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The motorcycle Kuznets curve

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Abstract: The evolution of motorcycle ownership is a crucial issue for road safety, as motorcyclists are highly vulnerable road users. Analyzing a panel of 153 countries for the period 1963-2010, we document a motorcycle Kuznets curve which sees motorcycle dependence increase and then decrease as economies develop. Upswings in motorcycle ownership are particularly pronounced in densely populated countries. We also present macro-level evidence on the additional road fatalities associated with motorcycles. Our results indicate that many low-income countries face the prospect of an increasing number of motorcycle-related deaths over coming years unless adequate safety initiatives are implemented.

Keywords: motorcycles, economic development, Kuznets curve, road safety, road fatalities

JEL classification: R41, O18, Q43

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The motorcycle Kuznets curve

1. Introduction

How does dependence on motorcycles evolve during the process of economic development? Using data for a large panel of countries for the period 1963-2010 we find that motorcycle ownership exhibits a Kuznets-style inverse-U pattern as average incomes increase, with the per capita motorcycle fleet on average increasing until mid-range income levels and then subsequently declining.[1] In contrast, the fleets of cars and trucks tend to expand monotonically. A country's population density has a large effect on the motorcycle Kuznets curve pattern: more crowded countries tend to see much larger upswings in motorcycle dependence through the middle stages of economic development. We also present evidence on the extent to which dependence on motorcycles is associated with higher national road death rates.

Detailed knowledge on how motor vehicle fleets evolve as economies grow is useful for planning infrastructure, policies, and programs for the transport sector. The evolution of motorcycle ownership is a particularly crucial issue for road safety, which is a leading public health issue. Road crashes were the cause of 1.3 million deaths in 2011, making them the ninth-leading cause of death globally and the number one cause of death for people between 15 and 29 years of age (World Health Organization [WHO] 2013a). Up to 50 million people worldwide also suffer non-fatal injuries each year, which carries large human and financial costs. The global

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[1] Kuznets (1955) posited that inequality proceeds along an inverse-U as per capita incomes increase. His name has been used in describing similar inverse-U patterns for outcomes such as pollution.

road death toll is expected to increase to around 2.4 million per year by 2030 in a business-as-usual scenario, becoming the fifth-leading cause of death (WHO 2013b).

Motorcyclists are highly vulnerable road users: in the United States, road fatality risks per vehicle mile travelled are estimated to be 30 times higher for travel by motorcycle than for travel by passenger car (National Highway Traffic Safety Administration [NHTSA], 2012). Similar ratios have been reported by, for example, Australia (Department of Infrastructure, Transport, Regional Development and Local Government, 2008) and the United Kingdom (Department for Transport, 2012). Globally, motorcyclists account for around 23% of all road deaths (WHO, 2013b), although this share exceeds 50% in some developing countries (Lin and Kraus, 2009). The vulnerability of motorcyclists emanates from their lack of direct protection, their young average age, the often minimal training and testing requirements for motorcycle use, and relaxed motorcycle inspection procedures (Asian Development Bank, 2003). The “Global Plan for the Decade of Action for Road Safety 2011-2020”, adopted by the United Nations General Assembly in March 2010, highlights the importance of protecting vulnerable road users such as motorcyclists (WHO, 2010).

This is the first study on the motorcycle Kuznets curve. Prior studies (e.g. Nagai et al., 2003; Pongthanaisawan and Sorapipatana, 2010) have presented cross-sectional evidence that motorcycle ownership increases in the initial stages of development, but have not fully documented the motorcycle Kuznets curve. Kopits and Cropper (2005) used data for 88 countries to find that the total number of motor vehicles increases with per capita income, but did not explicitly consider motorcycles. Others (e.g. Dargay et al., 2007) have focused solely on vehicles with four or more wheels. This paper also adds to the literature examining the effects of motorcycle use on road fatalities. Most existing evidence relates to developed countries, although Grimm and Treibich (2013) study India. Consideration of middle-income countries is crucial given that it is in these countries that both motorcycle dependence and road death rates are highest.

Motorcycles, defined here as two- or three-wheeled road motor vehicles including mopeds and motorized scooters, are a primary form of transport in many developing countries.[2] Motorcycles make up more than three-quarters of the total road motor vehicle fleet in countries such as Burkina Faso, the Central African Republic, India, Indonesia, Laos, the Maldives, Myanmar, and Vietnam (International Road Federation [IRF], 2012). Historically, motorcycles have also played an important role in the motor vehicle fleets of some now-developed countries. In 1963, motorcycles accounted for 70% of all road motor vehicles in Sweden and Poland, 64% in Portugal, 60% in Japan, 58% in the Netherlands, 55% in Italy, 44% in Austria, and 41% in France. These rates had all fallen to below 14% by 2010.

[2] An alternative term is “powered two-wheelers” (Haworth, 2012), although we avoid this because our data cover three-wheeled vehicles also. The data used in this paper exclude off-road vehicles, but do not allow a disaggregation of the type of motorcycles being used in each country or on factors such as whether they are used for transport or recreation, or whether they provide private or public (e.g. taxi) transport. We note that some countries have taxi networks that are reliant on auto rickshaws, which fall under our definition of “motorcycles”. Future research may wish to use country case studies to explore how the composition of the motorcycle fleet changes as economies develop.

Table 1 presents international data on the fleets of motorcycles, cars, buses, and trucks (a category which includes lorries, vans, and pick-ups) for various country groups and example countries. Motorcycle ownership is higher in middle-income countries (63 motorcycles per thousand population in 2007) than either low-income (4) or high-income countries (53). This is an initial indication of the existence of a motorcycle Kuznets curve. In contrast, the fleets of cars and trucks are largest in high-income countries. The coefficient of variation (standard deviation divided by mean) is larger for motorcycles than other vehicles in middle- and high-income countries, suggesting that countries take different paths in terms of motorcycle adoption. Our results will show that population density is a key underlying reason for why heterogeneous motorcycle adoption paths have been observed as countries develop.

