Cars

SUMMARY

The typical urban household in China owns a TV, a refrigerator, a washing machine, and a computer, but does not yet own a car. In this paper, we draw on data for a panel of countries and detailed household level surveys for the largest emerging markets to document a remarkably stable relationship between GDP per capita and car ownership, highlighting the importance of within-country income distribution factors: we find that car ownership is low up to per capita incomes of about US$5000 and then takes off very rapidly. Several emerging markets, including India and China, the most populous countries in the world, are currently at the stage of development when such takeoff is expected to take place. We project that the number of cars will increase by 2.3 billion between 2005 and 2050, with an increase by 1.9 billion in emerging market and developing countries. We outline a number of possible policy options to deal with the implications for the countries affected and the world as a whole.

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Economic Policy April 2008 Printed in Great Britain

Mass car ownership in the emerging market giants

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1. INTRODUCTION AND MOTIVATION

The pilot lowers the plane's wheels and the sudden increase in noise wakes you up. Disoriented, you try to remember which leg of your long flight you are on. Looking out of the window, you see a complicated highway intersection, busy with plenty of cars. You realize that you are about to land in an advanced economy, where you will transfer to another flight. A few hours later, you reach your final destination in one of the world's lowest income countries, where paved roads are few, and traffic mostly consists of a mix of carts and bicycles.

Cars are pervasive in modern economies, and are almost a defining gauge for how we view a country's degree of economic development. Widespread car ownership has major implications for everyday life, countries' economic and social fabric, and government policies. Important spillovers are generated not only on the production side (through the demand for various inputs), but also on the demand side (for complementary goods and services), as cars make it easier to go shopping or to enjoy

This paper was prepared for the October Panel Meeting of *Economic Policy* in Lisbon (October 2007). We are grateful to two anonymous referees and our discussants Christian Schultz and Jonathan Temple. We also thank the other participants in the Panel Meeting for helpful comments. Maria Victoria Fazio provided excellent research assistance. Any errors are our own. The views expressed herein are those of the authors and should not be attributed to the IMF, its Executive Board, or its management.

The Managing Editor in charge of this paper was Jan van Ours.

Economic Policy April 2008 pp. 243–296 Printed in Great Britain

a vacation, with beneficial effects for consumers, but also for suppliers of goods and services, and the economy as a whole. Turning to policies, at the national level, a demand for cars can only be accommodated through the provision of the requisite infrastructure, with important fiscal consequences, and through suitable regulations governing traffic to keep accident risks, traffic congestion, noise, and pollution in check. Domestic long-term fiscal scenarios and strategic decisions on appropriate types and amounts of infrastructure thus require taking a view on future demand for cars, and for transportation more generally. At the international level, cars account for a major share of oil consumption,[1] as well as for 7% of global greenhouse gas emissions (Stern, 2007). Accurate projections of future developments in car ownership are thus a key input in forecasting worldwide prices of energy and commodities, especially oil, as well as climate conditions.

Beyond their practical economic relevance, cars have a number of features of analytical interest to economists. First, they have been, broadly speaking, a relatively homogeneous product – both over time and across countries. Their comforts and safety features have no doubt improved, and their relative price has declined, but their basic workings have remained similar for almost a century now. Accordingly, researchers have traditionally felt comfortable studying the demand for 'cars', perhaps because we all recognize one when we see it, despite the availability of many different brands and models. Second, cars have been one of the main tradable, durable goods in modern economies for decades, and they are the second most expensive single item purchased by the typical advanced country family, after its house or apartment. Third, owing to their 'lumpy' nature and relatively high cost, cars are only affordable for households with incomes above a given threshold (which we will seek to estimate in this paper). Fourth, partly owing to the presence of substantial externalities, cars are one of the consumer products that have traditionally seen a major degree of involvement on the part of governments, through taxes, regulation, the need for major infrastructure in order to be useful, and – in some cases – various kinds of implicit or explicit subsidies to domestic producers.

The motivation for our study is best summarized in Figure 1. The top panel is a cross-country scatter plot of car ownership (per thousand inhabitants) against per capita incomes (in US dollars – not PPP-adjusted) for the year 2000; each data point's size is proportional to the country's population. The bottom panel is the same scatter plot for the year 2050, according to the projections that we derive (as explained in subsequent sections) drawing on estimates based on data for a panel of countries.[2]

As seen in the top panel, a casual look at cross-country data suggests a non-linear relationship between car ownership rates and income per capita. Ownership rates are

[1] Gasoline currently accounts for as much as 45% of oil consumption in the United States, one of the most gasoline-reliant economies (US Energy Information Administration, www.eia.doe.gov).

[2] Although projecting car ownership over the next decades requires a certain leap of faith regarding the stability of our assumptions and the continued applicability of our approach, studies that analyse climate change usually present projections for the very long run; we thus present our projections through 2050, following the Stern report in this regard.

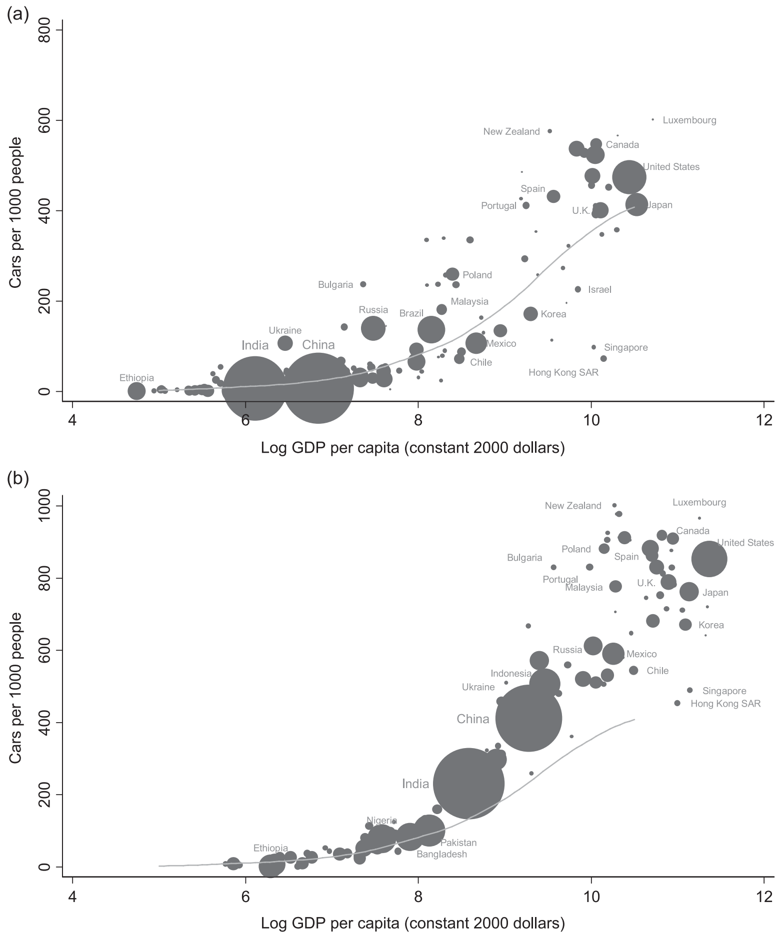

Figure 1. (a) Car ownership and income, cross-country scatter plot, 2000; (b) Authors' projections for 2050

Notes: The solid line corresponds to a semi-parametric regression in an unbalanced panel for 1970–2003 and is drawn for illustration purposes only. GDP data are not PPP-adjusted. Projections in the bottom panel are based on Specification (5), Table 4 (unrelated to the descriptive fitted line shown).

Data sources: World Road Statistics, International Road Federation; World Development Indicators, World Bank.

usually minimal in the lowest income countries, but increase rapidly as per capita incomes grow past an initial threshold (estimated at about US$5000 per capita in 2000 prices, about 8.5 in the log scale in the figure); ownership rises with per capita incomes even among the most advanced countries, though it seems reasonable to expect that a saturation point will eventually be reached. Underlying this (non-linear) macroeconomic association between rising per capita incomes and average car ownership, of course, is the fact that more and more households are attaining the income levels at which they can afford a car, as we confirm below using household level data.

The threshold per capita income level where a major take-off in car ownership tends to occur is being attained by several important emerging market countries,

Table 1. Durable consumer goods per 100 households (in 2006 or most recent available)

	China		India		
	Urban	Rural	Urban	Rural	Total
Automobiles	4.3	. . .	4.0	0.7	1.7
Bicycles	117.6	98.4	51.9	57.2	55.7
Cameras	48.0	3.7	0.0	0.0	0.0
Computers	47.2	. . .	0.0	0.0	0.0
Microwave ovens	50.6	. . .	. . .	. . .	. . .
Motorcycles[a]	20.4	44.6	28.3	7.9	13.6
Refrigerators	91.8	22.5	30.8	4.8	12.1
Telephones	93.3	64.1	. . .	. . .	. . .
Telephones: mobile	152.9	62.1	. . .	. . .	. . .
Televisions[b]	137.4	89.4	70.4	27.5	39.5
Video disc players[c]	70.2	. . .	8.2	1.7	3.6
Washing machines	96.8	43.0	12.5	0.9	4.1

Notes: [a] Data for India includes scooters. [b] Data for China includes only colour TVs. Data for India includes all TVs. [c] Data for India includes VCRs.

Sources: Data for China is based on tabulations of the National Bureau of Statistics (NBS) Urban Household Survey and Rural Household Survey, available through CEIC Data. Data for India is from the National Sample Survey Organization's (NSSO) Consumer Expenditure Survey.

including China and India, the world's most populous nations. The vast majority of urban households in China own appliances such as washing machines, televisions and refrigerators (Table 1). Almost half of urban households own a computer. Yet, although traffic jams do occur in a handful of major cities, ownership of automobiles remains limited, at less than five per hundred households. International experience suggests that a powerful economic force – consumer demand – will cause this to change within the next few decades, and it is important to estimate exactly how quickly this major transformation will take place.[3] India – with slightly lower per capita income – is likely to follow suit. Again, traffic is notorious in a few cities such as Delhi (with 4 million vehicles), but ownership is limited when considering India as a whole. As shown in the next sections, we project that emerging market countries, and China and India in particular, will account for the bulk of growth in car ownership over the next decades.

The empirical study of car demand has a long history in economics, with many applications to advanced countries – especially the United States (for example, Farrell, 1954; Suits, 1958; Bernanke, 1984; and Eberly, 1994). A handful of studies have relied on panels of country-level observations, and have in some cases used such estimates to project future car ownership. The most extensive study to date, to our knowledge, has relied on a panel of 45 countries since 1960 (Dargay *et al.*, 2007).

[3] Indeed, vehicle ownership is already growing fast in China – from 5.5 million in 1990 to 37 million in 2006 according to the International Energy Agency's *World Energy Outlook 2007*.

In this paper, we extend the work to a much larger panel of countries, and also analyse long time series information for several European and other countries that are now advanced. Beyond the use of a richer data set, we build on Storchmann's (2005) emphasis on the importance of income distribution and 'threshold' effects. While previous studies have used flexible (if somewhat ad-hoc) functional forms allowing for different elasticities of car ownership with respect to per capita incomes at different income levels, we start from the simple observation that car ownership seems to rise suddenly beyond a per capita income threshold (which we estimate). Based on income and inequality measures, we estimate the share of the population whose income is above that threshold. This simple and intuitive approach fits the data well, and has quantitatively substantive implications for our projections in emerging market countries, notably China and India. More importantly, this is the first study, to our knowledge, to derive projections of car ownership from household-level data for China and India – the countries that are expected to experience the largest increases in ownership over the next decades.

Having estimated the relationship between incomes and car ownership from different angles, we then project that the number of cars will increase by 2.3 billion (that is, by about 350%) worldwide by the year 2050, with the bulk of the increase occurring in emerging market countries, especially China and India. Indeed, we project substantially faster growth in car ownership in these two important countries, compared with previous studies (and controlling for different assumptions regarding future economic growth).

What do these projections imply for economic policy at the national and international level? Should emerging market countries use their vast – and today still cheap – labour resources to build roads or railways/metro lines? Should international agreements seek to moderate the demand for cars, or perhaps provide incentives for greater reliance on less polluting types of cars? Clearly there are myriad policy options that could be considered: taxes, subsidies, regulations, and standards on particular types of cars or fuels, in the context of domestic policies or international initiatives. We certainly do not pretend to have answers that we can back up with quantitative analysis for all these policies. In this paper, we offer some general thoughts on possible options where further investigation would seem to be especially valuable, particularly where these can be linked – in an admittedly tentative manner – to our estimation results (e.g., regarding the sensitivity of car ownership to gasoline prices).

