THE ECONOMICS OF ROAD SAFETY: AN INTERNATIONAL PERSPECTIVE

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AN INTERNATIONAL PERSPECTIVE

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16. Abstract

This report examines some recent explanations for the rising road fatality rates in developing countries. A key insight of these recent studies is that road fatalities per capita follow a Kuznets curve (an inverted-U shaped pattern with rising income per capita). The rising fatalities per capita in developing countries can be expected to reach a peak and then fall. However, if present trends continue, the already high fatality rates in developing countries could rise for several years before peaking.

The report adopts the road fatalities Kuznets curve as a framework, and decomposes the per capita fatality rate into two terms that are multiplied together: vehicles per capita and fatalities per vehicle. Reducing either term, holding the other fixed, would lower fatalities per capita. Reducing motorization (vehicles per capita) is unlikely to be used as a policy to reduce fatalities because it is inextricably linked to economic growth. Consequently, the focus should be on reducing fatalities per vehicle.

The report concludes with an economic analysis of the costs and benefits of using new vehicle technologies to reduce fatalities per vehicle in developing countries. To illustrate potential benefits, the report estimates the number of lives that could be saved in China and India as functions of the rate of improvement in fatalities per vehicle.

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Contents

Introduction

This report examines the relationship between economic development and road fatalities based on recent studies indicating that the relationship tends to follow a Kuznets curve. A Kuznets curve is a graph with measures of increased economic development on the horizontal axis (usually GDP per capita) and measures of income inequality on the vertical axis. Kuznets (1955) hypothesized such a curve to have an inverted-U shape.

Kuznets argued that the inverted-U shape is the result of the normal development of an economy from primarily agricultural to primarily industrial. When an economy is primarily agricultural it has a low level of income inequality. During the early stages of industrialization income inequality increases over time, and then at some critical point it starts to decrease.

Since Kuznets's seminal analysis of the development data, many researchers have found similar relationships in other domains. One of the most productive yet controversial efforts has been in the field of environmental economics. The environmental Kuznets curve plots measures of environmentally destructive emissions on the vertical axis and measures of economic development on the horizontal axis. Brock and Taylor (2005) provided a thorough and largely sympathetic survey of the environmental Kuznets curve literature, putting it solidly within the economic theory of growth. For an assessment of the literature research from a more skeptical viewpoint see Stern (2004).

Applying the Kuznets curve to road fatalities is an outgrowth of the environmental Kuznets curve literature. Kopits and Cropper (2005) appear to be the first researchers to explicitly refer to the relationship between traffic fatality risk and per capita income as a Kuznets curve. They apply the Kuznets curve to a large international data set and develop projections of future traffic fatalities with it. They predict that the global road death toll will grow by 66% over the next twenty years, but their analysis suggests that this overall growth comes from a combination of influences: A decline in fatalities in high-income countries (that are on the falling side of the Kuznets curve) is not enough to offset an increase in fatalities in developing countries (that are on the rising

side of the Kuznets curve). Their analysis concludes that China (with a predicted 92% increase in fatalities over the next 20 years) and India (a 147% increase in fatalities) are the biggest contributors to the global growth in road fatalities.

A key element of Kopits and Cropper (2005) is the decomposition of fatalities per capita into the product of two factors: vehicles per capita and fatalities per vehicle. As per capita income grows, vehicles per capita also grows, but fatalities per vehicle decline. It is the combination of these two offsetting effects that is responsible for the inverted-U shape of fatalities per capita when they are plotted against per capita income.

Koornstra (2003), in an unpublished study for the World Business Council for Sustainable Development, used the Kuznets curve framework to develop forecasts of road fatalities for China, India, and a number of other countries and regions through 2050. Koornstra's findings were published in WBCSD (2004), and detailed numerical forecasts of road fatalities and the variables that influence them were made available by WBCSD.

In this report, a simulation model based on the Kuznets curve for road fatalities was used to predict the effects of lowering per vehicle fatality rates on aggregate fatalities. The numerical implementation of the model used Koornstra's forecasts of future road fatalities in China and India, along with the assumptions he used for the growth of GDP, population, and vehicles on the road.

The report is organized as follows. The next section develops the simplified Kuznets curve framework and derives methods to compute the peak of the Kuznets curve and other outcomes of interest. The subsequent sections apply this framework to China and India.