-Table 1-

The empirical results that we present in this paper indicate that low-income countries are set to see large rises in motorcyclist deaths as per capita incomes increase. Our estimates show that the motorcycle share of the vehicle fleet typically peaks at a per capita gross domestic product (GDP) of $3,000-$4,000 and that motorcycles per thousand population on average increase until a mid-range per capita GDP of $7,000-$9,000. To explore the implications of vehicle mix for road fatalities, we use our large international sample to estimate the marginal effects of motorcycles and other motor vehicles on national road death tolls. Our findings add to the evidence that motorcycle travel is particularly risky.

The initial increase and subsequent decrease in motorcycle ownership as per capita incomes increase is likely a function of three considerations. First, affordability: motorcycles are cheaper than cars, and for people exiting poverty are often the only option when it comes to private motor vehicles. As incomes reach higher levels, four-wheeled vehicles become more affordable, and motorcycles are likely to lose market share (Jou et al., 2012). The second and third considerations are safety and comfort: motorcyclists are exposed to higher safety risks than drivers of other motor vehicles, and travel in automobiles is in many instances more comfortable. If safety and comfort are normal goods we should expect to see a reorientation of vehicle demand away from motorcycles as incomes increase.[3]

This paper is structured as follows. Section 2 describes our method and data. Section 3 presents results on how vehicle fleets evolve as economies develop. Section 4 explores how vehicle fleet sizes affect road death rates. The final section concludes.

2. Approach

To quantify the evolution of the number of motorcycles per thousand population (*M*) as per capita income increases, we estimate the following specification:

$$\ln M_{c,t} = \alpha_1 \ln Y_{c,t} + \alpha_2 (\ln Y_{c,t})^2 + \alpha_3 \ln P_{c,t} + \delta_c + \omega_t + \varepsilon_{c,t} \quad (1)$$

where c and t represent country and year, Y is GDP per capita in real purchasing power parity-adjusted US dollars, P is population density, and ε is an error term. We include country and year

[3] Working against this might be an increase in demand for recreational motorcycling as incomes increase.

fixed effects (δ_c and ω_t) in all specifications because time-invariant factors such as a country's geography and commonly time-varying factors such as the world oil price may be correlated with both GDP per capita and vehicle ownership. We present specifications both with and without the squared log GDP per capita term.

It is natural to expect that motorcycles will be more popular in densely-populated countries, as people in these countries have less room for parking and smaller vehicles are more advantageous in situations of dense traffic. This applies to both privately-owned vehicles and vehicles used for taxi transport (such as auto rickshaws, e.g. Thailand's *tuk-tuks*). Space constraints might also lead governments to prioritize motorcycle use or discourage larger vehicles via taxes and other policies. The data in Table 1 indicate that motorcycles are indeed more popular in crowded countries: countries with above-median population density on average own 3.5 times as many motorcycles per thousand population as countries with below-median population density. Some densely-populated middle-income countries (e.g. Thailand) have particularly high rates of motorcycle ownership. This motivates our inclusion of population density in Eq. (1). To allow the effect of economic development on motorcycle ownership to vary in countries with different population densities, we also estimate the specification:[4]

$$\ln M_{c,t} = \beta_1 \ln Y_{c,t} + \beta_2 (\ln Y_{c,t})^2 + \beta_3 \ln P_{c,t} + \beta_4 (\ln P_{c,t} * \ln Y_{c,t}) + \beta_5 (\ln P_{c,t} * (\ln Y_{c,t})^2) + \delta_c + \omega_t + \varepsilon_{c,t} \tag{2}$$

[4] An alternative approach to exploring Kuznets curve heterogeneity is the binary dependent variable modelling method of Burke (2012).

We estimate similar models for five additional dependent variables: (a) the log of all other motor vehicles (cars, buses, trucks) per thousand population; the logs of each of (b) cars, (c) buses, and (d) trucks per thousand population; and (e) the motorcycle share of the total road motor vehicle fleet. We are unaware of suitable international data on non-motorized vehicles such as bicycles. Our estimation sample uses annual data for 153 countries for 1963-2010, which is the largest sample among studies of vehicle ownership. These countries represented 94% of the global population in 2010. Our data on motor vehicles are from the IRF (2012), the only source that covers an internationally-representative sample. We obtain GDP data from Feenstra et al. (2013) and data on population density from the World Bank (2013). A full list of variable definitions and data sources is provided in the Appendix. Eqs. (1) and (2) do not control for other potential determinants of vehicle adoption (e.g. road infrastructure) because these are likely to be affected by economic development, and so may attenuate our estimates of the reduced-form income effect.[5] We focus on vehicle fleets rather than distance travelled by vehicle type because data for the latter are not available for most countries in our large international sample.

Our fixed effects estimates utilize each country's "within variation" over a long time period (up to 48 years), so it is important to comment on the quality of the IRF time-series on vehicle fleets. In particular, we were concerned that the data on motorcycles may be affected by changes in

[5] Our approach is similar to studies of the "environmental Kuznets curve" which estimate reduced-form specifications without controlling for variables which might in fact be the channels via which income effects operate. See, for example, Stern (2010). We note, however, that we find similar Kuznets curve results for the motorcycle share of the motor vehicle fleet in specifications that include the set of controls used in Table 3.

definitions and accounting methods over time. We removed a number of suspicious observations from our dataset and identified several countries that appear to have experienced changes in data definitions during the sample period. Our results are similar in sub-samples that exclude these countries.

After documenting the motorcycle Kuznets curve we turn to a second question: how does vehicle ownership affect the number of road fatalities? While there is substantial evidence from mechanical models, crash tests, and fatality statistics that motorcycle travel is more risky than travel in other motor vehicles (Tay, 2003; Grimm and Treibich, 2013; NHTSA, 2012), the overall effect of motorcycle dependence on the *total* number of road deaths is not necessarily clear because crashes involving motorcycles are less dangerous for *other* crash participants.[6] Motorcycles might also potentially be used less frequently and/or for shorter trips than other motor vehicles. An analysis for a sample of 32 industrialized countries by Kopits and Cropper (2008) found no significant effect of the motorcycle share of the motor vehicle fleet on vehicle-occupant deaths per vehicle kilometer travelled, although did find that motorcycle use leads to fewer pedestrian deaths. Using data for Queensland, Tay (2003) found that increases in the fleet of motorcycles increase road deaths, but increases in the numbers of cars and buses reduce road

[6] The numbers of motorcycle deaths and total road deaths can trend in different directions. In the United States, for instance, motorcycle deaths increased over the years 1997-2008 even while the total number of road deaths fell (NHTSA, 2014). A number of factors have likely contributed to this, including an increase in the use of more powerful motorcycles, a repeal of helmet laws in some states, and the effect of the recession and rising gasoline prices in stimulating substitution back to motorcycles (Wilson et al., 2009; Sivak and Schoettle, 2010).

deaths. As far as we are aware, ours is the first study to explore the impact of vehicle mix on road deaths for an internationally-representative sample.