2. CAR OWNERSHIP IN PANELS OF COUNTRIES

We begin by drawing on data for panels of countries to establish the non-linear relationship between per capita incomes and car ownership, with a take-off around a fairly robust per capita income level of US$5000 (in 2000 prices). We first take the long-run view, considering car ownership over the past decades for many countries, and going back to the economic boom years of the immediate post-World War II

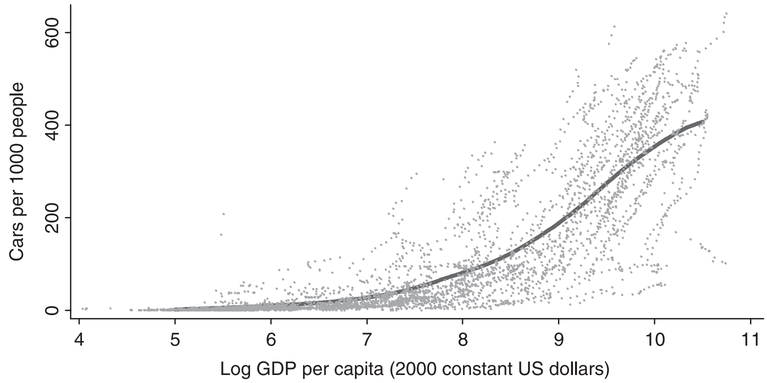

Figure 2. Car ownership and real per capita income in a panel of countries (1970–2003)

Notes: Line corresponds to the fitted values from a locally weighted regression. The data refer to 122 countries over 1963–2003 (3255 actual observations, owing to missing data).

Data sources: Car ownership from *World Road Statistics*, International Road Federation; real per capita income from World Development Indicators, World Bank.

period for several of today's most advanced economies. Simple plots of car ownership over time (or against growing GDP per capita) provide strong suggestive evidence that a rapid take-off in car ownership seems to be the historical norm. We then turn to cross-country regressions for the most recent data. This allows us to exploit the information from the largest cross-section of countries, but also helps us to introduce our estimation method in the simplest and most transparent way. Finally, we run panel regressions which we will then draw on as the baseline estimates ultimately to project future car ownership.

2.1. The long-run view

The same relationship that we saw in the cross-sectional scatter plots presented in the introduction is also apparent in a panel of countries: based on data for 122 countries over 1970–2003, car ownership (per thousand people) is initially low at per capita incomes below US$5000 in 2000 prices (about 8.5 in a log scale), but increases rapidly with income levels thereafter (Figure 2). There does not seem to be evidence of satiation: even at the highest income levels, the semi-elasticity of car ownership with respect to per capita income (the change in cars per person for a given percentage change in per capita income) remains high, though it falls slightly beyond a per capita income of US$10 000 (log GDP per capita approximately 9.25), hence the (elongated) S-shape. The wide dispersion of data points around the local-weighted regression line shows that the relationship between car ownership and per capita incomes is far from perfect. Nevertheless, it is worth noting that car ownership is more closely related to income levels than are other consumer goods or other indicators of material well-being (for example, the socio-economic indicators analysed by Easterly, 1999).

The same message holds focusing on the time series information. Long time series data are available for the United States (since 1900, from national sources), Japan, and 13 European countries (since 1951, from national sources and *Annual Bulletin of Transport Statistics for Europe and North America*). These data confirm the 'boom' in ownership rates for a number of advanced countries, notably postwar Europe and Japan around a real income of US$5000, even though the take-off occurred at different times in different countries (Figure 3). Low rates of car ownership in Japan and Europe prior to 1960 were, in our view, primarily the result of low per capita GDP levels: the technology for mass car ownership was clearly available – mass car production and ownership had been in place in the United States even before World War I.

Although our interest is primarily in the take-off of car ownership in the relatively early stages of economic development, we also note that there is little evidence to date of satiation even in the most advanced countries, despite an apparent consensus on the likely importance of this phenomenon according to previous studies of car demand. The decline in car ownership according to the official statistics in the United States beginning in the early 1990s is largely the result of a change in definition: personal use vans, minivans, and utility-type vehicles are no longer defined as cars. The apparent slowdown in the growth of car ownership in Japan in the 1990s is due to the slowdown in GDP growth: against a GDP per capita scale, the growth in car ownership in Japan is still quite strong. And ownership is still growing rapidly throughout Europe.

2.2. Preliminaries: cross-country regressions, methodology and functional forms

Having observed the broad relationship between car ownership and per capita incomes through a number of charts, we now introduce our methodological approach and turn to regression analysis. An important element in our approach relates to how overall per capita income levels and their within-country distributions interact to determine car ownership. In this respect, the main explanatory variable we focus on is the share of population above a certain income threshold. The simple theoretical rationale is presented in Box 1, which draws on the seminal work of Farrell (1954). A compelling theoretical case for a similar 'threshold' approach has been made by Storchmann (2005), who traces its implications for the interaction of average income and inequality in determining car ownership. In turning to empirical estimation for a panel of 90 countries over 1990–97, however, Storchmann (2005) focuses on the interaction of per capita income with measures of inequality such as the Gini coefficient, and the changes in such interaction as per capita income grows. In our paper, we take a more 'structural' approach, by empirically relating car ownership to the share of a country's population above an income threshold, which in turn we estimate so as to achieve the best fit.

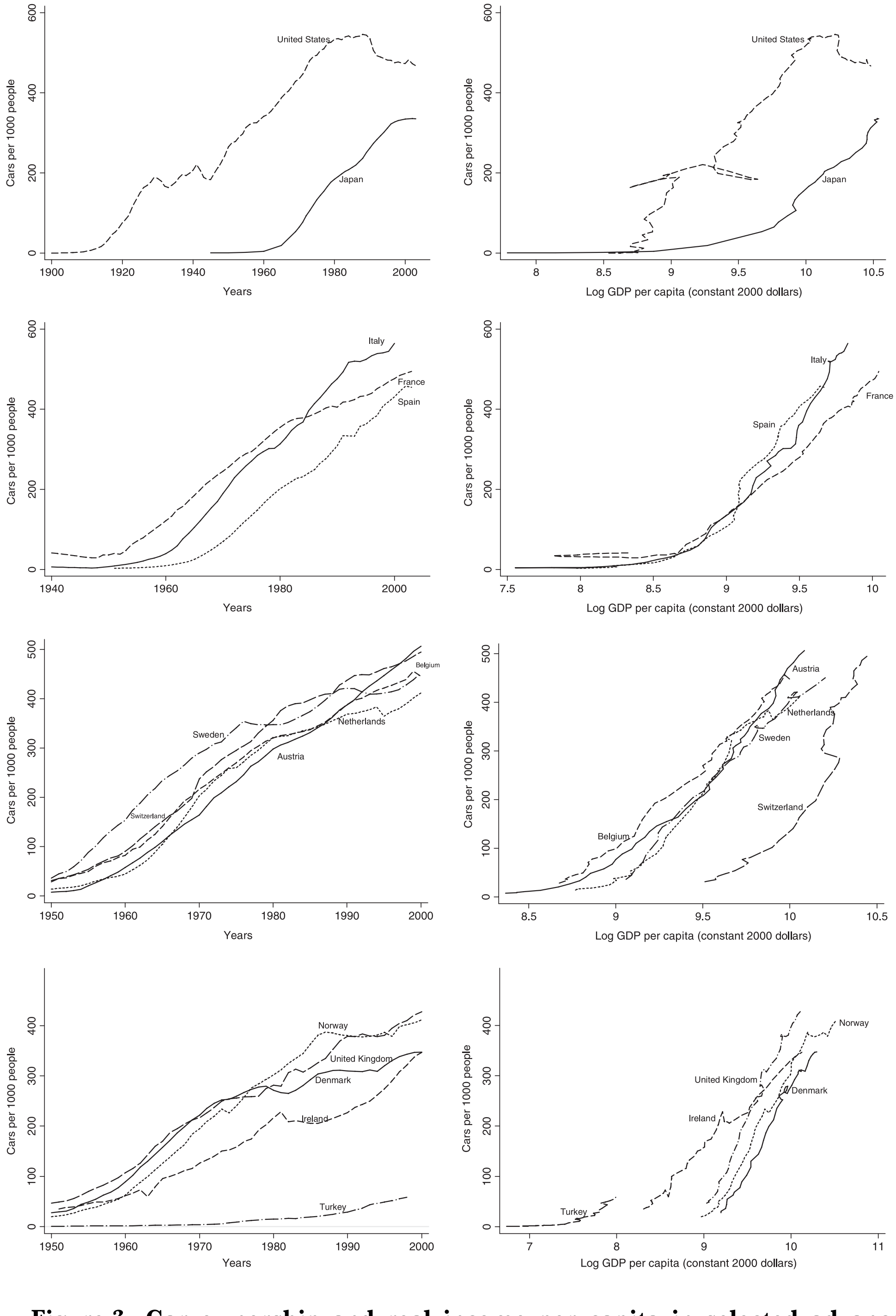

Figure 3. Car ownership and real income per capita in selected advanced economies

Sources: Car ownership from national sources; income from Maddison (2003). See Data Appendix.

Box 1. The income 'threshold' approach

In this paper, we emphasize the lumpiness of cars and argue that this plays an important role in explaining why car ownership rates are low and somewhat insensitive to increases in countrywide per capita income levels among poor countries, whereas per capita income becomes a major determinant of ownership once a middle-income level is reached. A key variable in our empirical analysis is the share of a country's population that is above a given income threshold for car affordability.

The association of an individual's car consumption with his or her income being above a threshold is formalized in Farrell (1954). In that model, individuals differ in their tastes with respect to cars, which in turn affects how rich they have to be before buying a car. Intuitively, someone who particularly likes cars is more willing to forsake the consumption of other goods, and will buy a car provided he or she can afford it. On the other hand, someone who does not like cars much will only buy one if he or she is very rich. Each level of this 'taste' for cars will be associated with an income threshold for ownership. Conversely, for a given level of income, there will be a corresponding taste threshold for buying a car. The probability that an individual with a given income level will own a car is just the probability that the individual's taste is above the threshold associated with her income level. Farrell (1954) assumes a log-normal distribution function for tastes, and uses data from a large sample of US families divided into nine income groups to estimate the ownership levels associated with different income levels.

This approach is well founded, and conceptually appealing. However, it would be impractical to apply it directly to a large number of countries, as it requires disaggregated data. One way to simplify the analysis is to assume that tastes can only attain two levels: one in which individuals will own a car if they can afford to, and one in which they will not. Such binary distribution of tastes implies a single income threshold for car ownership. Moreover, since there is a single (homogeneous) threshold at the individual level, this same threshold would explain the countrywide ownership pattern (i.e. there are no aggregation problems). Of course, assuming a binary distribution is an oversimplification of the actual problem being studied. But the binary distribution can provide a first approximation to a richer setting where tastes among those prone to buying a car are tightly distributed. For example, consider a bimodal distribution, where there are a number of individuals who would not buy a car even if they were rich (e.g., minors and the very elderly will not own a car even if they are part of a rich household). If among the individuals that would buy a car provided they are sufficiently rich there is variation in tastes, each level of taste will be associated with a different income threshold. But if the variation in tastes is sufficiently small, the different income thresholds can be approximated by a single income threshold (since the mass of the income distribution in that range of varying income thresholds is small). Given the nature of our exercise, we make this simplifying assumption, considering a single income threshold when taking this simplified model to the data.

An alternative approach, undertaken for example by Dargay *et al.* (2007), is to estimate the relationship between vehicle ownership and per capita income using a 'Gompertz' function, which allows different curvatures at different income levels, and explicit estimation of a 'saturation' level for different countries depending on various explanatory variables. With theory giving limited guidance regarding the exact functional form taken by the relationship we opted for what seems to us a simple and intuitively appealing approach, recognizing of course that this may ultimately be an empirical matter.[4] Based on past experience – including in the most advanced countries (see, for example Figure 3) – information on saturation levels seems to be rather limited: no country seems near saturation yet. Thus we do not emphasize the issue of saturation, nor do we attempt explicitly to estimate saturation levels, focusing instead on the 'take-off' that seems to be especially relevant for developing and emerging market countries.

In order to estimate the share of population above a certain income threshold in the data for each country, we follow the approach used in Dollar and Kraay (2002): we assume a log-normal income distribution whose mean is given by the level of GDP per capita, and whose variance is estimated based on the Gini coefficient.[5] Since cars are a tradable good, our income measure is based on GDP in constant 2000 US dollars, which, as appropriate, does not incorporate PPP adjustments. Table 2 presents summary statistics for our sample.

Table 3 presents regression results based on a cross-section of 122 countries in 2000.[6] As expected, car ownership increases with income.[7] All else equal, one would expect higher inequality to increase the growth in ownership rates at low levels of income,

[4] More generally, one could consider various functional forms. For example, we experimented with a Box–Cox transformation of the dependent variable. In the end, we did not find compelling evidence that more complicated functional forms would lead to substantially different projections, and opted for the simple approach adopted in the paper.

[5] Although the approach provides a useful approximation for the share of the population above a certain threshold, a number of possible limitations need to be noted. The approach combines figures from different data sources (and based on different concepts): the mean of the distribution is based on the national accounts, while the Gini used to estimate the variance comes from household surveys. Moreover, per capita GDP can be substantially higher than average household income (which would have been more appropriate had it been readily available for a sufficient number of countries). Finally, the assumption of log-normality may imply imperfect approximation when focusing on the tails of the distribution.

[6] Whenever an observation was missing for a country, we used the data from the closest available year.

[7] We report a linear relationship (rather than, say, a Tobit) between car ownership and the logarithm of per capita income primarily for illustrative purposes, because a number of previous studies have used this functional form.