The road fatalities Kuznets curve

This section describes the simplified Kuznets curve we use in our analysis of road fatalities. Following Koornstra (2003) and Kopits and Copper (2005), fatalities per capita was defined as the product of vehicles per capita and fatalities per vehicle. That is,

$$\frac{F}{P} = \left(\frac{V}{P}\right)\left(\frac{F}{V}\right) \text{ with F = fatalities, P = population, and V = vehicles.} \quad (1)$$

We specify a reduced-form demand function for vehicles per capita as a polynomial in income per capita:

$$v = \frac{V}{P} = a + b\left(\frac{Y}{P}\right) + c\left(\frac{Y}{P}\right)^2 + d\left(\frac{Y}{P}\right)^3 + e\left(\frac{Y}{P}\right)^4 \quad (2)$$

Gross domestic product (GDP = Y) is the income measure used and Y/P is GDP per capita. The elasticity of vehicle demand with respect to income implied by this reduced-form demand function is not constant but varies with Y/P. The parameters of this function were estimated with Koornstra's projections of vehicles per capita and GDP per capita from the WBCSD report.[1]

We define fatalities per vehicle as function of income per capita and motorization. Fatalities are undesirable, so the fatalities per vehicle function is interpreted as a negative demand function (a demand to reduce fatalities per vehicle). It is reasonable to assume that as income per capita grows, the demand for fewer fatalities per vehicle rises, meaning that safety (in the form of fewer fatalities per vehicle) is what economists call a normal good.

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[1] Fitting Koornstra's values to the reduced-form demand function yields the following estimated functions that were used in this report. Lower order polynomials were rejected because the resulting predictions of fatalities per vehicle significantly diverged from his forecasts.

China:

$$\frac{V}{P} = -3.5 + \times 10^{-2} + 9.5 + \times 10^{-5}\left(\frac{Y}{P}\right) - 1.9 \times 10^{-8}\left(\frac{Y}{P}\right)^2 + 2.7 \times 10^{-12}\left(\frac{Y}{P}\right)^3 - 1.3 \times 10^{-16}\left(\frac{Y}{P}\right)^4$$

India:

$$\frac{V}{P} = -9.3 + \times 10^{-3} + 6.7 + \times 10^{-5}\left(\frac{Y}{P}\right) + 2.8 \times 10^{-8}\left(\frac{Y}{P}\right)^2 - 2.7 \times 10^{-11}\left(\frac{Y}{P}\right)^3 + 4.3 \times 10^{-15}\left(\frac{Y}{P}\right)^4$$

Koornstra's forecasts for WBCSD used two alternative measures of motorization in predicting fatalities per vehicle: all motorized vehicles per capita and four-wheeled motorized vehicles per capita. Since most of the motorized vehicles in China (62%) and India (71%) are two-wheeled, this study used all motorized vehicles per capita. The fatalities per vehicle negative demand function is:

$$\frac{F}{V} = \alpha \left(\frac{Y}{P}\right)^{-\lambda} \exp\left(\rho\left(\frac{V}{P}\right)\right)$$ (3)

The parameters are a scaling factor (α), an income elasticity of demand for reducing fatalities per vehicle (λ), and a motorization factor (ρ). The parameter λ enters the fatalities per vehicle with a negative sign, since the demand for fatalities is the inverse of the demand for lower fatalities.[2] Note that this specification links the fatalities per vehicle function to the vehicles per capita function (in the exponential).

Multiplying vehicles per capita (Equation 2) times fatalities per vehicle (Equation 3) gives the function used for the Kuznets curve:

$$\frac{F}{P} = \left(a\left(\frac{Y}{P}\right)^{-\lambda} + b\left(\frac{Y}{P}\right)^{1-\lambda} + c\left(\frac{Y}{P}\right)^{2-\lambda} + d\left(\frac{Y}{P}\right)^{3-\lambda} + e\left(\frac{Y}{P}\right)^{4-\lambda}\right)\alpha\exp\left(\rho\left(\frac{V}{P}\right)\right)$$ (4)

Here, as in Equation 3, the V/P term in the exponential represents Equation 2.

In theory, one could find the peak of the Kuznets curve (if there were a peak) by setting the derivative of Equation 4 with respect to Y/P equal to zero and solving for the real non-negative roots of this equation. The dependence of the fatalities per vehicle function (Equation 2) on the vehicles per capita function (Equation 3) means that the derivative of Equation 4 involves powers of Y/P as high as 7-λ. Finding the peak analytically is impractical. Instead, we find the peak visually.

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[2] Fitting these values to the reduced-form negative demand functions yield the following estimated functions:

China: $\dfrac{F}{V} = 0.044\left(\dfrac{Y}{P}\right)^{-0.325} e^{-4.481*(V/P)}$ India: $\dfrac{F}{V} = 0.027\left(\dfrac{Y}{P}\right)^{-0.228} e^{-5.866*(V/P)}$

Kuznets curve: Applications

This section applies the road fatalities Kuznets curve to describe and analyze the countries that Kopits and Cropper (2005) identify as the biggest contributors to global growth in road fatalities, China and India. We use Koornstra's data for calendar year 2000 as published in WBCSD (2004) as the base, and apply the simple Kuznets curve we derived in the last section to roughly match the more pessimistic peak of the curve found by Kopits and Cropper (2005).

