohol abuse and increased availability of medical care appear significant in reducing occupant deaths per VKT. Some of the reduction in occupant fatality rates, however, is unexplained: holding all else equal, occupant deaths per VKT decline by 4 per cent annually.

5.3.2 Factors affecting pedestrian fatality risk

Many of the factors that are associated with occupant fatality risk are also significant in explaining the decline in pedestrian fatalities per VKT, but there are important differences. In contrast to the occupant equations, increases in the percentage of the population over 65 significantly increases pedestrian fatality risk, as does the percentage of population in urban areas. Increases in the vehicle fleet, which proxy reduced pedestrian exposure, reduce pedestrian fatality risk, whereas they initially increase occupant fatality risk. It is also the case that some of the reduction in pedestrian fatalities remains unexplained. These results are discussed in detail below.

Demographic trends. An increase in the percentage of driving age population between 15 and 24 (Youth) increases pedestrian fatality risk, with an elasticity (evaluated at the sample mean of per capita income) ranging from 0.76 (0.32) to 1.01 (0.33). This suggests, as in the case of vehicle occupants, that this demographic trend could account for a 20 per cent decline in pedestrian fatalities per VKT over the sample period. The effect of Youth falls as incomes increase, although the elasticity exceeds 0.6 when per capita income reaches $25,000. The positive relationship between Youth and pedestrian fatality risk agrees with Peltzman (1975), although he grouped motorcyclists with pedestrians.

Interestingly, the percentage of driving-age population of 65 and over (Elderly) has a much larger positive effect on pedestrian fatalities per VKT than on occupant fatality risk. Given the elasticity estimate of 0.72 (0.24) (Base Model) and an average increase in Elderly of 21 per cent over 1970–2000 (from 14.46 to 18.22 per cent) for the countries in the sample, our results suggest that population ageing dampened improvements in pedestrian road safety by almost 15 per cent.

Why the effect of Elderly differs between the two equations is unclear. If elderly people are more likely to walk than to drive, then the significant effect in the pedestrian equation could simply reflect an increase in the total number of pedestrians.[25] On the other hand, it could reflect an

[25] Alternatively, pedestrian–vehicle accident risk could be higher for older pedestrians (Koepsell *et al.* 2002).

increase in accidents caused by elderly drivers[26] or lower pedestrian crash survival rates of elderly accident victims (in which case the occupant fatalities/VKT remain unchanged because of the protection offered by vehicle safety devices such as seat-belts and air bags). Distinguishing between these two causes remains a topic for future research.

Pedestrian fatalities per VKT do not increase with total population. However, the elasticity with respect to Urban is a near one, presumably reflecting an increase in total pedestrian activity. Given an average increase in Urban from 64 to 74 per cent for the countries in the sample, our results suggest that increases in the urban population dampened improvements in the pedestrian fatality rate by over 15 per cent from 1970–2000.

Motorisation. Increases in the motor vehicle fleet reduce pedestrian fatalities per VKT, as the formal model suggests, although the effect is generally insignificant in the early years of the sample period; by 1995, however, the elasticity with respect to vehicles increases to over −0.50 (0.20).

Pedestrian fatality risk also increases with a country's rate of motorisation, at a somewhat faster rate than in the occupant equation. Even with an elasticity of nearly 1, the magnitude of this effect is not large; decreases in the rate of motorisation contributed to approximately a 4 per cent decrease in pedestrian fatalities per VKT over the sample period. Pedestrian fatality risk is unaffected by changes in the percentage of motorised two-wheelers in the vehicle stock (Model 4).

Road infrastructure. The beneficial effect of road building is consistently larger in the pedestrian equation than in the occupant equation, perhaps because larger road networks include more motorways that are separated from foot traffic. However, as with vehicle occupants, the effect diminishes over time and, by the mid-1990s, the elasticity falls to zero.

Alcohol. Alcohol use, as proxied by the death rate due to cirrhosis of the liver, is significant, with an effect that is twice as large as in the case of vehicle occupants.[27] It is likely that this reflects not only an increase in the probability of a drunk driver being unable to avoid an imminent accident (q), but also risky behaviour by pedestrians under the influence

[26]If the accidents are occurring at lower speeds, then vehicle occupant fatalities per accident may not increase but pedestrian deaths per accident will. However, our findings do not support the hypothesis that slower speeds by elderly drivers could increase the variance in driving speed, thereby increasing fatality rates (Lave, 1985), since that should have caused occupant deaths per VKT to increase as well.

[27]As in the case of vehicle occupants, the Liver coefficient is robust to the inclusion of other variables (Kopits, 2004).

of alcohol (thereby increasing e' in equation (10$'$)). Long-term trends in the liver cirrhosis death rate and the Liver coefficient estimate of 0.23 (0.07) in Table 4 suggest that changes in alcohol use contributed to less than a 10 per cent decline in pedestrian deaths/VKT in most high-income countries, 1970–2000.