Table 2. Summary statistics

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
log(GDP per capita)	3255	7.64	1.59	4.03	10.74
Gini coefficient	3255	38.96	11.50	14.69	73.90
No. of cars/1000 people	3255	116.97	149.22	0.05	641.17
Gasoline price	365	64.62	27.63	2.00	133.00
Urbanization	3255	51.16	23.36	4.48	97.16
Household size	3062	4.30	1.34	2.20	8.80
log(Population density)	3160	3.72	1.36	0.12	6.88

Notes: Unbalanced panel of 122 countries for 1963–2003. Data on cars from World Road Statistics, International Road Federation; GDP per capita, urbanization, household size, and population density from the World Bank's World Development Indicators; Gini coefficient from the UNU/WIDER World Income Inequality Database. See Data Appendix for sources.

because higher inequality increases the number of households with sufficiently high income to buy a car. However, at a more advanced stage of development, higher inequality will have the opposite effect, by creating a larger mass of poor households that cannot afford a car despite a relatively high average income in the country. The estimated impact of inequality alone is negative; however, when inequality, income and their interaction are all entered in the same specification, the coefficient on inequality becomes positive whereas the coefficient on its interaction with income is estimated to be negative. Thus, higher inequality increases car ownership at low levels of income but decreases it at high levels of income, as suggested by our priors. Moving to our preferred approach, column 6 presents estimates where the share of population above a certain income threshold is used instead of income, inequality and their interaction. The income threshold is chosen (through a grid search) so as to maximize the regression's adjusted R^2 coefficient. For example, when only this threshold variable is used as a regressor (column 6, Table 3), the optimal threshold is found to be \$4500, and this univariate regression yields an R^2 of 0.83. The estimated slope coefficient suggests that a one percentage point increase in the share of the population with income above \$4500 leads to an increase in car ownership by 4.3 cars per thousand inhabitants. When further control variables are introduced (columns 6–11), the optimal threshold remains at US\$4500–5000.

The threshold approach fits the data well despite its simplicity. While this threshold variable by itself does slightly worse in terms of overall R^2 than log(GDP), Gini and its interaction, its coefficient still remains significant and quantitatively important even when those other three variables are included. Inspection of the residuals corresponding to columns 3 and 7 in Table 3 reveals that the specification underlying column 3 fits very well low income countries, but its fit for emerging market countries (where most of the growth in car ownership over the next half a century will take place) and advanced countries is far worse than that of the specification underlying column 7. Beyond better fit for the most relevant country group from the standpoint

Table 3. Income, inequality and car ownership in a cross-section of countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Log(GDP per capita)	88.31**	73.47**	186.8**	63.60**	52.58**		5.858	106.6**		−3.793		−3.344	−7.336
	(5.53)	(4.87)	(11.3)	(7.42)	(7.68)		(8.57)	(20.6)		(9.28)		(9.65)	(9.07)
Gini coefficient		−4.440**	18.82**	−4.171**	−3.922**			11.32**					
		(0.70)	(1.98)	(0.74)	(0.73)			(2.35)					
Log(GDP per capita) × Gini			−3.161**					−2.041**					
			(0.27)					(0.36)					
I(Optimal threshold)						429.5**	409.9**	211.4**	352.3**	364.2**	341.5**	352.6**	334.8**
						(19.9)	(46.5)	(56.9)	(29.9)	(48.0)	(32.4)	(52.0)	(45.9)
Urbanization				−0.799	−0.806				−0.0687	0.010	−0.0440	0.0233	−0.0221
				(0.50)	(0.52)				(0.36)	(0.44)	(0.41)	(0.48)	(0.46)
Household size				−33.55**	−24.70**				−33.03**	−33.31**	−42.76**	−43.02**	−25.73**
				(6.84)	(6.37)				(7.99)	(7.93)	(8.65)	(8.66)	(7.03)
Log(population density)				−16.01*	−2.917				−5.715	−5.497	−8.406	−8.156	6.160
				(7.51)	(8.42)				(5.56)	(5.57)	(5.70)	(5.70)	(5.77)
Gasoline price											−0.206	−0.226	
											(0.31)	(0.32)	
Log(road miles per capita)					39.80**								36.51**
					(10.9)								(10.8)
Constant	−525.8**	−237.2**	−1098**	81.41	1.665	6.618	−25.36	−582.9**	206.4**	227.6**	271.2**	290.8**	132.7
	(38.6)	(48.4)	(90.0)	(74.4)	(76.3)	(5.83)	(48.8)	(130)	(53.5)	(63.0)	(63.1)	(75.7)	(70.9)
Estimated optimal threshold						4500	5000	5000	5000	5000	5000	5000	5500
Observations	122	122	122	111	111	122	122	122	111	111	99	99	111
Adjusted R^2	0.71	0.78	0.87	0.81	0.83	0.83	0.83	0.88	0.86	0.85	0.87	0.87	0.87

Notes: Robust standard errors in parentheses. * significant at 5%; ** significant at 1%. See Data Appendix for sources.

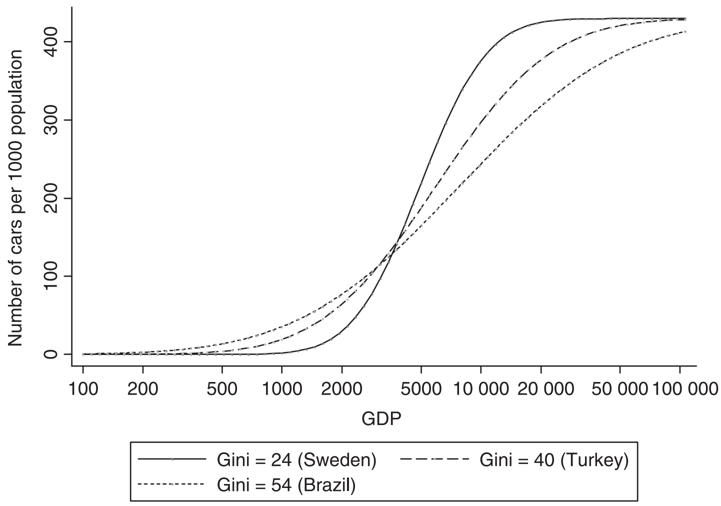

Figure 4. Impact of income growth on car ownership at different levels of inequality

Notes: Based on column 6, Table 3. Income measured on a logarithmic scale.

of projections, we focus on the threshold variable for a number of reasons. The threshold approach naturally delivers the observed S-shaped pattern for the relationship between car ownership and income.[8] The more 'reduced form' approach of adding income, inequality and its interaction risks 'overfitting the data', and is less able to capture the strong non-linearity with respect to income. Indeed, projections based on this approach can yield implausibly large estimates for emerging market countries (as shown for the case of India in a robustness exercise later in the paper). It is difficult to provide micro-foundations for the reduced form approach, unlike our preferred approach (Box 1). The income threshold approach imposes more structure in the model, and if that is indeed the relevant channel through which income and inequality affect car ownership, the estimated relationships are less likely to 'break down' over time, particularly in a long-term horizon where average income is expected to increase several-fold in key countries. Thus, it should prove more appropriate for the extrapolation exercises conducted in this paper.

The implications of interaction of the income threshold effect and income inequality are illustrated in Figure 4, which shows the evolution of car ownership rates as a function of income per capita for three hypothetical countries: a high inequality country (whose Gini coefficient is set to equal that of Brazil in 2000), an intermediate

[8] If income has a bell-shaped distribution, growth will cause an increasingly large mass of households to cross an income threshold that lies above the average income (since we are moving from the tail to the fat part of the distribution). Conversely, once the average income is above that threshold, further growth will bring an increasingly small mass of households above the threshold (since we are moving from the fat part of the bell to its tail).

inequality country (whose Gini coefficient is set to equal that of Turkey), and a low inequality country (whose Gini coefficient is set to equal that of Sweden). At low levels of income, there are more cars in the high inequality country. But as incomes rise, the low inequality country will have a higher ownership rate, and reach a saturation level faster (at per capita income levels well beyond those observed so far).

As for the other control variables, in principle the effect of household size on car ownership is ambiguous. Households tend to be larger in poorer countries. Controlling for income, larger households may be more likely to buy a car because it is a 'public good' within the household. But larger households may have a larger dependency ratio, lowering the resources available for buying a car, and may also dilute per capita ownership if households have a satiation point at one or two cars. In our estimates, household size has a negative and significant effect on ownership. Population density (in logarithms, to reduce the impact of outliers) and urbanization do not have much explanatory power.

Gasoline prices – which in the data display substantial cross-country variation, mostly due to variation in taxes – do not have a statistically significant effect on ownership. (They do have a negative and significant impact in a few specifications, but the results are not robust.) As we will discuss in more detail when presenting our panel estimates (Section 2.3), previous studies have shown that although higher fuel prices have a significant impact on fuel consumption, the bulk of the effect occurs through a shift toward vehicles characterized by greater fuel efficiency and a reduction in the number of vehicle miles travelled.

The availability of roads (and railways) may also be expected to play an important role in determining car ownership. The logarithm of the number of road miles per capita is positively and significantly associated with car ownership. However, endogeneity issues are likely to be a source of concern: in particular, the length of the road grid itself may be determined by the size of the car fleet.[9] To explore the possibility that railways might act as a substitute, we also estimated the relationship between car ownership and the logarithm of the ratio of total road miles to railway miles to the list of regressors. We found a positive relationship, but not significant in most specifications (not shown, for the sake of brevity).

In regressions (cross-section and panel) whose results are also not shown for the sake of brevity, we also included the logarithm of the PPP index (both in isolation, and interacted with the income threshold variable) as an additional control. The economic rationale is that the PPP index is a proxy for how much non-tradable consumption economic agents would need to forsake in order to purchase a car. In most specifications, the estimated coefficients turned out to be small in magnitude, and the results were fragile to changes in specification.

[9] In the United States, the number of new homes built in the suburbs increased dramatically in the immediate aftermath of World War II; a couple of years later, the sale of cars took off rapidly; finally, again a couple of years later, in response to traffic congestion, new roads started to be built linking the suburbs to the main US cities (Meyer and Gómez-Ibáñez, 1981). The sequence of events suggests that road building is endogeneous to developments in car ownership.

2.3. Panel regressions

Moving from a single cross-section to a panel substantially increases the data available for estimating the demand for cars and makes it possible to exploit the time-series information in the data. But it also raises a number of issues related to the appropriate specification, particularly for the threshold variable discussed above. We might wonder, for example, whether the optimal income threshold for explaining car ownership and the effect of crossing that threshold vary over time. Figure 5 plots the results of regressions of car ownership on the threshold variable for repeated cross-sections over time (one cross-sectional regression per year, beginning in the early 1960s). Figure 5a shows the income threshold that maximizes the fit of the regression, and suggests that a constant threshold around $5000 would provide an adequate fit from 1970 onwards. Figure 5b shows the corresponding effect on ownership of crossing that threshold, which has become stronger over time. Finally, Figure 5c shows the constant coefficient in those regressions, and does not suggest any significant trend over time.[10] A formal test of the null hypothesis that (a) the threshold, (b) the impact of crossing the threshold and (c) the intercept are constant over time rejects the null hypothesis for (a) and (c) but not for (b). (These results are reported in the appendix.)

These changes over time may be driven, at least in part, by a trend decline in the relative price of cars: the relative price of a new car in the United States (measured as the CPI for new cars divided by the overall CPI index) declined by 50% from 1970 to 2006. To make it possible for our panel regressions to capture such coefficient changes over time, we adopt two approaches. The first is to include the relative price of new cars in the United States as an interaction term with the income threshold variable. (Unfortunately, new price data for all countries were not available.) The second – which we use as our baseline approach – is to take a more agnostic approach and include an interaction between the income threshold variable and a time trend. As shown in Figure 6, however, the relative price of new cars over the past three decades has declined at a fairly steady pace, implying that the two approaches (interaction with car prices or interaction with a time trend) yield similar messages. While this declining relative (quality-adjusted) price of cars can help explain a rising coefficient for the income threshold variable, one might wonder why the income threshold itself is not being affected. After all, if cars are becoming cheaper, more and more households should be able to afford them. A possible explanation is that most of the decline in the relative (quality-adjusted) price of cars is due to quality adjustments, and that the real price of a 'standard, best-selling' car of the day has not declined. Tentative support for this possibility is provided by the example of a Toyota Corolla in the United States, which cost US$1876 in 1970 – that is, US$9443 in 2005 dollar

[10] The spikes for the *unbalanced* panel lines in the figures in the early 1990s in particular simply reflect the introduction of new countries in the sample.