For each country we give the values of the base variables and the values of the parameters for the system in Equations 1 through 4. We use these variables and parameter values to describe the relevant outcomes (fatalities per capita and its peak) in the base case.

Then for each country we simulate the impact on fatalities per capita of an identical, modest, phased reduction in the rate of fatalities per vehicle relative to the base case scenario. The percentage reduction in fatalities per vehicle begins at 0% in 2010 and grows linearly to 20% in 2050. China experienced 87 fatalities per 25,000 vehicles in 2000, and in the base case would experience 7.5 fatalities per vehicle in 2050. Our simulation cuts the 2050 rate to 6.0 fatalities per vehicle. India experienced 123 fatalities per 25,000 vehicles in 2000, and in the base case would experience 23.2 fatalities per vehicle in 2050. Our simulation cuts the 2050 rate to 18.6 fatalities per vehicle. We then examine how the reduction in fatalities changes the Kuznets curve. We end this section by comparing the effects of the identical fatality reduction for the Kuznets curves of China and India.

China

     Background. This section presents the analysis of the road fatalities Kuznets curve for China. The base values of the variables we are examining are given in Table 1. These are for calendar year 2000 and 2050 and are based on Koornstra (2003). Fatalities include occupants of vehicles and pedestrians. Vehicles include four-wheel and two-wheel motor vehicles, both passenger and commercial.

Table 1
Base values for China, 2000 and 2050.

Calendar Year	2000	2050
Population (millions)	1,272	1,472
GDP per Capita	$980	$8,043
Vehicles (millions)	54	491
Fatalities (thousands)	187	146
Fatalities per 100,000 Persons	14.7	9.9
Fatalities per 25,000 Vehicles	87.3	7.5
Vehicles per 250 Persons	10.5	83.1

     Gross domestic product (GDP) measures the value of all the goods and services produced in China. GDP represents the resources China has available to spend on domestic and imported goods and services, including road safety. On a per capita basis, China currently has very low values of GDP and vehicles. It is important to bear in mind that these per capita averages do not reflect the extreme diversity within China. Private vehicle ownership is concentrated in higher income groups, but fatalities are concentrated among lower income pedestrians.

     In both the base case and the simulation of a 20% reduction in fatalities per vehicle by 2050, we used the WBCSD's assumption that GDP per capita grows at 4.3% per year. In the recent past, China's per capita GDP has grown more than twice this rate, but the high (double-digit) rates of the recent past are very unlikely to continue for the next 40 or more years.

The reduced-form demand for vehicles per capita as a function of income per capita allows the income per capita (GDP per capita) elasticity of demand to vary with income. China's income per capita elasticity of demand for vehicles per capita is 1.5 in 2000, falls below 1.0 by 2015, and remains below 1.0 through 2050. This means that in 2000 a 1% increase in per capita income would induce a 1.5 % increase in vehicles per capita, and from 2014 through 2050 a 1% increase in income per capita would induce less than a 1% increase in vehicles per capita. A diminishing effect of income on vehicle demand is observed in many countries and can be interpreted as the effect of an expanding choice-set (imported goods, education, bigger homes, etc.) as income grows. The model is calibrated to Koornstra's base case and is roughly consistent with Kopits and Cropper (2005).