To explore the impact of vehicle mix on road deaths, we estimate the following equations:

$$\ln F_{c,t} = \gamma_1 m_{c,t} + \boldsymbol{\eta X}_{c,t} + \delta_c + \omega_t + \varepsilon_{c,t} \quad (3)$$

$$F_{c,t} = \theta_1 M_{c,t} + \theta_2 C_{\mathrm{c},t} + \theta_3 B_{c,t} + \theta_4 T_{c,t} + \boldsymbol{\eta X}_{c,t} + \delta_c + \omega_t + \varepsilon_{c,t} \quad (4)$$

where F measures annual road fatalities per 100,000 population, m is the share of motorcycles in the motor vehicle fleet, C, B, and T are the numbers of cars, buses, and trucks per thousand population, and $\boldsymbol{X}$ is a vector of additional potential determinants of road deaths. Eq. (3) estimates the effect of vehicle mix on road deaths. Eq. (4) allows identification of the marginal effects of each vehicle type on road deaths. The dependent variable and the vehicle counts in Eq. (4) are not logged as we wish to estimate marginal level effects rather than elasticities.[7] The vector of controls includes a broad suite of potential determinants of road deaths: the log of GDP per capita and its square, population density, road length, the share of roads that are paved, measures of the importance of alternative transport options (rail and air), the share of the population aged 15-24 years (who have high road death rates), the urban population, alcohol consumption, and the infant mortality rate as a proxy of medical standards (noting that few infant deaths are caused by road crashes).

[7] Most countries have fewer motorcycles than cars, meaning that a 1% increase in the number of motorcycles on average involves a smaller level increase than a 1% increase in the number of cars.

Our road fatality data are primarily from the IRF (2012), and include all reported deaths that occur within 30 days of a road crash.[8] We focus on fatalities because international data on non-fatal road crashes are less reliable (Luoma and Sivak, 2007; Sauerzapf et al., 2010; WHO, 2013b). Nevertheless, the accuracy of reported data on road deaths is likely to vary substantially. If the reporting of road deaths improves in a way that is correlated with development level, our GDP variable will control for some of these data quality differences. The country fixed effects also remove time-invariant differences in road death reporting.

To gain an insight into how the motorcycle ownership and road death data evolve in our sample, Figure 1 presents data for the two variables for India and Malaysia (two developing countries with relatively complete time-series). For both of these countries we can see that motorcycle ownership has increased over time. Road death rates have been increasing in India and, until the mid-1990s, in Malaysia also. Malaysia has had a decreasing road death rate since the mid-1990s, in line with the latter portion of the "road death Kuznets curve" that has received considerable attention in the literature (see, for example, Law et al., 2011). Many factors affect road deaths, and the generally upward trends in Figure 1 need not necessarily represent an effect of motorcycles on road death rates as other factors have not been taken into account. Our regressions in section 4 will control for a number of these additional factors.

[8] We supplement the IRF road data with a limited number of observations from the United Nations Economic Commission for Europe (2013) and the Organisation for Economic Co-operation and Development (2013). We are not aware of any source of data specifically on motorcyclist deaths for our large international sample. Law et al. (2009) used data on motorcycle deaths from the International Road Traffic and Accident Database, but these only cover developed countries.

- Figure 1-

3. Vehicle mix and economic development

Our estimates of the effect of GDP per capita on the vehicle mix are presented in Table 2. Specification A includes just log GDP per capita and the population density control. The estimates indicate that higher average income is associated with an increase in the number of cars and trucks. The average income elasticity of cars is 0.7, and that for trucks is 0.5.

-Table 2-

Specification B in Table 2 includes a squared log GDP per capita term to allow the relationships between GDP per capita and the various vehicle fleets to be non-monotonic. The estimate in column 1 suggests that motorcycles per thousand population on average evolve in an inverse U manner as GDP per capita increases, with a maximum occurring at a mid-range per capita GDP of $7,000 (a level reached by the Ukraine in 2010; standard error of turning point estimate = $4,000).[9] This is the motorcycle Kuznets curve. The estimate in column 6 provides a similar result for the motorcycle share of the vehicle fleet, which on average peaks at a GDP per capita level of $3,000 (the level of Vietnam in 2010; standard error of turning point estimate = $1,000). The estimates suggest that there is no "peak vehicle" GDP per capita level for cars or trucks – on average these fleets continue to expand even as average incomes reach high levels (as seen by

[9] For Specification B, GDP per capita turning points are calculated as $\exp(-\alpha_1/(2*\alpha_2))$.

the high GDP per capita turning points and the large standard errors of these turning points).[10] Interestingly, economic development typically results in an increasing number of buses per thousand population until a GDP per capita level of $9,000 (standard error = $5,000), although the number of buses remains small relative to the other vehicle types. Buses tend to become less common at higher income levels. The typical evolution of vehicle ownership as economies develop is presented in Figure 2. The average country sees motorcycle ownership peak at 26 motorcycles per thousand population.