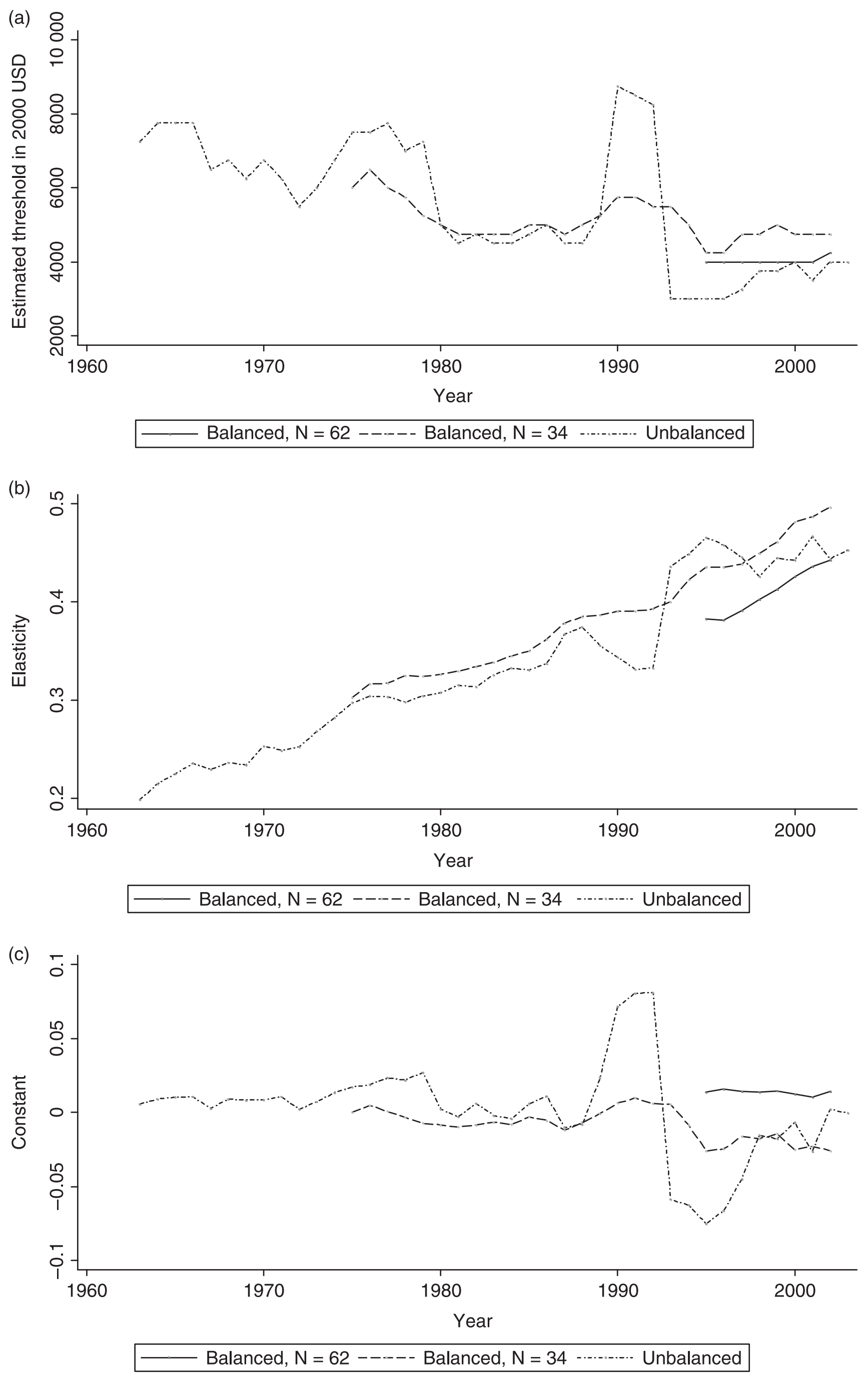

Figure 5. Regressing car ownership on share of population above income threshold, repeated cross-sections: (a) Optimal estimated threshold; (b) Impact of crossing optimal threshold on car ownership; (c) Intercept of regression

Notes: The unbalanced sample uses all available data. The 62-country balanced sample has data since 1995. The 34-country balanced sample has data since 1975.

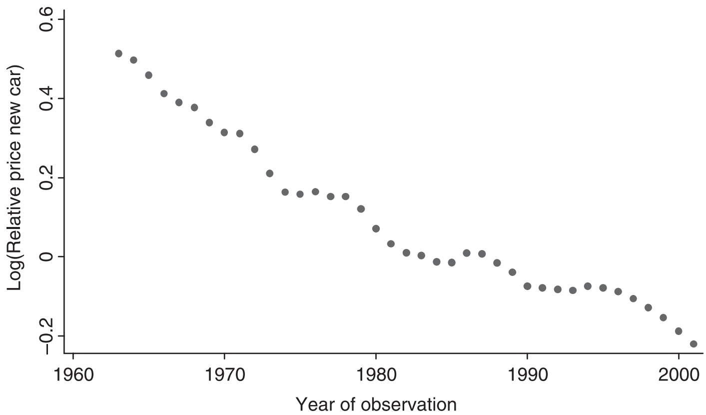

Figure 6. Relative price of new cars in the United States

Note: The data are drawn from the US Bureau of Labor Statistics, and refer to the logarithm of the consumer price index for new cars as a ratio to the overall consumer price index.

terms (inflated by the general CPI) – and \$17 545 in 2005.[11] Presumably the increase is much smaller (and perhaps the real price even declines), once we take into account the addition of ABS breaks, air bags, electric windows, and a host of other features that the older model did not have and are now standard.

We are now ready to present our main panel results. Table 4 regresses the number of cars per 1000 people on the share of population above a certain income threshold, the interaction of that share with time, and controls for urbanization, average household size and population density. Our preferred specification includes country fixed effects, the controls mentioned above, and a time trend for the effect of crossing the income threshold on ownership. In that preferred specification, the threshold value that maximizes the R^2 is \$4500. A one percentage point increase in the share of the population above that threshold would increase vehicle ownership in 2005 by 4.6 cars per thousand inhabitants. In 1970 the increase would have been by two cars per thousand inhabitants. Country specific factors accounted for by the fixed effects might include, for example, differences in car taxation, trade restrictions, or distribution arrangements. For example, the country with the highest fixed effect is the United States.[12]

Factors other than income (or its distribution) have either an insignificant or a small impact on car ownership. The coefficient on urbanization is small and not statistically significant when country fixed effects are considered. In our estimates, household size has a small negative effect on car ownership without country fixed

[11] The price of a Toyota Corolla rose in the 1970s and 1980s, but has been essentially stable since 1990 (data from *Consumer Reports*, various issues, by the Consumers Union of the United States).

[12] The difference between the fixed effect for the United States (the advanced country with lowest gas taxes) and that for the United Kingdom (the advanced country with the highest gas taxes) amounts to 214 cars/1000 people.

Table 4. Determinants of car ownership in a panel of countries

	No fixed effects			Fixed effects				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
I(Optimal threshold)	386.34	455.67	396.4	616.98	395.66	409.2	288.8	335.3
	(20.2)**	(17.2)**	(23.8)**	(11.8)**	(12.0)**	(12.2)**	(13.7)**	(15.0)**
I(Optimal threshold) × (year-2000)		6.72	6.84		7.35	7.36		4.09
		(0.70)**	(0.69)**		(0.18)**	(0.16)**		(0.48)**
Log(new US car rel. price)							−17.00	
							(2.81)**	
I(Optimal threshold) × Log(new US car price)							−411.5	−204.3
							(11.1)**	(28.0)**
Urbanization			0.25			0.76		
			(0.29)			(0.20)**		
Household size			−21.07			45.86		
			(6.17)**			(4.22)**		
Population density			−9.46			−25.64		
			(4.97)			(4.01)**		
Constant	13.26	2.83	140.7	0.64	25.20	−125.0	34.15	31.57
	(4.30)**	(3.83)	(43.5)**	(2.22)	(4.38)**	(19.7)**	(4.29)**	(4.40)**
Estimated optimal threshold	7000	5000	5500	11500	5000	4500	5500	5000
Observations	3255	3255	2967	3255	3255	2967	3255	3255
R-squared	0.79	0.84	0.85	0.72	0.83	0.84	0.82	0.83

Note: Robust clustered (by country) standard errors in parentheses. *R*-squared is adjusted *R*-squared for no fixed effects, and within *R*-squared for fixed effects. See Data Appendix for sources.

* significant at 5%; ** significant at 1%.

effects, which becomes positive once fixed effects are included (a one standard deviation in household size would raise ownership rates by 5%). Finally, population density has a negative, though small effect on car ownership: in the regressions without fixed effects, moving from the 25th to the 75th percentile of population density in 2005 would lower car ownership by 17 cars per thousand people; in the regressions with country fixed effects, increasing the logarithm of population density by one standard deviation of its within-country variation would lower car ownership by 4 cars per thousand people.

Note that since the effect of crossing the income threshold is allowed to vary over time, the relationship between car ownership and income will no longer completely 'level off' at high levels of income. Although it will still follow an 'S-shape', the relationship will exhibit a positive slope even at high levels of income. This may help explain why satiation does not seem to have been reached even in the most advanced countries.

Our use of a time trend reflects an agnostic approach to the factors underlying changes over time. A reasonable guess is that those changes may reflect the secular decline in the relative price of cars, illustrated in Figure 6. To explore this possibility, we ran the panel regressions using the logarithm of the price of new cars relative to the overall consumer price index for the United States. We found that indeed declining car prices have played a significant role, and probably underlie much of the explanatory power of the more agnostic trend variable. This said, in regressions that include not only an interaction with car prices but also an interaction with a trend (Table 4, column 8), both remain statistically significant, suggesting that falling prices of cars do not account for the full explanatory power of the more agnostic trend variable. A further reason why we use the results with a trend, rather than new car prices, as our baseline is that when moving to projections of car ownership, we would have little information to guide us in projecting car prices and would probably end up simply extrapolating a continued downward trend in car prices – which is essentially equivalent to our baseline approach.

An alternative approach for introducing dynamic considerations in this model is to introduce a lagged dependent variable. Table A2 in the appendix shows that the results – notably the estimated threshold – are broadly consistent with those presented above, and discusses our rationale for not choosing a dynamic specification as our baseline.

The regressions reported in Table 4 did not include gasoline prices as a control, because that variable is only available for 365 observations (about 11% of our panel, covering 102 countries). Table 5 shows the estimated effect of gasoline prices on car ownership in the sub-sample for which data are available. The estimated effect is not statistically significant, and the economic magnitude is rather small. In our data set, most of the variation in gasoline prices is cross-sectional: the variation in gasoline prices across countries in a given year is larger than the typical variation over time for a given country. But the effect of gasoline prices on car ownership seems to

Table 5. Gasoline prices and car ownership

	No fixed effects				Fixed effects	
	(1)	(2)	(3)	(4)	(5)	(6)
I(Optimal threshold)	424.56	431.71	440.14	448.92	294.64	299.65
	(20.1)**	(22.7)**	(19.8)**	(22.4)**	(63.6)**	(63.3)**
I(Optimal threshold) × year			11.39	11.56	8.52	8.50
			(2.62)**	(2.57)**	(0.79)**	(0.80)**
Gasoline price		–0.19		–0.22		–0.04
		(0.21)		(0.22)		(0.09)
Constant	2.21	11.64	3.96	15.24	48.06	49.03
	(6.7)	(13.14)	(6.63)	(13.4)	(24.2)*	(24.06)*
Threshold	4000	4000	4000	4000	3500	3500
Observations	365	365	365	365	365	365
R-squared	0.84	0.84	0.85	0.85	0.59	0.59

Note: Robust clustered (by country) standard errors in parentheses. *R*-squared is adjusted *R*-squared for no fixed effects, and within *R*-squared for fixed effects.

* significant at 5%; ** significant at 1%.

remain negligible even when we do not include country fixed effects or, as shown above, when we run the regression in a single cross-section. To the extent that cross-sectional variation in gasoline prices captures 'permanent' differences (e.g., gasoline in the United Kingdom being multiple times as expensive as in the United States), our results do not uncover a statistically significant impact of gasoline prices on vehicle ownership rates even in the long run.[13]

While these results might at first seem surprising, they are in line with previous studies. For example, based on a panel of 12 advanced countries for 1973–92, Johansson and Schipper (1997) estimate the long-run elasticity of vehicle ownership with respect to fuel prices at –0.1: the bulk of the estimated impact of fuel price changes on fuel usage comes instead through changes in the type of cars driven and in the number of vehicle miles travelled. Storchmann (2005) reports similar findings based on a panel of 90 countries in 1990–97 (with estimates ranging from –0.17 to –0.05). The results are also consistent with longer time-series studies based on data for a single country or a limited number of countries (see Graham and Glaister, 2002, for a comprehensive survey).

Although gasoline prices seem to have a limited impact on vehicle ownership, many previous studies have found a significant response of fuel consumption to fuel prices (see Box 2). In particular, higher gasoline prices seem to affect the type of

[13] Cross-sectional analysis of the relationship between gasoline prices and car ownership, or between gasoline prices and the fixed effects from our panel regressions, yields tentative evidence of a negative link among advanced countries, but the link is completely driven out by the inclusion of emerging markets and developing countries in the sample (not reported for the sake of brevity).

Box 2. Estimates of the elasticity of demand for automobile fuel with respect to fuel prices

A host of studies have estimated the response of motorists to fuel price changes, both in the long run and in the short run. Surveying the literature, Graham and Gleister (2002) report that most studies of the elasticity of demand for automobile fuel with respect to fuel prices on OECD countries find short-run elasticities ranging between –0.2 and –0.4, and long-run elasticities ranging between –0.6 and –1.1.