Base case. China's base case is shown in Figure 1. Vehicles per 250 persons and fatalities per 25,000 vehicles are indicated on the left vertical axis, and fatalities per 100,000 persons on the right vertical axis.
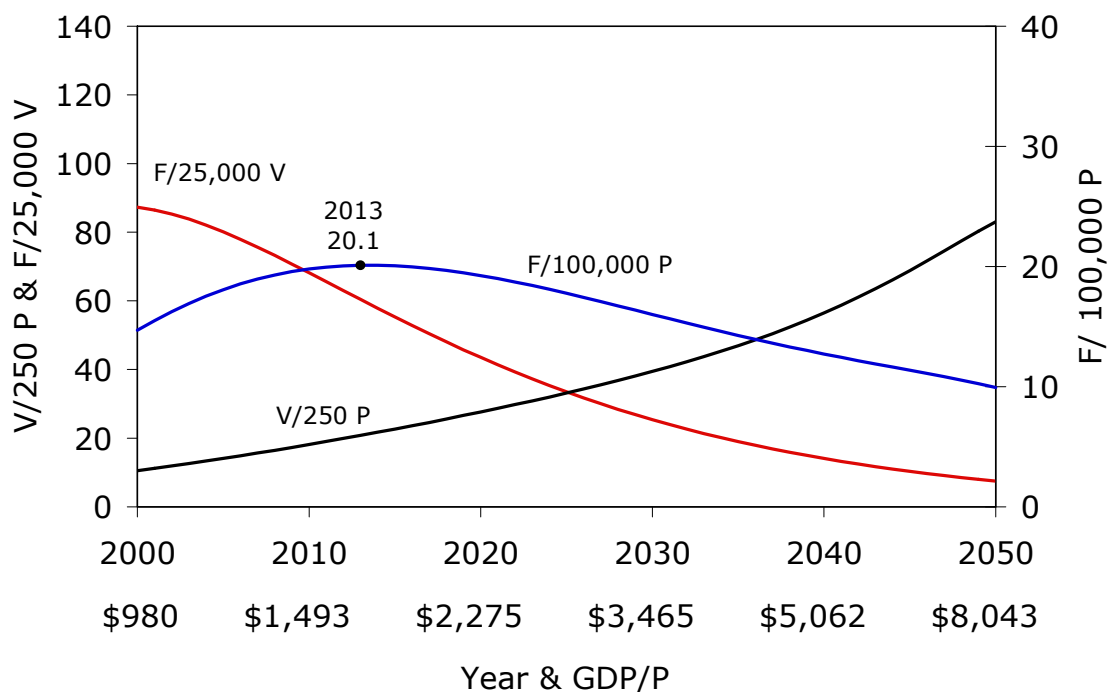

Figure 1. China's base road fatalities Kuznets curve.

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Vehicles per capita are expected to exhibit strong growth in China. China had 54 million vehicles in 2000, and the number is expected to reach 491 million by 2050. Fatalities per vehicle are expected to fall in China by 4.8% per year, from 87.3 fatalities per 25,000 vehicles in 2000 to 7.5 in 2050.

China's base road fatalities Kuznets curve (14.7 fatalities per 100,000 persons in 2000) is expected to peak in 2013 at 20.1 fatalities per 100,000 persons. The curve gradually falls after 2013, reaching 9.9 fatalities per 100,000 persons in 2050. Road fatalities in China numbered 187,000 in 2000 and are expected to peak in 2016, three years after the Kuznets curve peaks, at 282,000 fatalities. China's annual road fatalities are not expected to come back down to the 2000 level until 2041. (The Kuznets curve comes back down to the 2000 level in 2034.)

An indication of the significance of the rise in the Kuznets curve through 2050 can be given by considering that 1.6 million additional road fatalities are predicted in China between 2000 and 2050 over what would occur if fatalities per capita were to remain at 2000's already high level. Thus, just the incremental fatalities in China over this 50-year period due to the increasing rate of fatalities per capita are half of the 3.3 million cumulative road fatalities in the U.S. since 1900 (Advocates for Highway and Auto Safety, 2004). The fatalities expected in China are staggering. The base case predicts 12 million road fatalities in China between 2000 and 2050.

Simulation of 20% lower fatalities per vehicle by 2050. This case examines the effect on the Kuznets curve of a reduction in fatalities per vehicle for China. The growth in vehicles per capita and in GDP per capita is assumed to be unchanged from the base case, and the lower rate of fatalities per vehicle is assumed to begin in 2010. We assumed a relatively modest reduction in fatalities per vehicle—starting in 2010 at 0% and growing linearly to a 20% lower rate of fatalities per vehicle in 2050.