-Figure 2-

Specification C in Table 2 shows estimates of Eq. (2). These provide an important finding: the motorcycle Kuznets curve is much more pronounced in densely populated countries. This is most clearly seen in Figure 3, which presents estimates for the effect of GDP per capita on the motorcycle fleet for average countries and countries with 90th-percentile population density (371 people per square kilometer). Countries with a 90th-percentile population density typically see

[10] This finding is similar to that of Kopits and Cropper (2005). The work of Dargay et al. (2007) suggests there is a saturation level of vehicle ownership of around 800 vehicles per thousand population, a level well above the predictions of vehicle ownership that emerge from our regressions. Data for the United States indicate that the per-capita total motor vehicle stock has reduced since 2006, but this is at a very high level of over 800 vehicles per 1,000 population. Recent evidence of “peak car” in a number of developed countries (e.g. Goodwin and Van Dender, 2013) has typically referred to the distance travelled in cars rather than the size of the car fleet. As noted, we do not have data on distance travelled by vehicle type for most countries in our large international sample.

motorcycle ownership reach as high as 190 motorcycles per thousand population. A similar effect is seen for the motorcycle share of the motor vehicle mix (column 6, and Figure 4), which typically reaches 55% in countries with 90th-percentile population densities, more than double the share reached in the average country. The estimates do not provide any indication that the effect of GDP per capita on the fleet of cars varies significantly in countries with different population densities.[11]

-Figure 3-

-Figure 4-

It is possible that the evolution of the motorcycle fleets as economies develop is affected by variables other than population density. In unreported results we find no evidence, however, that either the level of urbanization or a country's average temperature lead to significant variations in motorcycle-income paths; our investigations indicate that it is population density that seems to be the key mediating variable explaining why there are differences in motorcycle-income relationships between countries. We also continue to find evidence of the motorcycle Kuznets curve if we exclude any of the seven World Bank (2013) geographical regions (e.g. East Asia and the Pacific) from our sample or control for additional variables such as the length of road networks, the share of roads that is paved, and the share of the population aged between 15 and 24 years.

[11] An F-test provides no evidence that the interaction terms are jointly significant in the cars specification.

In sum, the results in Table 2 and Figures 2-4 provide evidence of a motorcycle Kuznets curve which sees motorcycle dependence increase and then decrease as economies develop. The upswing is larger in densely populated countries, where the economics of motorcycle use are more favourable. The numbers of cars and trucks increase monotonically with per capita income. The number of buses increases and then decreases, but buses typically remain a small share of the vehicle fleet.

4. Vehicle mix and road deaths

Table 3 presents estimates of Eqs. (3) and (4). The estimation samples are slightly reduced due to limitations on data availability. Similarly to Grimm and Treibich's (2013) evidence for India, columns 1-2 suggest that countries with higher motorcycle shares of the road motor vehicle fleet have more road deaths. Column 2 suggests that a percentage-point increase in this share on average is associated with 0.5% more road deaths. This effect becomes statistically insignificant in column 3 when the full set of controls is included and the sample size is reduced, however.

-Table 3-

Columns 4-6 of Table 3 show the marginal effects of vehicle ownership on road deaths. The estimates suggest that the effect of increases in the motorcycle fleet on road deaths exceeds that for cars and trucks, but is likely smaller than that for buses.[12] On average a standard deviation increase in the number of motorcycles per thousand population results in two additional road deaths per 100,000 population each year. An alternative way of reporting these results is to

[12] The *p*-values for tests of these propositions are in the base of the Table.

estimate how many road deaths are associated with the peak of the motorcycle Kuznets curve. The estimates indicate that in countries which adopt 190 motorcycles per 1,000 population (the motorcycle Kuznets curve peak for countries with 90th-percentile population densities), these motorcycles result in a net addition of 5 road deaths per 100,000 population per year. This is a sizeable number when compared against the global average road death rate of 18 deaths per 100,000 population per year (WHO, 2013b). In contrast, additional cars are on average associated with a reduction in road fatalities (see also Tay, 2003). This is potentially because of the safety features of cars (cf. motorcycles) and the lower speeds associated with traffic congestion when there are more cars on the roads. We find a large marginal effect of buses on road deaths (significant in columns 4-5, but not 6), although no evidence that the number of trucks has a significant effect on road deaths.

The results on the control variables in Table 3 provide evidence of the road fatalities Kuznets curve that has been documented elsewhere: road death rates increase until a mid-range GDP per capita, and then subsequently fall. The estimates also indicate that countries with populations that are more concentrated in urban areas have higher road death rates; use of rail transport reduces road death risks; and having a more youthful population is associated with more road deaths. Increasing alcohol consumption per adult by 1% on average results in around 0.1% more road deaths (significant at the 1% level).

Time-varying policies related to road safety are also important to consider. In additional cross-sectional estimates that control for the blood-alcohol limits of drivers in the year 2011 (using data from the WHO, 2013c) we continue to find similar results on our vehicle variables. We also find similar estimates in a specification including country-by-country time trends, although the magnitude on the motorcycle term is reduced to 0.01, with a *p*-value of 0.10. It is possible that there might be other variables in addition to those in the long list in Table 3 that are important to consider, but current data constraints for our large international sample mean that we leave this task to future research.

5. Conclusion

This is the first paper to document the idea and empirics of the motorcycle Kuznets curve. Using data for countries representing the vast majority of the world's population, we identify the existence of an inverse-U which sees motorcycle ownership initially increase and subsequently decrease as countries go from being poor to rich. The effect is particularly pronounced in densely populated countries, where motorcycles often become the most common type of motor vehicle. We also present macro-level evidence that dependence on motorcycles is associated with higher road death rates.

Knowledge on how the vehicle mix evolves as economies develop is of use for planning policies for the transport sector. Our results suggest that developing countries, particularly those with high population densities, should prepare for a relatively motorcycle-intensive phase of their transport development, which might require boosted investment in activities such as motorcycle licence testing. Countries passing through middle-income stages, on the other hand, should consider redirecting their resources to meeting the infrastructure and other challenges associated with continued rapid growth in four-wheeled vehicles. Managing the transition from the use of (compact) motorcycles to much greater use of (less compact) four-wheeled vehicles without large increases in congestion is a substantial challenge. There is scope for greater use of economic instruments such as congestion pricing in managing this transition (e.g. Litman, 2012).