Considering various studies on US data undertaken at different times over the past couple of decades, Parry *et al.* (2007) observe that more recent studies find a somewhat smaller response of fuel consumption to changes in fuel prices than was the case in earlier studies. The authors suggest that the decline in elasticity may reflect a fall in fuel costs relative to the value of travel time, as wages increase. They also decompose the factors underlying the long-run response of fuel consumption to increases in fuel prices, suggesting that roughly a third of gasoline demand elasticity is accounted for by changes in vehicle miles travelled, whereas the remaining two-thirds reflect long-run changes in average fleet fuel economy, as manufacturers incorporate fuel-saving technologies into new vehicles and consumers choose smaller vehicles. More generally, Graham and Gleister (2002) report that estimated elasticities of traffic levels with respect to fuel prices – both in the short run and the long run – are lower than is the case for elasticities of fuel usage.

Studies on developing countries are less abundant, perhaps owing in part to lower rates of car ownership. They find fuel demand elasticities with respect to fuel prices that are, for the most part, at the lower end of the spectrum identified by studies based on advanced economies: –0.2 in the short run and (a perhaps surprisingly small) –0.3 in the long run for India (Ramanathan, 1999); –0.1/–0.2 in the short run and –0.6/–0.8 for Indonesia (Dahl, 2001); and –0.1 in the short run and –0.5 for Sri Lanka (Chandrasiri, 2006). Estimates based on a panel of states for Mexico yield far higher elasticities: –0.6 in the short run and –1.1/–1.2 in the long run (Eskeland and Feyzioglu, 1997). It is not clear why, on the whole, own price elasticities of fuel are estimated to be on the relatively low side in developing countries, where one would perhaps expect gasoline expenditures to be a relatively large item in total expenditures of those households that own a car. It is possible that those households that own cars are the richest, and their behaviour is therefore insensitive to variation in gasoline prices. More likely, changes in other determinants of car ownership (including changes in per capita incomes, but also factors that are difficult to control for and act as omitted variables) have major implications for car ownership, so that the impact of changes in gas prices is hard to detect.

vehicles used and distances driven. That is, all else equal, higher gasoline prices will not cause Europeans to own fewer cars than their American counterparts, but may cause them to buy small cars instead of gas-guzzling (and, occasionally, military-looking) vehicles, and to travel by car for a lower number of total miles. Unfortunately, direct tests of this hypothesis using our data set are prevented by the limited availability of information on fuel efficiency on a comparable basis across countries: IRF has data on fuel use, but those data are only available for the entire fleet of vehicles. Previous studies that have painstakingly constructed measures of fuel intensity and driving distances show a sizeable effect of gasoline prices on those variables. For example, Johansson and Schipper (1997) estimate the elasticity of fuel intensity with respect to prices to be –0.4, and the elasticity of driving distances with respect to fuel price to be –0.2. (By comparison, the elasticities of fuel intensity and driving distances with respect to income are estimated to be 0.0 and 0.2, respectively.) Storchmann (2005) estimates the price elasticity of gasoline consumption to range from –1.04 to –0.78.

Our finding that gasoline prices do not seem to have a statistically significant impact on the overall number of cars, combined with previous evidence that higher gasoline prices may lead consumers to choose more fuel-efficient cars and to drive shorter distances, would seem to have potentially important normative implications. The fact that adjustment to higher gasoline prices seems to take place in the 'intensive' rather than in the 'extensive' margin suggests a smaller welfare cost for increases in gasoline taxation: people can still own a car – but a smaller one – and use it for a lower number of vehicle miles traveled. As we will see in Section 5, some externalities depend on the number of vehicles, others on total miles travelled, and others still on average fuel efficiency.

3. HOUSEHOLD-LEVEL ESTIMATES FOR CHINA AND INDIA

This section of the paper presents results based on a household-level estimation of car ownership rates in China and India. While car ownership remains relatively rare in these countries, household-level data make it possible to obtain valuable information about the level of income at which their households become more likely to own cars. By understanding the consumption behaviour of today's well-off households, we can project how the Chinese and Indian households will behave once economic growth brings the average household to a similar level of affluence. Perhaps the main advantage of using household-level data is that it may be able to capture factors specific to these countries that could be otherwise missed in panel estimates.

3.1. China

Our estimates are based on a subset of the 2005 Urban Household Survey covering 21 846 households in 10 provinces/municipalities, which was made available through a special collaboration agreement with China's National Bureau of Statistics for a project describing the evolution of income and consumption patterns in urban China (Chamon *et al.*, 2008). This section uses the results to predict the evolution of car ownership patterns over time.

In our sample, there were 3.68 cars per 100 households in 2005, with 3.55% of households owning a car: only 0.10% owned two cars, and only 0.02% owned three cars. In per capita terms, average ownership was 1.2 cars per 100 people, similar to the ownership rate based on aggregate data and used in our panel estimates.[14] Average per capita disposable income in our sample is RMB10 950, that is, US$1335 at 2005 exchange rates, or US$1132 when deflated to 2000 constant dollars. This average income is lower than GDP per capita, as expected.[15]

We use two regression methods to analyse the relationship between car ownership and income: probit and non-parametric estimations. Ideally, we would like to estimate an ordered probit for different levels of car ownership. But the very limited number of households with more than one car does not allow for a meaningful ordered probit estimation. Instead, we estimate a probit for whether or not the household owns a car. Given the limited variation in ownership, likely concentrated at the upper tail of the income distribution, we also estimate that relationship non-parametrically as a robustness check.[16]

Figure 7 presents the results. It also shows the distribution of income, and vertical lines at the $2500 and $5000 per capita levels for illustration purposes. Both estimates indicate very small ownership rates at low levels of income, which then steadily increase. Neither estimate levels off at the upper tail of the distribution, suggesting substantial scope for increases in ownership even among well-off households. There were not enough data to meaningfully estimate the non-parametric regression at that range of income. But the non-parametric regression tracks the probit results quite closely for the income ranges where both are available.

In order to project future car ownership rates, we assume the relationship between ownership and income remains constant as incomes grow. We shift the distribution of income to the right so as to raise average per capita income by 5.3% per year in 2005–30.[17] We are implicitly assuming that urban household disposable income will

[14] Although one might expect the urban-household-based survey to yield a higher ownership rate than do the aggregate data, because urban households are on average more than twice as rich as their rural counterparts, the survey may face challenges in sampling the richest households, which are most likely to own a car, whereas the aggregate data can use information on vehicle registration.

[15] As is well known, differences in the construction of GDP per capita compared with average household income in survey data likely account for most of this discrepancy. For example, the bulk of gross capital formation (which accounts for over 40% of GDP in the case of China) is not undertaken by the household sector, and therefore is not captured in a household survey; the same applies to government expenditure and net exports. Moreover, the rental value of owner-occupied housing is included in GDP but not in the household income measure used. These discrepancies can also be compounded by possible under-sampling of rich households and their capital income.

[16] We use a locally weighted regression with quartic kernel weights.

[17] See Data Appendix for sources of growth projections.

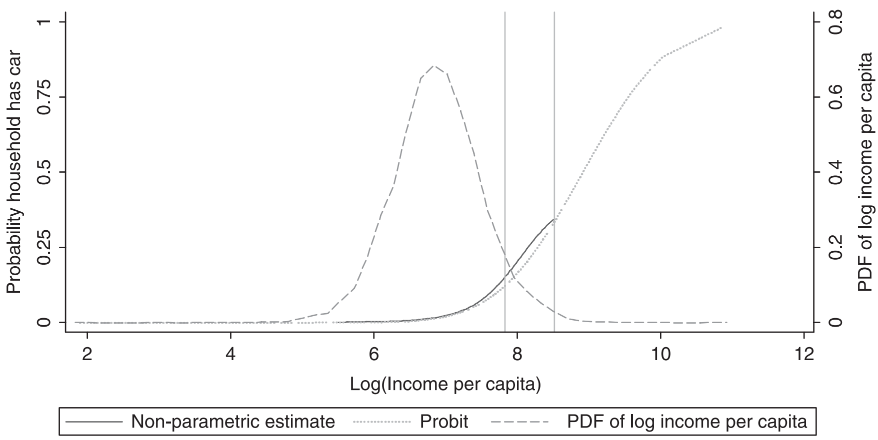

Figure 7. Urban China: Probability of household owning a car, non-parametric and probit estimates

grow at the same rate as per capita GDP during that period.[18] By shifting the entire distribution by the same amount, we are implicitly assuming that only its mean will change over time (with the other moments of the distribution remaining constant). Note that while under-sampling of rich households can lower the current car ownership rate in the survey, it will have a very limited effect on our projections.[19] The results are presented in Figure 8. A sizeable mass of the distribution is in the income range for which we cannot estimate car ownership non-parametrically in the 2005 data. Thus, we will base our projections on the probit estimates, whose extrapolation implies that 25.0% of households will own a car in 2030. If we continue extrapolating, 49.1% of households will own a car in 2050 (assuming a per capita income growth rate of 3.7% in 2030–2050).

Comparing these estimates based on household-level data with those based on aggregate data involves a number of challenges. First, our sample only covers a subset of urban households. Any mapping of these estimates to a national average would require an ad hoc assumption regarding ownership rates for rural households, and the share of population living in urban areas (currently at 43%). At present, car ownership rates are lower in rural China, mainly because several rural areas remain on average poor in absolute terms.[20] But a considerable degree of convergence in per

[18] One could argue that the growth in household disposable income should be larger, because households' share of GDP should be expected to increase over time (investment is unlikely to remain at 40% of GDP for the next 20 years). Income growth for urban households may however be smaller than the national average if there is convergence in urban-rural incomes, with the latter catching up.

[19] Adding a small mass to what currently is the very tail of the income distribution has a large effect on the share of households that can afford a car today, but will have a small impact on the mass of households that can afford a car in 2030.

[20] Unfortunately data on the gap in car ownership between rural and urban areas are scarce. The Chinese Bureau of Statistics provides data by province; a comparison (based on a reasonable guess – but not a formal definition of what constitutes urban and rural provinces) suggests that car ownership in the urban provinces was almost twice as large as in the rural provinces in 2002.

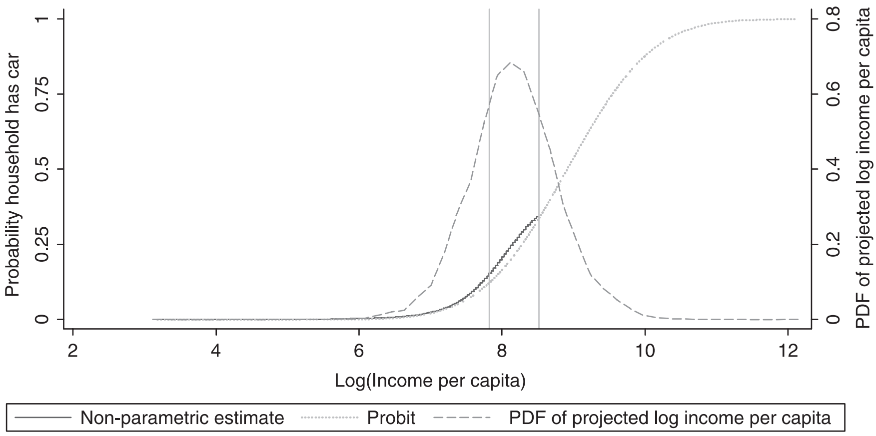

Figure 8. Urban China: Car ownership pattern in 2030 based on estimates from Figure 7

Notes: Based on a projected 5.3% per capita income growth rate – see Data Appendix for sources. Probit estimates predict 25.0% of households will own a car in 2030. Vertical lines drawn at $2500 and $5000 for illustration purposes.

capita incomes, the main determinant of car ownership, is expected to occur between rural and urban provinces by 2030.[21] To the extent that incomes in rural areas approach those projected for urban areas in 2030, it seems reasonable to assume rural ownership rates that are comparable to those of urban households. Trickle-down effects, whereby used cars are sold from the richer urban areas to the poorer rural ones could also help equalize ownership rates. Moreover, our panel estimates suggest a very small effect of urbanization on ownership rates (after controlling for income), so assuming a similar ownership rate for rural households is a reasonable first approximation. Given this assumption, a more detailed comparison with the panel estimates is performed in the next section.

3.2. India

Our estimates are based on the 2004 round of the National Sample Survey (NSS) Expenditure survey, covering 29 631 households in urban and rural areas. In our sample, there were 1.6 cars per 100 households in 2004, with 1.4% of households owning a car.[22] Only 0.08% owned two cars, and only 0.02% owned three or more cars. Given this very limited number of households with more than one car, as in the case of China, we limit the estimation to the probability that the household has a car. The average household size in India is 4.9, which implies a per capita ownership rate

[21] Although the urban-rural income gap may continue to diverge in the short run before converging in the long run.

[22] These data are broadly consistent with aggregate data: for example, the International Energy Agency's *World Energy Outlook 2007* estimates that there are currently 13 vehicles per 1000 people in India.