Figure 2 summarizes the simulation for China. The new fatalities-per-vehicle curve (dashed line) begins to diverge from the base curve (solid line) in 2011. In the simulation, fatalities per vehicle are reduced in 2050 from 7.5 fatalities per 25,000 vehicles to 6.0 fatalities per 25,000 vehicles.
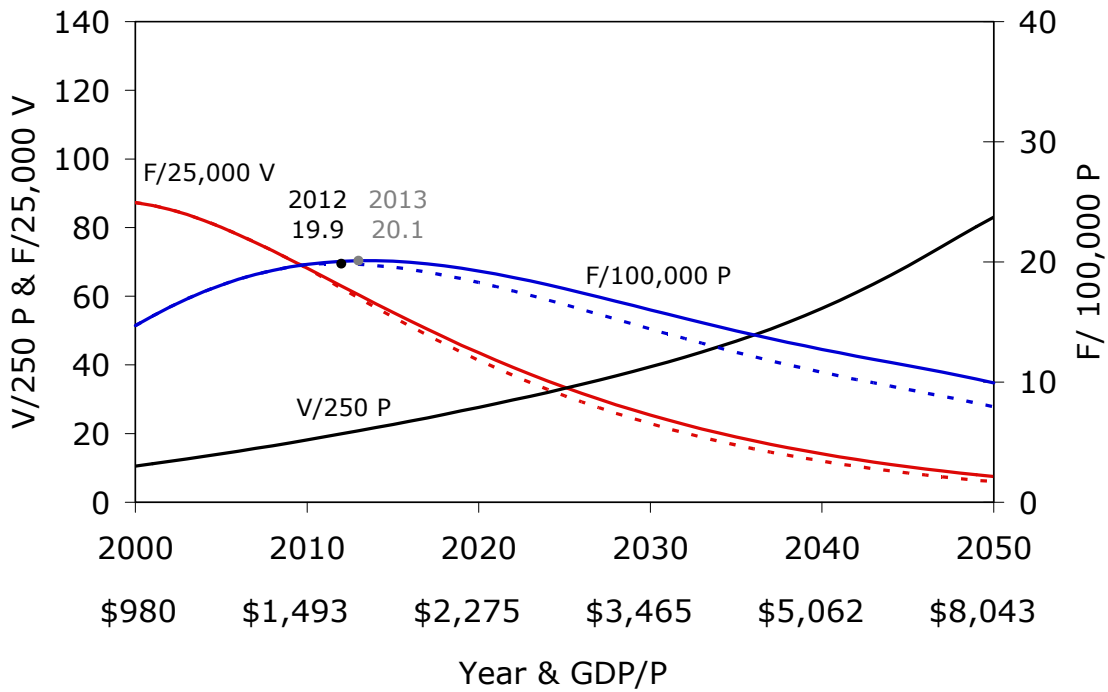
Figure 2. Simulation of 20% lower fatalities per vehicle by 2050 for China.

Technologies are assumed to be applied starting in 2010 that begin a gradual reduction in fatalities per vehicle that achieve a 20% lower rate of fatalities per vehicle in 2050. The peak of the Kuznets curve is pulled ahead by one year (from 2013 to 2012) and lowered from 20.1 to 19.9 fatalities per 100,000 persons. Figure 3 shows the cumulative lives saved in China in this simulation. The simulation results in 831,000 fewer fatalities between 2010 and 2050.
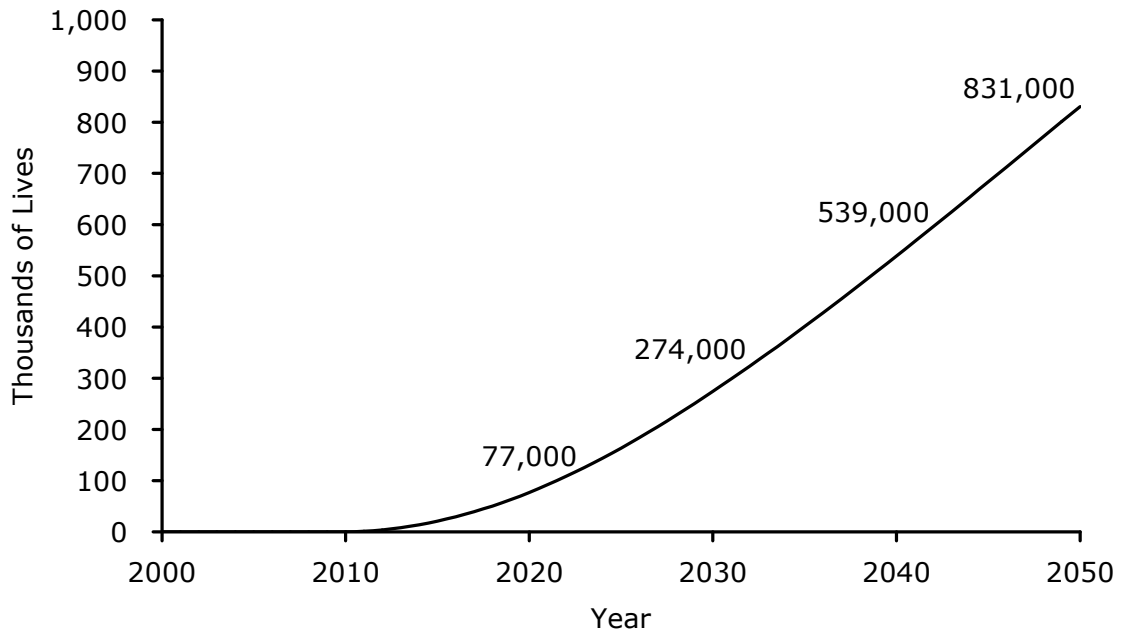
Figure 3. Cumulative lives saved in China in this simulation.

India

     Background.   This section presents the analysis of the road fatalities Kuznets curve for India. The base values of the variables we are examining are given in Table 2. These are for calendar year 2000 and 2050 and are based on Koornstra (2003). Fatalities include occupants of vehicles and pedestrians. Vehicles include four-wheel and two-wheel motor vehicles, both passenger and commercial.

Table 2
Base values for India, 2000 and 2050.