Medical treatment indicators. Increases in the availability of medical services have no statistically significant effect on pedestrian fatality risk. The insignificance of Physicians could be due to multicollinearity, although it is also not surprising that an increase in medical services has a larger impact on occupant fatalities than on pedestrian fatalities. One could assume that the likelihood of death is higher for unprotected road users such as pedestrians and bicyclists than vehicle occupants, regardless of how quickly accident victims are rushed to the hospital or the quality of available medical care.

To summarise our results: decreases in the percentage of young drivers and trends in road building have contributed to improvements in pedestrian safety over the past three decades, to a similar degree as for vehicle occupants. Growth in vehicle fleets and improvements in vehicle safety features also contributed to the decline in pedestrian fatality risk, especially in the later years of the sample period. Reductions in alcohol abuse have a larger impact on pedestrians than vehicle occupants. However, the results also suggest that improvements in pedestrian safety were significantly dampened by the growth in urban and elderly populations.

6.0 Conclusions

To examine fatalities per distance travelled we must use data from countries with reliable information on VKTs. This limits our study to high-income countries. We believe, however, that the experience of the IRTAD countries over the period 1963–2002 is relevant to the current situation faced by developing countries. The levels of per capita income of the poorest IRTAD countries in 1963 (such as Korea, Greece, Ireland, and Portugal) were the same as (or sometimes below) the income levels of many low- to middle-income countries today. Moreover, the pattern of traffic fatalities in many IRTAD countries at the beginning of our panel was similar to current patterns in developing countries: in 1970, the ratio of pedestrian to total traffic fatalities exceeded 40 per cent in nine IRTAD countries. We therefore believe that our findings have implications for developing countries today.

We find that the decline in the road death rate (fatalities/population) at high-income levels (Kopits and Cropper, 2005a,b) is dominated by a decline in the pedestrian death rate. Both pedestrian fatalities per VKT and per capita have steadily declined with growth in per capita income in the IRTAD countries, at least over the range of incomes one can expect in low- and middle-income developing countries over the next twenty years. Our more detailed models fail to explain exactly why this decline occurred; however, increased motorisation and a reduction in the proportion of young drivers in the population clearly played a role.

Our results suggest, however, that reductions in occupant fatalities will not automatically accompany increases in income. Neither occupant fatalities per VKT nor occupant fatalities per capita show a significant decline with income in the IRTAD countries. What does explain declines in occupant fatalities per VKT are reductions in alcohol abuse and improved medical services, and a reduction in the young driving age population. Reductions in alcohol abuse and improved medical services are clearly the result of explicit resource allocation decisions. The importance of demographic factors suggests that in countries where young persons (between 15 and 24 years of age) comprise an increasing share of the driving population, adopting policies to improve young driver education and reduce speeds will be crucial. The importance of young drivers in road fatalities diminished in industrialised countries as incomes increased, reflecting either increased risk aversion or more widespread driver education with increases in economic prosperity. However, the increased risk to both vehicle occupants and pedestrians posed by young road users more than offsets the beneficial effect of income growth, suggesting that interventions aimed at young drivers are still needed.

References

Cohen, A. and L. Einav (2003): 'The Effects of Mandatory Seat Belt Laws on Driving Behavior and Traffic Fatalities', *The Review of Economics and Statistics*, 85(4), 828–43.

Edlin, A. S. (1999): 'Per Mile Premiums for Auto Insurance', Working Paper 6934, National Bureau of Economic Research.

Garbacz, C. (1990): 'Estimating Seat Belt Effectiveness with Seat Belt Data from the Centers for Disease Control', *Economic Letters*, 34, 83–8.

Garbacz, C. (1992): 'More Evidence on the Effectiveness of Seat Belt Laws', *Applied Economics*, 24, 313–15.

Heston, A., R. Summers, and B. Aten (2002): Penn World Table Version 6.1, Center for International Comparisons at the University of Pennsylvania (CICUP), October.

International Road Federation (Various years): *I.R.F. World Road Statistics*, International Road Federation, Geneva, Switzerland.

International Road Traffic Accident Database (IRTAD): Federal Highway Research Institute (BASt)/OECD Road Transport Research Programme, Paris, France.

Keeler, T. E. (1994): 'Highway Safety, Economic Behavior and Driving Environment', *American Economic Review*, 84(3), 684–93.

Koepsell, T., L. McCloskey, M. Wolf, A. Vernez Moudon, D. Buchner, J. Kraus, and M. Patterson (2002): 'Crosswalk Markings and the Risk of Pedestrian–Motor Vehicle Collisions in Older Pedestrians', *Journal of the American Medical Association*, 288(17), 2136–43.

Kopits, E. (2004): Traffic Fatalities and Economic Growth. Ph.D. Dissertation, University of Maryland, College Park.

Kopits, E. and M. Cropper (2005a): 'Traffic Fatalities and Economic Growth', *Accident Analysis and Prevention*, 37(1), 169–78.