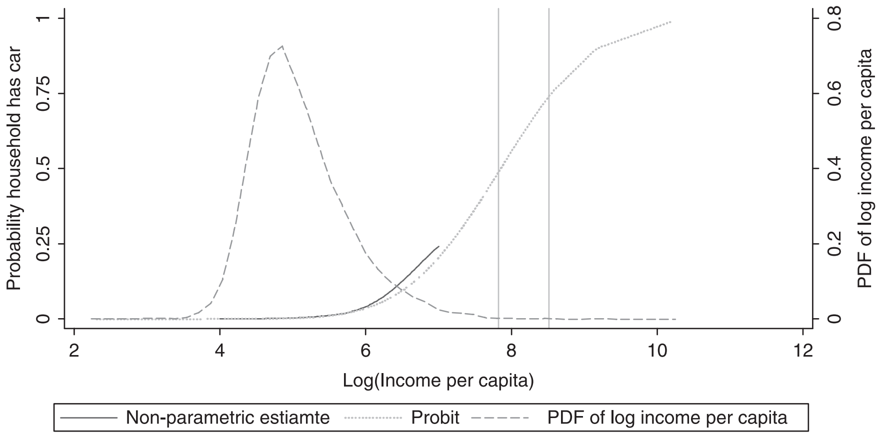

Figure 9. India: Probability of household owning a car, non-parametric and probit estimates

of only 0.3 cars per 100 people. This figure is smaller than the one in our panel sample (equal to 0.6 for 2000, the latest year available). The survey used does not report income. Instead, we use a measure of per capita expenditure, whose average is Rs9127, about US$200 in 2004, and US$182 in constant 2000 dollars terms. This measure is much lower than GDP per capita for similar reasons to the ones discussed above for China.

Figure 9 presents the results of a probit and of a non-parametric estimation for the household owning a car. We draw vertical lines at $2500 and $5000 per capita levels for illustration purposes and also plot the distribution of income. The results are qualitatively similar to the ones for China, although Indian households are even further away from the relevant income range for car ownership.

Figure 10 presents the estimates from Figure 9 but with the income distribution shifted to the right so as to raise the average per capita income by 4.9% per year, India's projected growth in per capita GDP from 2005 to 2030. Based on the probit estimates, we project 11.0% of households will own a car in 2030 and 34.0% of households will in 2050 (assuming a 5.2% growth in income in 2030–50).

4. PROJECTING FUTURE CAR OWNERSHIP WORLDWIDE

Having estimated the relationship between car ownership and income, we are ready to project future ownership by extrapolating that relationship with projected population and income growth figures. Projected population estimates are available from the UN Population Division as far out as 2050. Projected real GDP growth rates are available from the International Monetary Fund's *World Economic Outlook* for the next 5 years, and are complemented by Economist Intelligence Unit (EIU) estimates available for 34 countries up to 2020, then by estimates by Goldman Sachs covering 12

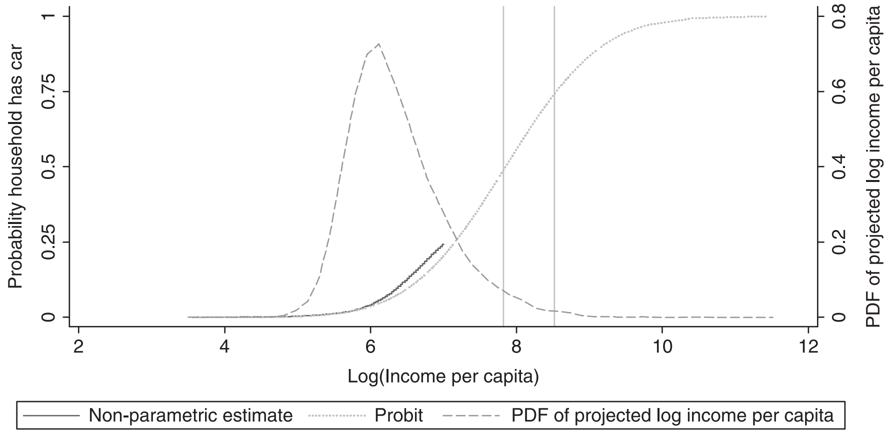

Figure 10. India: Car ownership pattern in 2030 based on estimates from Figure 9

Notes: Based on projected per capita income growth of 6.5% per year in 2005–30 (see Data Appendix for sources). Probit estimates predict 11.0% of households will have a car in 2030. Vertical lines drawn at $2500 and $5000 for illustration purposes.

countries, then by Price Waterhouse Coopers covering 17 countries, and finally by UN projections covering different world regions up to 2050 (see Data Appendix). Needless to say, projecting car ownership over the next four decades involves a big leap of faith, particularly with respect to economic growth projections, which are subject to a great deal of uncertainty and have crucial implications for our exercise. We draw on existing projections despite their limitations because our main objective is to estimate how a given level of income would impact on car demand.

Our preferred projections for future car ownership are based on its estimated relationship with income from column 5, Table 4. In that specification, car ownership is a function of the share of a country's population with an income per capita above US$5000, its interaction with a time trend, and country fixed effects. We assume that the trend in the effect of crossing the income threshold on car ownership continues at its historical rate. The resulting evolution of car ownership in different world regions is shown in Figure 11 and Table 6. As mentioned in the introduction, the number of cars worldwide is projected to increase from 0.6 billion in 2005 to 2.9 billion in 2050.[23] Note the rapid boom in ownership in China, with the boom in India lagging it by about a decade or two. China is expected to overtake the United States as the country with the largest car fleet in the world in 2030.

Even under a more conservative scenario, where the trend in the effect of crossing the income threshold on car ownership slows to half of its historical rate, we still project a major rise in global car ownership. While in our preferred scenario the

[23] It is important to note that our projections assume 'business-as-usual' or 'current policies', and the increase in mass car ownership may well trigger policy changes.

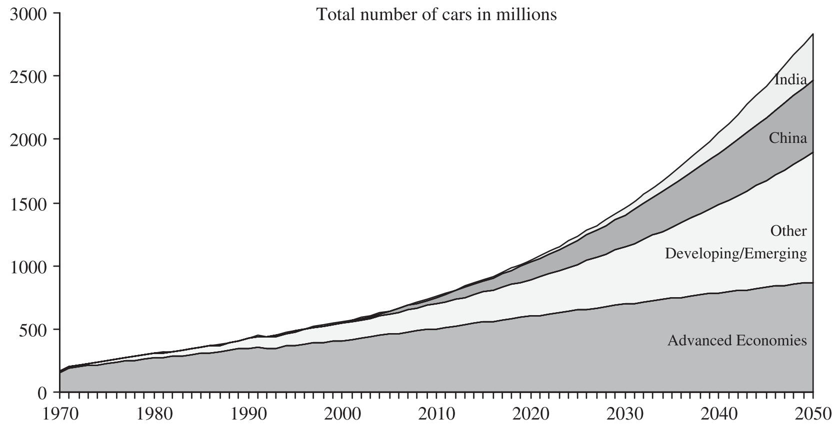

Figure 11. Evolution of global car fleet in 2000–50 extrapolating panel estimates

Note: Projections based on panel regressions reported in Table 4, column 5.

global car fleet increases by 128% in 2005–30, the increase is 97% in this more conservative scenario. The projections for China in 2030 drop from 255 million vehicles in our preferred estimates to 215 million under this more conservative scenario, but China's car fleet still overtakes that in the United States by 2031.

The implications of an increase in the worldwide car fleet from 0.55 billion in 2000 to 2.9 billion in 2050 cannot be overemphasized. Consider a simple back-of-the-envelope calculation regarding greenhouse gases. According to the Stern Report, cars (and vans) in 2000 accounted for 6.3% of total CO_2 emissions (42 $GtCO_2$), or 2.6 $GtCO_2$. Under the strong simplifying assumption that the growth rate of car emissions will be the same as the growth rate in cars, worldwide emissions by cars would amount to 6.8 $GtCO_2$ in 2050. To put this in perspective, the Stern Report's 'business-as-usual' scenario foresees that total emissions (flow) from all sources will amount to 84 $GtCO_2$ in 2050 – which corresponds to a greenhouse gas level (stock) of 630ppm CO_2e and a temperature rise by 3°C from pre-industrial levels. Although the relationship between the net increase in the number of cars and the additional greenhouse emissions they will cause is difficult to estimate, and fuel efficiency is likely to be greater in the future, it seems that cars may nevertheless account for a significant share of the increase in emissions from all sources.

4.1. Comparison of panel and household-level projections for China and India

The panel-based estimates for China and India are not directly comparable to the household-level estimates, because the former project cars/person while the latter project the share of households owning a car. In this section we make assumptions so as to map the latter into cars/person and compare the two sets of results. Comparability also requires an adjustment to the trend in the elasticities incorporated in

Table 6. Projected car ownership extrapolating panel estimates

No. of cars in millions						
Year	Advanced economies	Developing economies	USA	India	China	World
2005	457	189	153	7	21	646
2010	503	257	171	9	51	760
2020	601	445	211	19	134	1046
2030	695	778	253	55	255	1473
2040	785	1310	295	163	412	2095
2050	869	2038	337	367	573	2906
Share of worldwide car fleet (%)						
Year	Advanced economies	Developing economies	USA	India	China	China & India
2005	70.7	29.3	23.7	1.1	3.2	4.3
2010	66.2	33.8	22.5	1.2	6.6	7.9
2020	57.4	42.6	20.2	1.9	12.8	14.7
2030	47.2	52.8	17.2	3.7	17.3	21.1
2040	37.5	62.5	14.1	7.8	19.7	27.4
2050	29.9	70.1	11.6	12.6	19.7	32.4
Number of cars per 1000 population						
Year	Advanced economies	Developing economies	USA	India	China	World
2005	482.4	34.7	513.2	6.5	15.8	101
2010	519.1	44.5	547.8	7.8	37.3	112.8
2020	596.4	69.1	624.1	14.5	94.1	140.4
2030	672.5	111	699.8	38	176.2	183.1
2040	749.1	175.4	777.4	106	287.2	246
2050	824.6	261.1	853.3	230.7	411.6	328.1

Note: Based on fixed effects panel estimates in Table 4, column 5. GDP projections from the International Monetary Fund's *World Economic Outlook*, the Economist Intelligence Unit, Goldman Sachs, Price Waterhouse Coopers, and United Nations projections – see Data Appendix.

the latter. The panel nature of those estimates allows us to extrapolate a continued trend increase in the impact of crossing the income threshold on car ownership. In our household-level estimates, based on a single cross-section of households, we assume the relationship between income and car ownership remains constant when making the projections. To make results more comparable, we consider 'panel without trend' projections, in which we draw on the panel estimates but hold constant the impact of an increase in the share of population above the income threshold to the estimated impact for 2003 (the last year in our panel sample).

We assume that household size in urban China remains constant at its current level of 3 people per household. In the case of India, we assume that household size declines from 4.9 people per household today to 4.4 people per household in 2030 and to 3.9 people per household in 2050. These assumptions are based on a

Table 7. Comparison of household-level estimates and panel estimates for car ownership per 100 inhabitants in China and India

Year	China			India		
	Household-level data (urban)	Preferred panel	Panel without trend	Household-level data	Preferred panel	Panel without trend
2030	10.0	17.6	12.2	2.5	3.8	2.8
2050	21.8	41.2	23.3	10.9	23.1	13.4

Notes: Household-level data estimates for China based on a sub-sample of urban households. Preferred panel estimates extrapolate the effect of crossing the income threshold based on its past trend. 'Panel without trend' estimates hold that level fixed at its 2003 level for comparability with household-level estimates. Household-level estimates of share of households owning a car converted to cars/person estimates based on assumptions described in Section 4.1.

cross-country regression of household size on log GDP per capita, using the fitted values to project the changes for India as it becomes richer.[24]

We assume that one-fifth of the 25.0% of households projected to own a car in urban China in 2030 will own two of them, and that share rises to one-third among the 49.1% of households owning a car in 2050.[25] These assumptions imply ownership rates in urban China of 10.0 and 21.8 cars/100 people in 2030 and 2050 respectively. Table 7 shows these figures are similar to our 'panel without trend' projections for China as a whole (urban and rural). In the case of India, we assume none of the 3.8% of households projected to own a car in 2030 own two of them, but that share rises to one-quarter among the 34% of households projected to own a car in 2050. These assumptions imply ownership rates of 2.5 and 10.9 cars/100 people in 2030 and 2050 respectively. These projections are also comparable to our 'panel without trend' projections.

Being able to construct similar forecasts based on such different approaches and data sets is reassuring. In particular, it gives us more confidence that the simple income threshold approach we applied to a panel of countries is capable of providing a fairly reasonable first order approximation, at least for the two most important countries from the standpoint of the forecasting exercise.

While most of the focus in these comparisons has been on the panel without trend estimates, it is worth noting how much the latter diverge from our preferred panel estimates that allow for a time trend for the effect of income on car ownership (the projected ownership rates differ almost by a factor of two). This trend could become stronger, if the emergence of China and India catalyses a critical mass for the development of cheaper 'popular' cars. While such cars may not have much of an effect

[24] The assumptions regarding future developments in India's household size are also consistent with the UN Population Division's projections of a decline in India's fertility rate from 3.1 in 2000–5 to 2.0 in 2025–30.

[25] These assumptions are based on patterns observed in other countries: for example, in Mexico one-fifth of the households owning a car own more than one, and our projected level of income for China in 2030 is quite close to Mexico's current level.

in richer countries, they could have major implications for countries like China and India, making car ownership soar above even our preferred panel estimates. This suggests one should read our household-level and panel without trend estimates as a somewhat conservative scenario (taking as given the projections of sustained income growth in those countries), with a substantial up-side risk.