Calendar Year	2000	2050
Population (millions)	1,041	1,572
GDP per capita	$460	$2,569
Vehicles (millions)	47	292
Fatalities (thousands)	225	272
Fatalities per 100,000 persons	21.6	17.3
Fatalities per 25,000 vehicles	122.7	23.2
Vehicles per 250 persons	11.0	46.7

     India's income per capita is less than half of China's throughout the 2000 to 2050 window. India's vehicles per capita are 0.5 of a vehicle per person higher than China's in 2000, but by 2050 are only about 56% of China's. It is important to bear in mind that, as was the case for China, these per capita averages do not reflect the extreme diversity within India. Private vehicle ownership is concentrated in higher income groups, but fatalities are concentrated among lower income pedestrians.

     Based on the WBCSD's assumptions, India's GDP per capita grows at 3.5% per year in both the base case and in the simulation of a 20% reduction in fatalities per vehicle in 2050. In the recent past, India has had faster per capita GDP growth than this, but growth rates near the 8% average of India's recent past are very unlikely to continue for 40 years.

     The reduced-form demand for vehicles per capita as a function of income per capita allows the income per capita (GDP per capita) elasticity of demand to vary with

income. Recall that China's income per capita elasticity of demand for vehicles per capita falls below 1.0 in 2015 and stays there through 2050. India's income per capita elasticity of demand for vehicles per capita is below 1.0 from 2000 through 2050. India's income elasticity of vehicle demand is below China's for most of the 2000-2050 period (China's ranges from 1.5 to 0.8 and India's ranges from 0.75 to 0.99). This difference is responsible for the much slower growth of vehicles per capita in India than in China. The India model is calibrated to Koornstra's base case and is roughly consistent with Kopits and Cropper (2005).

Base case. India's base case is shown in Figure 4. Vehicles per 250 persons and fatalities per 25,000 vehicles are indicated on the left vertical axis, and fatalities per 100,000 persons on the right vertical axis.
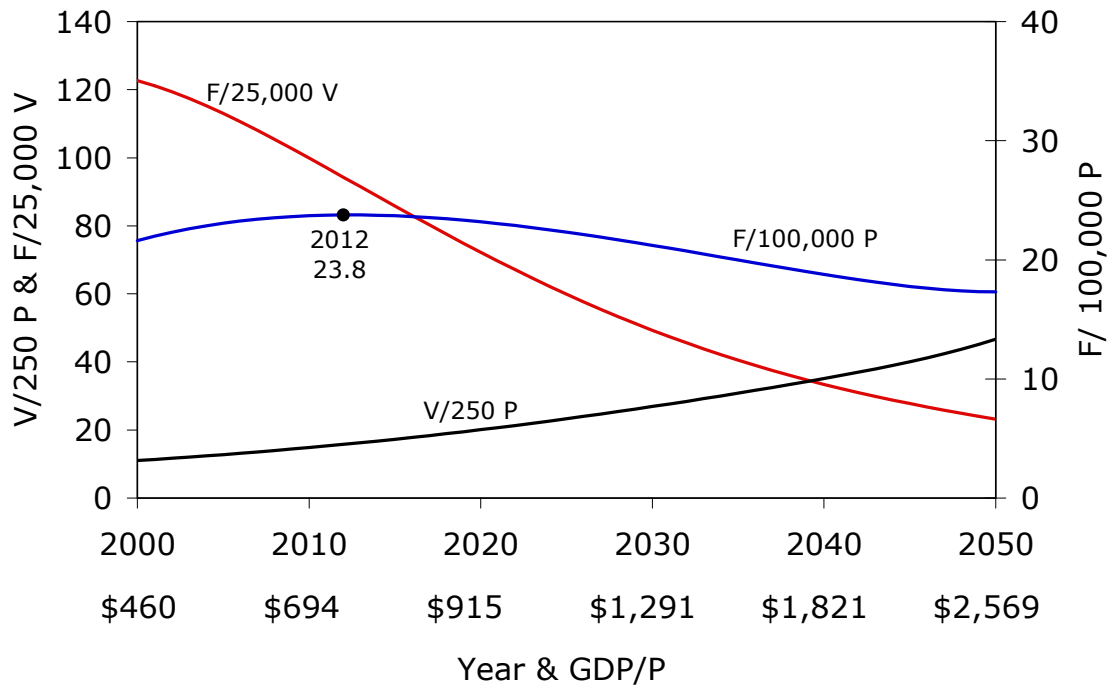

Figure 4. India's base road fatalities Kuznets curve.

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Vehicles per capita grow much more slowly for India than for China. India had 47 million vehicles (87% of China's) in 2000, and is expected to have 292 million (59% of China's) by 2050. Fatalities per vehicles in India are expected to fall by 3.3% per year, from 122.7 fatalities per 25,000 vehicles in 2000 to 23.2 in 2050.