The international community is aiming to substantially reduce road deaths during the United Nations' Decade of Action for Road Safety 2011-2020 (WHO, 2010). Yet our results suggest that road death rates in many low-income countries are set to rise as their per capita incomes increase (Table 3). Part of this rise will be due to ongoing uptake of motorcycles, as many countries currently have GDP per capita levels well below the motorcycle Kuznets curve turning point. Low-income countries could take steps to avoid some of these deaths by implementing initiatives to reduce motorcyclist deaths. These may include public transport projects, designing roads with separate lanes for motorcycles, adequate motorcyclist helmet laws and standards, and improved training and testing of motorcyclists.

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Tables

Table 1

International road motor vehicle fleets, 2007.

	per '000 population Motorcycles	Cars	Buses	Trucks	% Motorcycle share of road motor vehicles
World	54	138	3	52	22
Country groups					
Low-income	4	7	1	3	30
Middle-income	63	52	3	19	46
High-income	53	445	3	167	8
Population density					
Below-median	20	189	3	108	6
Above-median	69	116	3	27	32
Selected countries					
Ethiopia	0	1	0	2	3
Bangladesh	5	2	0	0	65
China	67	23	2	8	67
Thailand	238	54	7	76	63
Germany	43	499	1	52	7
US	24	450	3	366	3
Coefficient of variation for countries in group					
World	2.0	1.1	1.1	1.1	1.3
Low-income	1.3	1.9	0.9	1.0	1.0
Middle-income	1.9	1.0	0.9	0.6	1.3
High-income	1.6	0.3	1.1	0.7	1.3

Notes: Data are for 2007 rather than 2010 so as to maximize country coverage. Income classifications are from the World Bank as of July 2012. Country groupings use data for a total of 127 countries. The coefficient of variation is the standard deviation divided by the mean. Source: IRF (2012). See the Appendix for definitions.

Table 2
Motor vehicle regressions, 1963-2010.

	(1)	(2)	(3)	(4)	(5)	(6)
	ln, per '000 population					%
Dependent variables	Motorcycles	Other motor vehicles	Cars	Buses	Trucks	Motorcycle share of road motor vehicles
Specification A						
Ln GDP per capita	0.26	0.59***	0.72***	0.21	0.46**	-1.63
	(0.21)	(0.17)	(0.17)	(0.18)	(0.20)	(2.73)
Ln Population density	1.33***	0.27	0.23	1.48***	0.27	23.96***
	(0.48)	(0.17)	(0.18)	(0.23)	(0.22)	(5.54)
R^2 (within)	0.19	0.65	0.63	0.45	0.42	0.13
Specification B						
Ln GDP per capita	3.87**	1.70	1.76	2.44*	1.65	55.63***
	(1.52)	(1.32)	(1.23)	(1.34)	(1.55)	(18.48)
(Ln GDP per capita)^2	-0.22**	-0.07	-0.06	-0.13*	-0.07	-3.44***
	(0.09)	(0.07)	(0.07)	(0.07)	(0.08)	(1.13)
Ln Population density	0.74	0.09	0.06	1.11***	0.08	14.58**
	(0.50)	(0.21)	(0.23)	(0.22)	(0.27)	(5.96)
GDP per capita turning point ($)	7,468 (3,945)	338,124 (1,264,460)	1,229,440 (6,511,012)	8,994 (4,860)	99,228 (265,981)	3,219 (974)
R^2 (within)	0.22	0.66	0.63	0.47	0.43	0.18
Specification C						
Ln GDP per capita	-1.51	0.39	0.28	4.44***	0.44	-4.98
	(2.74)	(1.09)	(1.21)	(1.51)	(1.39)	(43.55)
(Ln GDP per capita)^2	0.07	0.00	0.02	-0.22***	-0.00	-0.16
	(0.16)	(0.07)	(0.07)	(0.09)	(0.08)	(2.56)
Ln Population density	-5.30**	-1.30	-1.56	3.97**	-1.14	-50.47
	(2.63)	(1.86)	(1.84)	(1.75)	(2.24)	(35.52)
Ln GDP per capita*Ln Population density	1.36** (0.60)	0.32 (0.39)	0.37 (0.39)	-0.60 (0.39)	0.28 (0.47)	14.88* (8.17)
(Ln GDP per capita)^2*Ln Population density	-0.07** (0.03)	-0.02 (0.02)	-0.02 (0.02)	0.03 (0.02)	-0.02 (0.02)	-0.79* (0.45)
GDP per capita turning point ($)	8,655 (4,544)	404,270 (1,805,889)	1,243,692 (20,300,000)	10,563 (6,568)	132,739 (477,197)	3,757 (1,024)
R^2 (within)	0.24	0.66	0.63	0.48	0.43	0.20
Conclusion	Inverse U	Increasing	Increasing	Inverse U	Increasing	Inverse U
Country fixed effects: Yes						
Year fixed effects: Yes						
Observations: 3,141						
Countries: 153						

Notes: ***, **, and * indicate statistical significance at 1%, 5%, and 10%. Coefficients on constants not reported. For coefficient estimates: robust standard errors clustered by country are in parentheses. For predicted GDP per capita turning points: robust standard errors based on the delta method are in parentheses. The R^2s reflect the power of the explanatory variables and year dummies. GDP per capita turning points are for countries with sample-mean log population densities. Other motor vehicles = cars + trucks + buses.