4.2. Comparison with previous studies

It is difficult to compare our estimates with those from previous studies, since any change in the underlying assumptions on income growth will have large implications for the estimated ownership rates. There are also definitional differences that must be taken into account. For example, our paper focuses on cars, while others such as Dargay *et al.* (2007) estimate the demand for vehicles (which also includes vans and trucks). One possible way to partially correct for these differences is to use the ratio of per capita vehicle ownership growth to per capita income growth. Dargay *et al.* (2007) estimate that ratio to be 2.20 for China and 1.98 for India in 2002–30. Their estimates are similar to those from the International Energy Agency's *2006 World Energy Outlook*, which are 1.96 and 2.25 respectively (in 2006–30). Our household-level estimates indicate a ratio of 2.04 for urban China and 1.25 for India in 2005–30.[26] Based on our 'panel without trend' specification the ratios for China and India are 2.67 and 1.51, and based on our preferred panel specification they are 3.89 and 2.12 respectively. For the developing world as a whole, our preferred panel estimates imply a ratio of 2.05, which is also higher than the 1.61 ratio estimated in Dargay *et al.* (2007) for non-OECD countries (which in turn was already substantially higher than those of previous studies).[27]

Thus, our preferred panel estimates suggest a far stronger sensitivity of car ownership with respect to income in China (which is true even in our 'panel without trend' estimates). This result could reflect the highly non-linear nature of our estimation being better able to capture the dynamics around the income levels where the major take-off in car ownership occurs.

Our preferred projections assume that technological progress will allow cars to continue to become more affordable – an assumption that looks reasonable especially in light of recent discussion in the popular press regarding the possible launch of extremely cheap cars on the Indian market. Robust demand in China and India can further contribute to the development of cheaper vehicles. Moreover, as China and India become richer, a larger global market for used cars may emerge (with used cars making their way from China to lagging developing regions).

[26] For the sake of comparison, the initial level of car ownership used to compute these ratios was based on the aggregate data.

[27] From a methodological standpoint, the panel aspects of our study have a number of differences with respect to Dargay *et al.* (2007). Beyond the differences in functional form and the issue of saturation, discussed above, our interest in long-run projections implies that we do not seek to estimate an asymmetric response to income increases versus decreases (which in any case makes essentially no difference to the long-run projections, as shown by Dargay *et al.*, 2007). We do not project population density and urbanization, which did not seem to be very significant in our regression estimates, and Dargay *et al.* (2007) again show to have little impact on the projections.

Table 8. Projected car ownership in 2030 under alternative panel estimates

Estimate	Advanced economies	Developing economies	USA	China	India	World
Number of cars in millions						
Baseline Projection	695	778	252	254	55	1473
Trend on Threshold Effect Declines by Half	603	671	221	216	48	1274
Threshold Effect Remains at 2003 Level	511	564	189	177	41	1074
Baseline with Saturation at 2 cars per 3 people	662	777	241	255	55	1439
Dynamic Panel Projection	591	541	210	141	59	1132
log(GDP per capita), Gini and their interaction	533	1022	193	244	259	1554
Share of worldwide fleet						
Baseline Projection	47.2	52.8	17.2	17.3	3.7	–
Trend on Threshold Effect Declines by Half	47.5	52.5	17.6	16.4	3.8	–
Threshold Effect Remains at 2003 Level	47.3	52.7	17.3	16.9	3.8	–
Baseline with Saturation at 2 cars per 3 people	46.0	54.0	16.7	17.7	3.8	–
Dynamic Panel Projection	52.2	47.8	18.6	12.5	5.2	–
log(GDP per capita), Gini and their interaction	34.3	65.7	12.4	15.7	16.6	–
Number of cars per 1000 population						
Baseline Projection	672.5	111.0	699.8	176.2	38.0	183.1
Trend on Threshold Effect Declines by Half	584.0	95.7	611.5	149.2	33.1	158.4
Threshold Effect Remains at 2003 Level	494.7	80.4	523.3	122.1	28.2	133.6
Baseline with Saturation at 2 cars per 3 people	641.6	110.8	666.7	176.2	38.0	179.0
Dynamic Panel Projection	572.5	77.2	582.1	97.5	40.8	140.8
log(GDP per capita), Gini and their interaction	515.9	145.8	534.9	168.6	178.5	193.3

Notes: Baseline estimates correspond to those reported in Table 6. Estimates varying trend on threshold effect are based on our baseline estimates, but instead of multiplying the coefficient on Threshold * (year − 2000) by year-2000, multiply it 3 + 27/2 in the case where the trend declines by half, and by 3 in the case where the level is held constant at its 2003 level. Baseline with Saturation at 2 cars per 3 people imposes a maximum ownership rate of 667 cars/1000 people. Dynamic Panel Projection corresponds to the first specification in Table A2. Finally, the last specification uses a reduced regression including log(GDP), Gini and their interaction instead of our threshold approach.

4.3. Robustness of projections

The discussion has focused on our preferred estimates. But it is useful to consider forecasts under alternative scenarios and specifications. Table 8 compares the projections for 2050 in our baseline with those of five alternative estimates. If the trend on the effect of ownership from crossing the income threshold declines to half of its historical rate, the projected global fleet declines from 1473 million to 1274 million.

This reduces the growth in 2005–30 from 128% to 97%. If we assume that the trend on the effect of crossing the threshold disappears, the projected global fleet in 2030 declines to 1074 million (lowering its growth in 2005–30 to 66%). Returning to our baseline specification, we impose a saturation of 2/3 in the per capita ownership rate (for example, due to the share of the population that is either too young or too old to drive). The resulting effect on the global fleet in 2030 is negligible (2005–30 growth declines from 128% to 123%), since this constraint is not binding for China and India (it only binds in advanced countries). A dynamic specification (with lagged dependent variable), based in the first column of Table A2, implies a global fleet of 1132 million in 2030 (a 123% growth relative to 2005). Finally, we consider a specification that does not use the income threshold approach, but instead uses a reduced form regression with log(GDP per capita), Gini and their interaction as controls. This specification projects a global fleet of 1554 million cars in 2030 (a 141% growth relative to 2005), which is actually higher than our baseline projection.

This robustness exercise has shown that while it is possible to somewhat lower our projections under more conservative assumptions, we will still experience a very large increase in car ownership (assuming, of course, that past history is a guide for the future). It is worth noting that most of the alternative estimates considered were more conservative. If we were to consider a scenario where the development of extremely cheap cars and an increasing global market for used cars strengthen past trends, we would project an even stronger surge in demand.

5. ACCOMPANYING POLICIES

The projected increase in car ownership worldwide – and especially in key emerging market countries – involves prospects of improved welfare and economic opportunities for large sections of the world's population, but also serious challenges for policymakers. Mass car ownership has historically been an integral component of the transition to an advanced economy. Workers can cover longer distances in their daily commutes, effectively increasing the size of the labour market and facilitating specialization in production; consumers can purchase goods from shops located further away – which results in greater competition in the retail sector; remote fishing villages can develop as tourist resorts, with (mostly) positive effects on incomes and welfare; and so on. As emphasized by a host of previous studies, however, cars have major undesirable external effects including local and global pollution, noise, accidents, and traffic congestion.

In this section, we outline a few possible policy options/levers and put forward some general considerations, though we do not venture an analysis of trade-offs among possible policies. A key input for this section is an up-to-date, comprehensive review of the literature on cars' negative externalities with a focus on the United States (Parry *et al.*, 2007); we broadly follow its categorization of the various policies that are best suited to address each type of externality. Beyond the policies' general effectiveness, exactly which policies each country will adopt is likely to depend on the country's stage of development; the size and age of the existing car fleet; the presence of a domestic car industry; political-economy considerations; and the government's ability to enforce policies, regulations and standards. We add some facts and simple considerations regarding the various policies' applicability to emerging market countries. This material – presented below – is summarized in Table 9.

5.1. Local externalities

Many externalities are local: these include local air pollution, traffic accidents, noise, and traffic congestion. Congestion in particular is also time-specific, in the sense that it occurs only at certain times of the day. At a conceptual level, these local externalities are relatively easy to deal with, because much can be accomplished through specifically targeted policies, as follows.

5.1.1. Local air pollution. Emissions of carbon monoxide, nitrogen oxides, and hydrocarbons that cause smog and health problems at the local level have been substantially reduced in many advanced countries by imposing tighter vehicle emission standards, which in turn have become possible as a result of technological innovations. This represents an opportunity for emerging markets that do not yet have a large existing fleet of vehicles: if countries start out with tight emission standards before they experience a take-off in car ownership, they seem likely to be able to keep local pollution (from this source) under control. At the same time, many emerging market countries rely on imports of used cars from advanced countries – consumers in emerging market countries are keen to keep used vehicles running for as long as they can, so as to avoid the expense of purchasing brand new ones. Storchmann (2005) reports that for several large countries in Africa the share of imported used cars (mostly from Japan and Europe) in total new registrations is more than half; and that some formerly communist countries also had similarly large shares until the late 1990s. To the extent that such used imported cars are older and do not meet modern emission standards, this will remain an issue in emerging market countries for some time to come – until eventually the older, more polluting vehicles are retired. Most of the demand for new cars will come from China; as China grows richer, it may start selling used cars to lagging developing countries. Thus, tight emission standards on new vehicles are important, particularly in countries where demand growth will be strongest. Whether countries importing used cars should apply a strict standard depends on a trade-off between the welfare of potential buyers of such vehicles, and that of others who would be adversely affected by the resulting pollution. There is also a danger that standards would be used to protect a possibly inefficient domestic car industry from the competitive pressures imposed by the availability of imported used cars. Beyond regulation of standards for emissions by individual cars, in emerging market countries it would also be important to ensure that standards are introduced

Table 9. Various policies' applicability to emerging markets and their impact on externalities

Policy	Considerations for emerging markets	Impact on:				
		Congestion	Local pollution	Greenhouse gasses	Noise	Accidents
Fuel tax	Regressive in advanced countries but more progressive in emerging markets	Some	Some, but does not affect exhaust emissions per mile travelled	✓ Some (Most)	Some	Some
Standards on exhaust emissions	New car fleet means opportunity for standards to be immediately effective, but used (older) imported cars from advanced countries may be polluting	None	✓ Most	None	None	None
Road-specific congestion toll that varies with time of day	This policy made possible by new technology may be an opportunity for the few large cities where congestion is an issue, but there may be implementation challenges	✓ Most	Some	Some	Some	Little
Increase road capacity	Imposes burden on finances in countries where there are great competing needs, and where scope for leakage of public funds may be high	Some, but not clear	Adverse	Adverse	Adverse	Not clear
Increase insurance premium (or levy tax) on vehicle miles travelled	Not yet used even in advanced countries. May raise implementation challenges in emerging markets	Some	Some, but does not help with per-mile fuel efficiency	Significant	Some	✓ Most
Standards on safety features (e.g., airbags, seat belts, and child restraints)	Emerging market consumers may find it difficult to afford some of the more costly safety features	None	None	None	None	✓ Most
Increase taxes on light trucks/SUVs	SUVs less relevant, but light trucks might be vehicles of choice	None	A little	Some (fuel efficiency)	None	Some
Fuel Economy Standards (e.g., CAFE)	In emerging markets (especially the smaller ones), where most vehicles are imported rather than produced, standards may be politically easier to impose but more difficult to enforce.	None	None	Some, if standards binding and effective	None	None
Promote alternative fuels or plug-in hybrids	Technological development currently is occurring in advanced countries	None, or adverse	None, or adverse	Could be major, depending on degree of technological breakthrough	None, or adverse	None, or adverse

Note: Much of the information contained in this table is drawn from Parry *et al.* (2007).

and respected for the quality of fuel – notably with respect to the phasing out of leaded gasoline, an initiative which seems to have brought about net benefits in the United States (Parry *et al.*, 2007). In most of China and India, vehicle emission standards are currently at the level of the Euro II standards, which came into force in the European Union in 1996, and standards are at the Euro III level in a few cities or provinces in China and India. Standards are expected to be tightened to the Euro IV level in both countries over the next few years.