India's base road fatalities Kuznets curve (21.6 fatalities per 100,000 persons in 2000) peaks in 2012 at 23.8 fatalities per 100,000 persons. Fatalities per 100,000 persons gradually fall after 2012 to 17.3 fatalities per 100,000 persons in 2050. There were 225,000 road fatalities in India in 2000. The toll is expected to peak at 301,000 fatalities 2024, and thereafter gradually fall to 272,000 in 2050. If fatalities per capita in India were to remain at or below the 2000 level, then 483,000 fewer road fatalities would occur between 2000 and 2050. This portion of the Kuznets curve with fatalities per capita higher than the 2000 rate is responsible for 3.34 more fatalities per 100,000 persons in China than in India. The base case predicts about 14 million road fatalities in India between 2000 and 2050.

Simulation of 20% lower fatalities per vehicle by 2050. This case examines the impact on the Kuznets curve of 20% lower fatalities per vehicle in 2050 for India. The growth in vehicles per capita and growth in GDP per capita are assumed to be unchanged from the base case. We simulated a reduction in fatalities per vehicle starting at 0% in 2010 and growing linearly to 20% in 2050.

Figure 5 summarizes the improved situation for India. The new fatalities-per-vehicle curve (dashed line) begins to diverge from the base curve (solid line) in 2011.
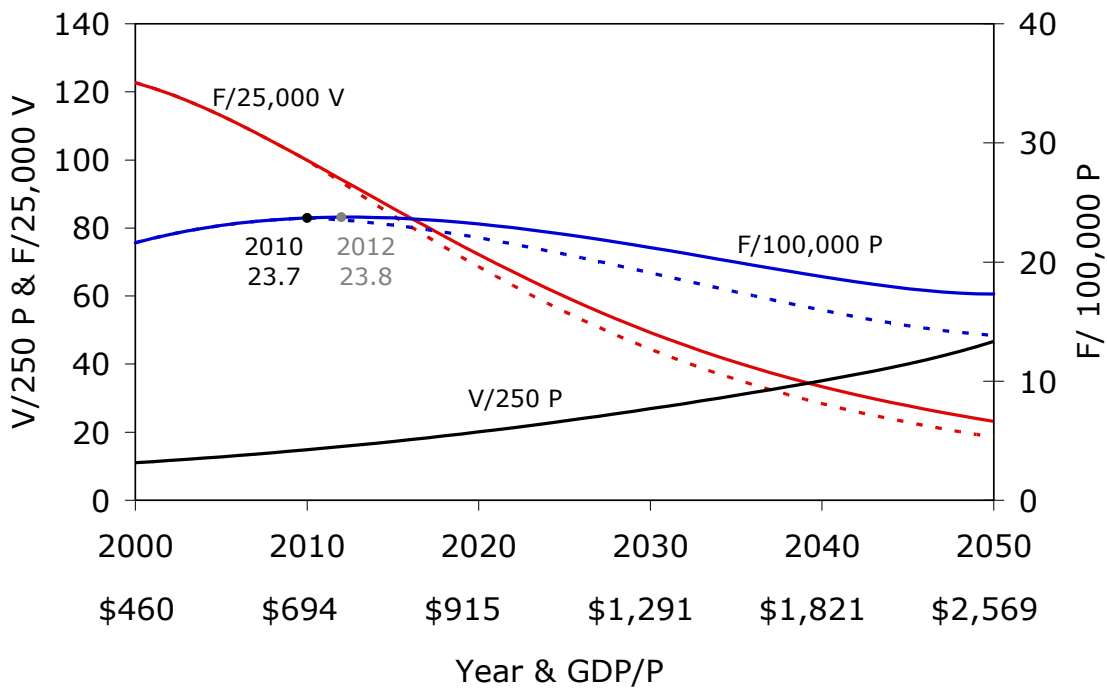
Figure 5. Simulation of 20% lower fatalities per vehicle for India.