Table 3

Road death regressions, 1963-2010.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Ln Road deaths per 100,000 population (columns 1-3)			Road deaths per 100,000 population (columns 4-6)		
Motorcycle share of road motor vehicles (%)	0.012***	0.005*	0.001			
	(0.003)	(0.003)	(0.002)			
Motorcycles per '000 population				0.04***	0.03**	0.03***
				(0.01)	(0.01)	(0.01)
Cars per '000 population				-0.03***	-0.01*	-0.01
				(0.00)	(0.01)	(0.01)
Buses per '000 population				0.27**	0.22*	0.13
				(0.11)	(0.11)	(0.09)
Trucks per '000 population				-0.00	0.00	0.00
				(0.01)	(0.01)	(0.00)
Ln GDP per capita		3.62***	1.93***		29.36***	18.80**
		(0.87)	(0.45)		(8.34)	(8.57)
(Ln GDP per capita)^2		-0.20***	-0.10***		-1.53***	-1.00*
		(0.05)	(0.03)		(0.46)	(0.52)
Ln Population density		0.68***	0.21		8.04***	2.01
		(0.21)	(0.22)		(2.16)	(2.84)
Ln Road length per capita			0.02			0.44
			(0.04)			(0.61)
Paved road share (%)			0.00			0.02*
			(0.00)			(0.01)
Ln Total motor vehicles per '000 population			0.26***			
			(0.08)			
Rail share of energy used in transport (%)			-0.01*			-0.14**
			(0.00)			(0.06)
Ln Air passengers per capita			0.02			0.57
			(0.03)			(0.45)
Population aged 15-24 (%)			0.02*			0.51***
			(0.01)			(0.19)
Urban population (%)			0.00			0.16*
			(0.01)			(0.09)
Ln Alcohol consumption per adult			0.09***			1.68***
			(0.04)			(0.52)
Ln Infant mortality rate			0.21			1.26
			(0.14)			(1.72)
Country fixed effects: Yes						
Year fixed effects: Yes						
GDP per capita turning point ($)	-	10,748	9,866	-	14,774	12,386
		(2,940)	(5,785)		(6,245)	(12,075)
p-value for test:						
Effect of motorcycles equals that of cars				0.00	0.00	0.00
Effect of motorcycles equals that of buses				0.04	0.10	0.30
Effect of motorcycles equals that of trucks				0.05	0.11	0.00
R^2 (within)	0.22	0.45	0.48	0.36	0.47	0.48

Observations	2,781	2,781	1,859	2,782	2,782	1,859
Countries	142	142	104	142	142	104

Notes: ***, **, and * indicate statistical significance at 1%, 5%, and 10%. Coefficients on constants not reported. For coefficient estimates: robust standard errors clustered by country are in parentheses. For predicted GDP per capita turning points: robust standard errors based on the delta method are in parentheses. The R^2s reflect the explanatory power of explanatory variables and year dummies.

Figures

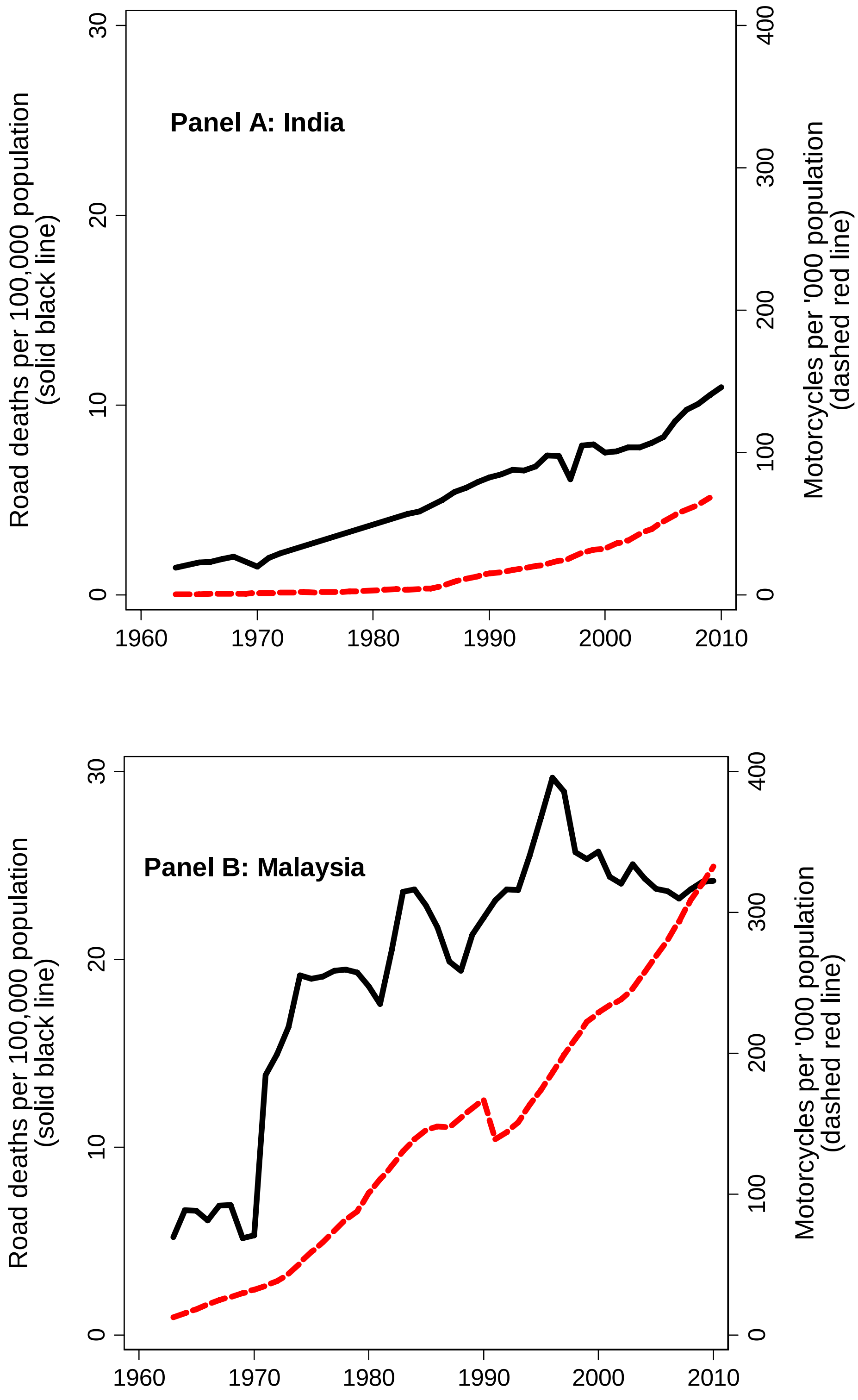

Fig. 1. Road death and motorcycle ownership rates: India (Panel A) and Malaysia (Panel B).

Data sources are as in Appendix. Missing observations are interpolated (in this Figure only).