Kopits, E. and M. Cropper (2005b): 'Why Have Traffic Fatalities Declined in Industrialized Countries? Implications for Pedestrians and Vehicle Occupants', World Bank Policy Research Working Paper 3678.

Lave, C. (1985): 'Speeding, Coordination, and the 55 mph Speed Limit', *American Economic Review*, 75, 1159–64.

Lee, J. and F. Mannering (2002): 'Impact of roadside features on the frequency and severity of run-off roadway accidents: an empirical analysis', *Accident Analysis and Prevention*, 34(2), 149–61.

Liang, K.-Y. and S. Zeger (1986): 'Longitudinal Data Analysis Using Generalized Linear Models', *Biometrika*, 73(1), 13–22.

Lindgren, B. and C. Stuart (1980): 'The Effects of Traffic Safety Regulation in Sweden', *The Journal of Political Economy*, 88(2), 412–27.

Noland, R. (2003a): 'Medical treatment and traffic fatality reductions in industrialized countries', *Accident Analysis and Prevention*, 35, 877–83.

Noland, R. (2003b): 'Traffic fatalities and injuries: the effect of changes in infrastructure and other trends', *Accident Analysis and Prevention*, 35(4), 599–611.

Nunziata, L. (2002): xtdw.ado: a Stata command for Durbin Watson statistic in fixed effects panel data models. Available to download from: http://www.nuff.ox.ac.uk/users/nunziata/publications.htm.

Organization for Economic Cooperation and Development (OECD): Annual National Accounts for OECD Member Countries. Comparative tables available from OECD Statistical Database: http://www.oecd.org/document/28/0,2340,en_2825_495684_2750044_1_1_1_1,00.html.

Organization for Economic Cooperation and Development (OECD): Health Data 2003. http://www.oecd.org/document/30/0,2340,en_2649_34631_12968734_1_1_1_1,00.html.

Organization for Economic Cooperation and Development (OECD) (various years): OECD Energy Statistics.

Page, Y. (2001): 'A Statistical Model to Compare Road Mortality in OECD Countries', *Accident Analysis and Prevention*, 33, 371–85.

Peden, M., R. Scurfield, D. Sleet, D. Mohan, A. Hyder, E. Jarawan, and C. Mathers (eds.) (2004): *World Report on Road Traffic Injury Prevention*, Geneva, Switzerland, World Health Organization.

Peltzman, S. (1975): 'The Effects of Automobile Safety Regulation', *Journal of Political Economy*, 83(4), 677–726.

Ruhm, C. J. (1996): 'Alcohol Policies and Highway Vehicle Fatalities', *Journal of Health Economics*, 15, 435–54.

United Nations: World Population Prospects. The 2002 Revision Population Database, http://esa.un.org/unpp/.

US Census Bureau: International Data Base (IDB), http://www.census.gov/ipc/www/idbsprd.html.

Wooldridge, J. (2003): 'Cluster-Sample Methods in Applied Econometrics', Working Paper, Michigan State University.

World Bank. World Development Indicators 2004, http://www.worldbank.org/data/wdi2004/index.htm.

Zlatoper, T. J. (1984): 'Regression-Analysis of Time-Series Data on Motor Vehicle Deaths in the United States', *Journal of Transport Economics and Policy*, 18(3), 263–74.

Appendix

Data sources

The primary sources of transport and road safety related variables are the OECD International Road Traffic Accident Database (IRTAD) and the International Road Federation World Road Statistics yearbooks (IRF, various years). These series were checked against and supplemented by data from national statistical agencies and other sources. Health-related data come primarily from OECD Health Data 2003 and the World Health Organisation (WHO). Total population and population cohorts are taken from the US Census International Database, the United Nations Population Database, IRTAD, and national statistical agencies. Figures on urban population come from the World Bank World Development Indicators (WDI). See Kopits (2004) for more detail on all data sources.

In an effort to increase the sample size, the official statistics on total VKT were extended using predicted values from regressions of VKT on total motor vehicle fuel consumption (petrol and diesel).[28] The predicted values increased the sample size by 126 observations (from 704 to 830).[29]

Income data come from the Penn World Tables 6.1 (Heston *et al.*, 2002) for 1963–2000 and were extended to 2002 using per capita GDP growth rates (OECD National Accounts).[30] Real per capita GDP is measured in 1996 international dollars. This series comes from the Penn World Tables RGDPCH variable (real per capita GDP, chain method) and accounts for differences in purchasing power across countries and allows for comparisons over time.

[28] Fuel consumption data come from the IRF World Road Statistics yearbooks, OECD Energy Statistics (various editions), and national sources. See Appendix B of Kopits (2004) for a complete discussion of this extension and for the estimation results for equations in Table 2 using the base VKT data.

[29] Extrapolating the VKT series adds additional measurement error to the dependent variable. However, since all computed standard errors are already heteroskedasticity-corrected, no additional variance correction is necessary to account for the use of predicted data.

[30] Kopits (2004) describes the 2000–2002 extension in detail.