Technologies are assumed to be applied starting in 2010 that begin a gradual reduction in fatalities per vehicle, and that achieve a 20% lower rate of fatalities per vehicle in 2050. The peak of the Kuznets curve is pulled ahead by 2 years (from 2012 to 2010). The simulation results in 1,165,000 fewer fatalities between 2010 and 2050. Figure 6 shows the cumulative lives saved in India in this simulation.
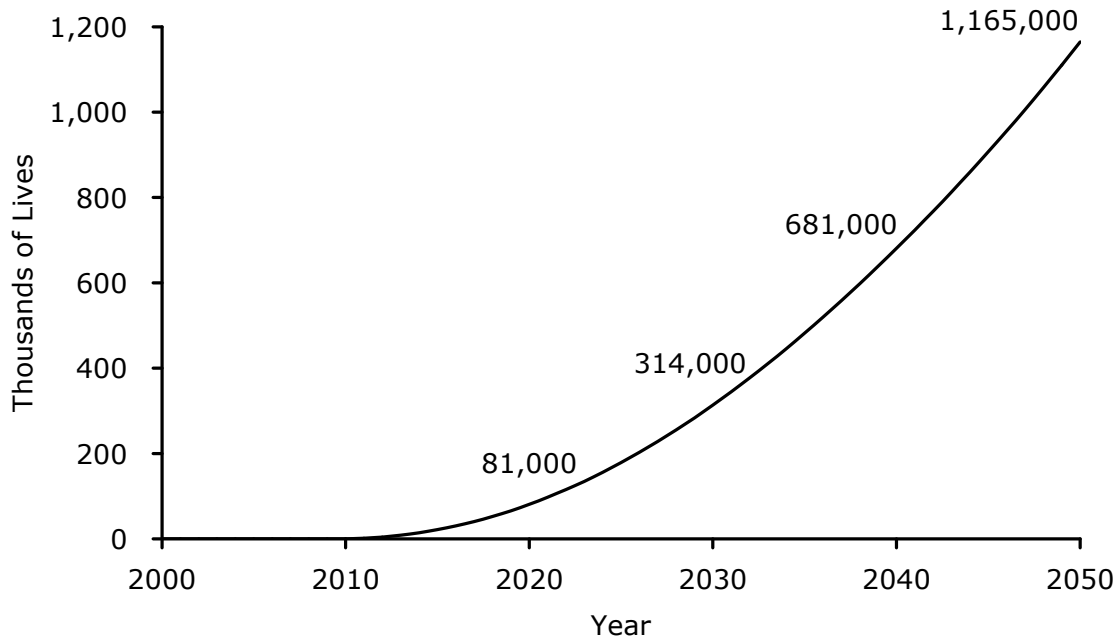
Figure 6. Cumulative lives saved in India in this simulation.

Comparing China and India

We simulated identical percentage improvements in fatalities per vehicle in China and India. The improvements (reductions in fatalities per vehicle) started at 0% in 2010 and grew linearly to 20% in 2050. The simulation avoids 831,000 fatalities in China and 1,167,000 fatalities in India.

To identify the sources of this difference between China and India we look at the definition of the Kuznets curve, $\frac{F}{P} = \left(\frac{F}{V}\right)\left(\frac{V}{P}\right)$, rearrange terms, and end up with an expression that splits the percentage growth in total fatalities into three additive terms.

$$\frac{dF}{F} = \frac{d\left(\frac{F}{V}\right)}{\frac{F}{V}} + \frac{d\left(\frac{V}{P}\right)}{\frac{V}{P}} + \frac{dP}{P}$$ (5)

Equation 5 states that the percentage change in fatalities is the sum of the percentage changes in fatalities per vehicle, vehicles per person, and population. Table 3 shows the compound annual growth rates (2000 to 2050) of the elements of Equation 5, computed in the base case.

Table 3
Compound annual growth rates from 2000 to 2050 of the elements of Equation 5.

	F/V	V/P	P	F
China	-4.8%	4.2%	0.3%	-0.5%
India	-3.3%	2.9%	0.8%	0.4%

Fatalities per year fall in China between 2020 and 2050, but they grow in India. What explains this difference? First, the foundation for improvement must come from lowering fatalities per vehicle, and China is expected to lower its fatalities per vehicle much faster than India (4.8% per year versus 3.3% per year). Next, the improvements in fatalities per vehicle are offset by the growth in vehicles per capita. Adding the growth rates of V/P and F/V gives the net reduction in F/P (the change in fatalities before differences in the level of the population are taken into account). China has faster growth in V/P than India, but because China is lowering its F/V so much faster than India, the growth rate of F/P is a negative 0.8% per year for China versus a negative 0.4% per year for India. Finally, India's population is growing much faster than China's (0.8% vs. 0.3%, respectively).

Summary

This report described the link between economic development and road fatalities, as summarized by the Kuznets curve, and explored the implications of this link for China and India. The Kuznets curve provides a framework in which to analyze and explain the rise in fatalities in the early stages of economic development, and holds out the prospect that road fatalities per population are likely to decline eventually.

To help develop policies and technologies that could shorten the time it would take to make that prospect a reality, the Kuznets curve can be divided into two components. Vehicles per capita, one of the components, is an indicator of development. Slowing the rate of growth in vehicles per capita would save lives, but would also probably impede economic development. The component of the Kuznets curve that could be the basis for strategies to reduce fatalities without impeding economic growth is fatalities per vehicle.

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