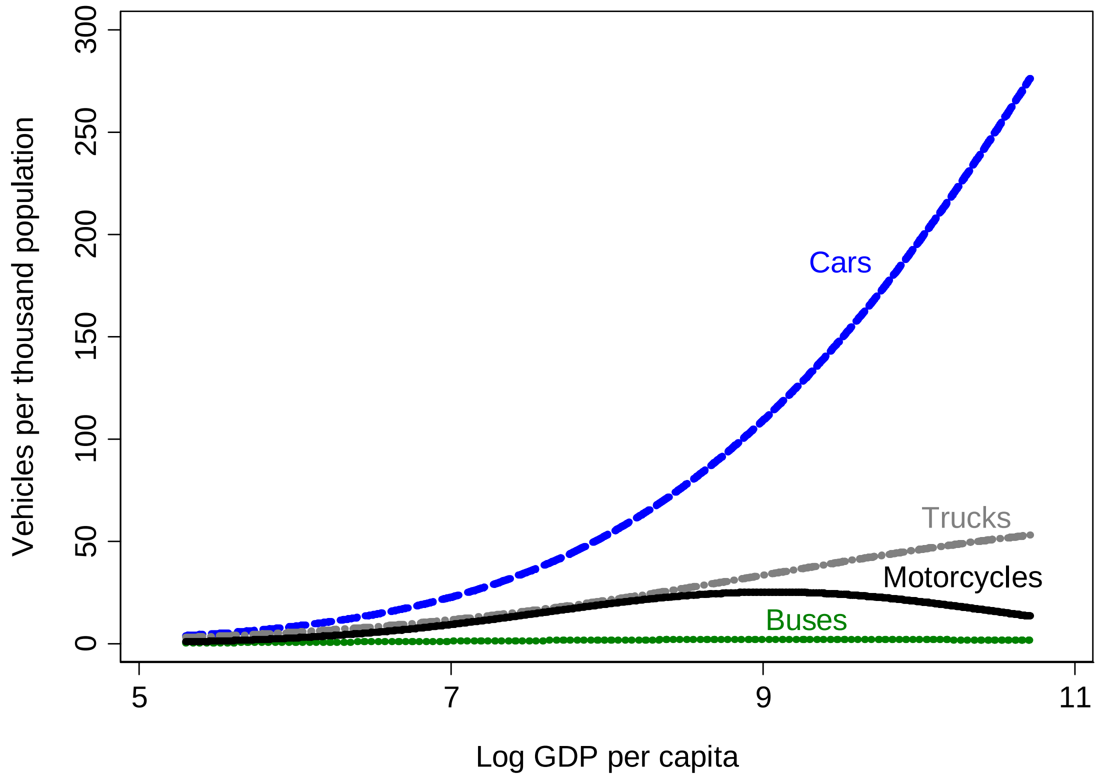

Fig. 2. Regression predictions for vehicle types. Prediction lines use Specification C of Table 2 and are for countries with mean log population density, a mean country fixed effect, and the year-2010 time effect.

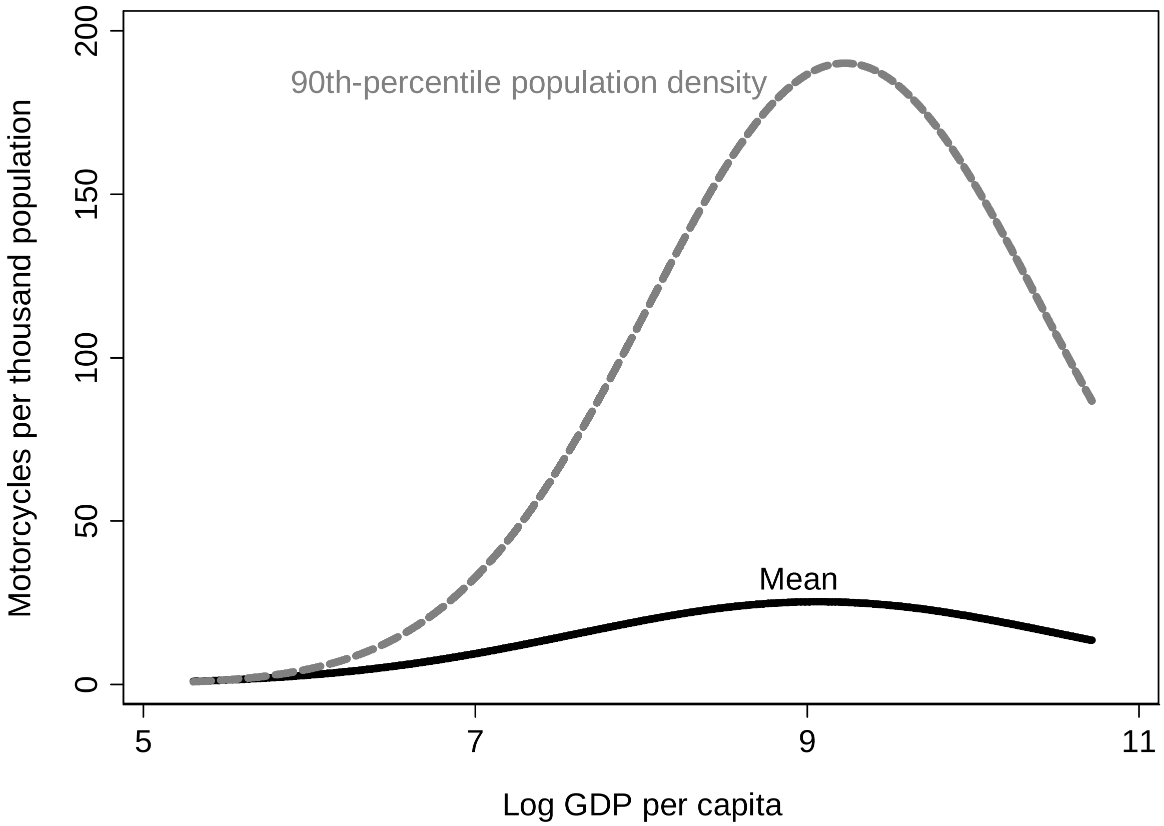

Fig. 3. Motorcycle fleet regression predictions, for countries with mean and 90th-percentile log population density (corresponding to 66 and 371 people per square kilometer, respectively). Prediction lines use a mean country fixed effect and the year-2010 time effect.

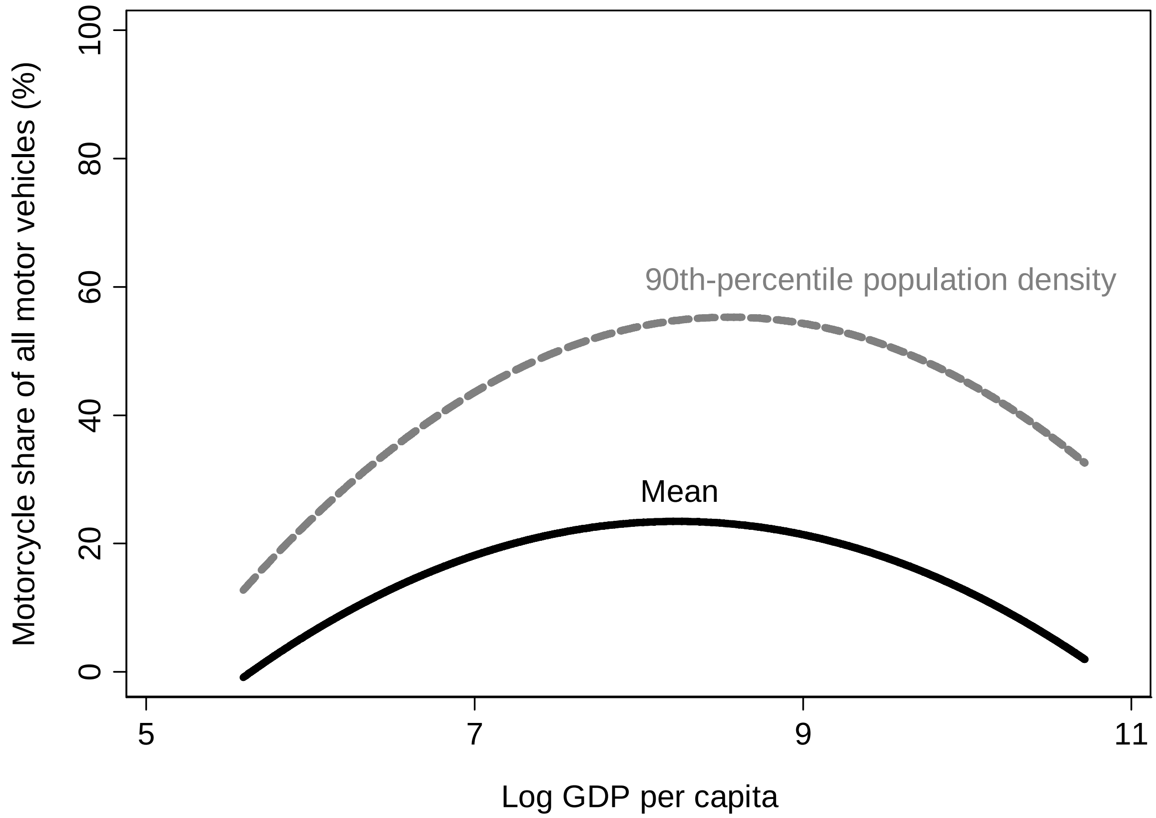

Fig. 4. Regression predictions for the motorcycle share of the motor vehicle fleet, for countries with mean and 90th-percentile log population density (corresponding to 66 and 371 people per square kilometer, respectively). Prediction lines use a mean country fixed effect and the year-2010 time effect.

Appendix: Variable descriptions

Motorcycles per ‘000 population: Two- or three-wheeled road motor vehicles per thousand population. International Road Federation (2012). Population data for this and other variables are from Feenstra et al. (2013). Several observations with apparent errors were removed.

Other motor vehicles per ‘000 population: Road motor vehicles other than motorcycles, per thousand population. Includes cars, buses, and trucks. International Road Federation (2012).

Cars per ‘000 population: Road motor vehicles intended for the carriage of passengers and designed to seat no more than nine persons (including the driver), per thousand population. Termed “passenger cars” by the International Road Federation (2012).

Buses per ‘000 population: Passenger road motor vehicles designed to seat more than nine persons (including the driver), per thousand population. International Road Federation (2012).

Trucks per ‘000 population: Rigid road motor vehicles designed, exclusively or primarily, to carry goods, per thousand population. Includes lorries, vans, and pick-ups. International Road Federation (2012).

GDP per capita: Expenditure-side real GDP at chained purchasing power parities and in 2005 $US, divided by population. Feenstra et al. (2013).

Population density: Population per squared kilometer of land area. World Bank (2013).

Road deaths per 100,000 population: Number of reported deaths that occur within 30 days of a road crash. Includes all deaths (e.g. of vehicle occupants, motorcyclists, cyclists, and pedestrians). International Road Federation (2012). We supplemented the series for 12 countries with data from the Organisation for Economic Co-operation and Development (2013) or the United Nations Economic Commission for Europe (2013).

Road length per capita: Length of the total road network, in kilometers, divided by population. International Road Federation (2012). Data linearly interpolated.

Paved road share (%): % of road length that is surfaced with crushed stone, hydrocarbon binder, bituminized agents, concrete, or cobblestones. International Road Federation (2012). Data linearly interpolated.

Total motor vehicles per '000 population: Sum of motorcycles and other motor vehicles, both per thousand population. International Road Federation (2012).

Rail share of energy used in transport (%): % share of rail sector's energy use in total energy used in the road, rail, and domestic aviation sectors. IEA (2013).

Air passengers per capita: Domestic and international passengers of air carriers registered in the country, divided by population. World Bank (2013).

Population aged 15-24 (%): % of population aged 15-24. Five-yearly United Nations (2010) data on the 15-24 year old population were linearly interpolated. Data on total population from Feenstra et al. (2013).

Urban population (%): People living in urban areas as defined by national statistical offices as a share of the total population. World Bank (2013).

Alcohol consumption per adult: Annual alcohol consumption (in liters of pure alcohol) per adult (age 15+). WHO (2013c).

Infant mortality rate: Number of infants dying before reaching one year of age, per 1,000 live births. World Bank (2013).

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