5.1.2. Traffic accidents. Casualties resulting from traffic accidents have declined in advanced countries over the past decades. In the United States, fatality rates have fallen from 5.1 per 100 million vehicle miles travelled in 1960 to 1.5 per million vehicle miles travelled in 2003 (US Department of Transportation, cited in Parry *et al.*, 2007). In the EU-15, total road fatalities steadily declined from 78 000 in 1970 to 31 000 in 2005 (European Union Road Federation, 2007): considering the increase in car use observed during the period, this is an impressive improvement, even if it might partly reflect better recording of fatalities. The trend toward fewer traffic accidents seems likely to reflect factors including greater seatbelt use and improved vehicle technology with respect to safety features, suggesting that standards and regulations (as well as their enforcement) play an important role in this area. For emerging markets, traffic accidents will probably remain an especially pressing issue: in 2004, road fatality rates per million vehicles were less than 200 in most OECD countries, but exceeded 400 per million vehicles in Poland, Hungary, Korea, and Turkey, and 1200 in Russia (OECD Factbook 2006, pp. 226–9). Indeed, road fatalities on a per inhabitant basis were higher in Russia, Poland, and Korea than in the United States, despite much higher car ownership and total vehicle miles travelled in the United States. Looking forward, consumers in countries with relatively low per capita incomes may be tempted to demand vehicles that do not have expensive safety features, such as air bags. Moreover, the coexistence of vehicles of different types on the same roads, particularly in crowded urban areas, just adds to the overall risk of accidents. All this implies that difficult public choices will need to be made regarding safety and traffic regulations in such countries. Differential taxes depending on vehicle size (e.g., higher taxes on sport-utility vehicles and pick-up trucks) would seem to help consumers internalize the greater damage they tend to cause to others – all else equal – in the event of an accident (White, 2004); such differential taxes would also provide a further source of progressity. There are also promising proposals for linking a person's insurance payments to the number of vehicle miles travelled (and perhaps to the driver's and the car's relative risk factor). However, these have not been adopted in advanced countries yet on a significant scale, and would seem to raise implementation and monitoring issues in an emerging-market-country environment.

5.1.3. Traffic congestion and noise. The estimated costs of traffic congestion are substantial: for example, they are estimated at about $800 per traveller per year in a sample of 85 US urban areas (Schrank and Lomax, 2005). Costs resulting from vehicle noise have been estimated to be limited in advanced countries, but are probably higher in countries where the price of noise-mitigation items such as sound-proof walls and double-glazed windows is equivalent to a higher share of household incomes. Congestion has traditionally been an especially thorny problem because policies that discourage driving in general (such as, say, higher fuel taxes) have too little impact in discouraging driving on particular routes and at particular times, as would be required to curb congestion. Moreover, road building has often proved to be partly self-defeating, because it leads to more driving. There is an emerging consensus that time-varying tolls, made possible by recent technological advances (e.g. those leading to the use of in-vehicle transponders), are an effective and well-targeted policy to curb congestion. This approach has already been used for a few years in a limited number of large urban areas in Europe, including Stockholm (a time-varying cordon toll), London (the successful 'cordon' toll put in place in 2003), and Oslo. Although only a few major urban areas in emerging market countries have thus far been affected by congestion, time-varying cordon tolls seem to be a promising and effective approach to keep congestion in check. Again, emerging market countries' ability to jump directly to a new technology creates economic opportunities – loosely similar to their ability to adopt mobile phones on a nationwide scale without the need to establish a national network of fixed telephone lines.

To keep local externalities more generally in check, some local authorities in China have restricted the number of car registration permits (or driving licences) and have promoted local public transportation. Indeed, car ownership varies widely, from 133 vehicles per thousand inhabitants in Beijing to 11 vehicles per thousand inhabitants in Jianxi. This wide range largely reflects differences in per capita income. However, local policies matter, too. For example, Shanghai, with a slightly higher per capita income than Beijing, has less than half its car ownership, owing – it would seem – to factors such as restrictions on registration permits.

5.2. Global externalities

5.2.1. Greenhouse gases. Moving to truly worldwide external effects, emissions of carbon dioxide – the leading greenhouse gas – need to be kept in check to help reduce global warming. Among car-related policies, fuel taxes seem to be one of the most promising in this respect, though they are unlikely to curb the rise in fuel demand that will no doubt take place with the massive increase in car ownership that we project. We have seen that – based on both our estimates and a review of previous studies – the elasticity of car ownership with respect to fuel prices is rather small. However, previous studies have shown that the long-run elasticity of fuel demand with respect to fuel prices is substantial – as consumers opt for smaller or more efficient cars, and choose to travel shorter distances – ranging from −0.6 to −1.1 in advanced countries and, according to existing estimates, even lower or at the low end

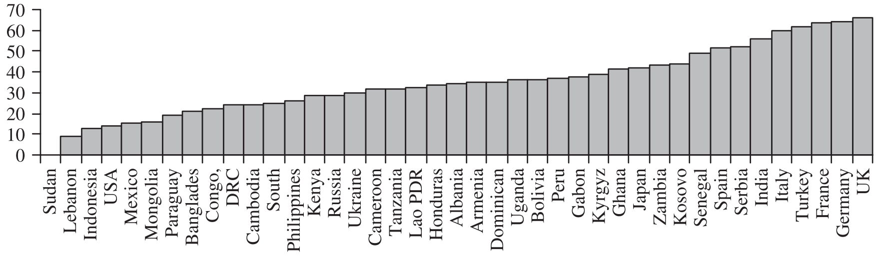

Figure 12. Fuel taxation in percent of gasoline retail price

Source: National web sites and publications.

of that spectrum in developing countries. Nevertheless, to the extent that savings are due to more fuel-efficient cars, this policy would have little impact on congestion, accidents, and the demand for public infrastructure. Where exactly should the level of fuel taxes be set in emerging market countries? Previous studies on this topic have unfortunately tended to focus on advanced countries. As is well known, existing variation in gasoline taxes among advanced countries is massive, ranging from about US$0.4 per gallon in the United States to more than US$2 in most of Western Europe and more than US$3 per gallon in Germany and the United Kingdom. In a careful analysis of externalities in the form of congestion, accidents, local and global air pollution, and a 'Ramsey tax' component that reflects the appropriate balance of excise taxes and labour taxes, Parry and Small (2005) conclude that the optimal level of the gasoline tax in the United States is twice as high as its current level, and in the United Kingdom it is half of its current level. Comprehensive information on gasoline taxes in emerging market and developing countries is hard to come by, but it is clear that such rates are on average lower than in advanced countries (US$0.23 per litre in non-OECD countries versus US$0.58 per litre in OECD countries in 1999, according to Bacon, 2001). Moreover, the range of taxation is quite wide, with some developing countries (especially some oil producers) levying as little as US$0.10 per litre on gasoline, whereas others (including several low-income countries in Africa) levy taxes that are on the order of those in Western Europe (and far higher on a PPP-adjusted basis) (Figure 12).

Thus, there is substantial scope for increasing fuel taxes in many, though not all, emerging market and developing countries. In addition, the adverse distributional impact of higher gasoline taxes – clearly regressive in advanced countries – would seem to be less of a concern in emerging market and developing countries, where they may be even progressive, particularly in low-income countries. At the same time, as pointed out by Bacon (2001), it is important to be mindful of how taxes affect the relative price of fuels (not just gasoline, but also diesel and kerosene). Indeed, kerosene is particularly problematic in low-income countries, because it can be used to adulterate gasoline or diesel without the consumer noticing, and is also widely used in cooking. (For example, according to the International Energy Agency's *World*

Energy Outlook 2007, illegal blending of kerosene with diesel is widespread in India, where kerosene is heavily subsidized whereas diesel is heavily taxed.) Thus, to the extent that taxes would have to rise on kerosene as well to avoid substitution of fuels, there would be adverse distributional consequences that would need to be mitigated through targeted needs-based transfers.

In addition to fuel taxes, some countries require manufacturers to meet fuel economy standards for the average fuel economy of the fleet of passenger vehicles that they produce (e.g., the Corporate Average Fuel Economy, or CAFE, program, in the United States). In the United States, these standards currently do not seem to be clearly binding, particularly because demand has increased for SUVs and pickup trucks which have their own standards. In emerging market countries, standards would seem to be more relevant for countries that are large enough to have a sizeable domestic production. China is making substantial use of fuel efficiency standards: national standards were introduced in 2005 and tougher standards will be implemented in 2008. At present, China's fleet average fuel economy standards are lower than in the United States, Canada and Australia, and somewhat higher than in Europe and Japan. China also has a tax on car ownership that is differentiated according to weight and engine size, to discourage sales of larger and more powerful vehicles. Local governments (mainly motivated by a desire to keep local pollution in check) are also supporting alternative fuels. There are scrappage rules. A national fuel tax is under discussion. In contrast, India does not have mandatory vehicle fuel efficiency standards; nevertheless, the large number of partnerships in India between local and foreign vehicle manufacturers may imply that efficient vehicle technology is nevertheless being introduced into the country.

5.3. Measures that affect many of the key externalities

Some measures are likely to have a desirable impact on many of the key externalities discussed above. In particular, many emerging market countries are currently facing a strategic choice: should they direct their public infrastructure investment (including maintenance) toward roads, or railways/metro lines instead? And to what extent should these countries encourage greater use of public transportation? Our empirical result that there is a positive and significant association between road miles per capita and cars per capita is merely suggestive, of course, given that causality could go either way. And we found little empirical evidence of railways being a substitute for cars. Data constraints need to be overcome and further empirical research is clearly needed here. Despite these caveats, however, there is little doubt that governments' strategic choices between different types of infrastructure and modes of transportation are an important factor underlying future trends in car ownership in different countries. The history of advanced countries suggests that governments do play (and probably cannot avoid playing) a major role in this respect (for example, through major pieces of federal legislation in the United States to plan and fund highways beginning in the 1940s–50s, and to provide grants in an attempt to promote local rail and bus transportation beginning in the 1960s – see Meyer and Gómez-Ibáñez, 1981). For countries where the take-off of car ownership is only beginning, a strategy on whether infrastructure investment and the tax/subsidy mix should foster the use of private cars or public transportation (the latter powered by appropriate types of fuel) is of critical importance at this stage. This is especially the case for those large emerging market countries that retain an impressive ability to mobilize resources, including labour that is still relatively cheap, to undertake public works of high quality and massive scale. Efforts to build a metro and convert the entire public transport fleet to compressed natural gas in Delhi, for example, go in the right direction but the scale of the nationwide challenge is of course much greater. In making strategic choices regarding the transportation sector, administrative capacity also needs to be taken into account. For example, countries with a weaker ability to monitor and enforce emission standards, may be more likely to rely on subsidies to public transportation and taxes on fuel.

Industrial policies and government attitudes toward the domestic car industry have also historically played a role (notably in European countries where the government often provided implicit or explicit subsidies – or even took over loss-making car companies). While with lower trade barriers today this would be expected to have less importance in determining car ownership (as opposed to car production), for large countries – China and India in particular – government policies are likely to continue playing an important role. In fact, at present domestically assembled cars (by Sino-foreign joint ventures but also state owned and new private Chinese companies) account for 96% of car sales in China.

It should also be noted that a partial mitigating factor of the implications of greater car ownership and use may come from the market's own self-correcting mechanism. Venturing an estimate of how our projected increase in car ownership would affect the worldwide price of oil and fuel prices more generally over the next few decades would require taking a view on the long-run elasticity of supply of oil and fuel – which would make it necessary to undertake a further, complicated study. It may be expected, however, that a massive increase in worldwide car ownership would imply a major rise in fuel demand, and that the ensuing hike in fuel prices may in turn help contain the increase in fuel consumption, as consumers demand more fuel-efficient vehicles. Thus, the increase in greenhouse gases that would result from our projected rise in car ownership is likely to be smaller than what one would obtain by simply multiplying current emission rates by the projected increase in fleet.

5.4. The limits of policy action: some back-of-the-envelope calculations

The enormity of the policy challenges implied by the projected increase in demand for cars over the next decades may be illustrated through some simple back-of-the-envelope calculations. While these have to be taken with more than the usual caveats, they suggest that conventional policies, such as increases in gas price taxation – while desirable – are unlikely to make a significant dent in the problem, unless they are taken to a draconian (and perhaps politically infeasible) limit.

As shown in Table 6, worldwide car demand is expected to grow by an average 3.4% per year over 2005–50 (the same growth applies for 2005–30). Assume that demand for the number of cars is unaffected by increases in gasoline prices, but that gasoline consumption does respond to higher gas prices, as consumers choose more fuel efficient cars – and producers accommodate such demand – and drive shorter distances. With a unit (long-run) demand elasticity of gasoline consumption with respect to gasoline prices, for worldwide gasoline consumption to remain constant the average gasoline consumption per car must also decline by 3.4% per year – that is, real gasoline prices would have to increase by 3.4% a year. Thus, if a gallon of gasoline costs $3 today, it would need to cost (in constant dollar terms) $8.2 in 2030 and $13.5 in 2050 to ensure that the much larger projected worldwide car fleet operates with the same overall fuel consumption as today.[28] To put this price increase in perspective, consider that gasoline prices grew by an annual average of 0.7% in real terms since 1972 – about 35 years ago and just prior to the first oil price shock – when the real price of gasoline in the United States was $2.3 converted in today's dollars. If the future growth rate of real gasoline prices turned out to be twice as high as that experienced over the past three and a half decades, worldwide gasoline consumption would grow by 2% per year. This implies a cumulative growth in gasoline consumption of 144% in 2005 to 2050.

It is worth stressing that the projected increase in car ownership in our baseline scenario is so large that even aggressive intervention to curb demand is unlikely to prevent this explosion in ownership. For example, suppose every country set taxes at a level sufficiently high to reduce ownership by 25% vis-à-vis our baseline counterfactual scenario. Such reduction roughly corresponds to the current difference in ownership rates between the United States and Denmark.[29] Such scenario would still yield an increase of 240% in the global car fleet between 2005 and 2050.

6. CONCLUSIONS

Economic history suggests that as people get richer, they increase their use of private transportation – notably, cars. Many emerging markets, including some of the world's most populous countries, are reaching the stage of development where a rapid take-off in car ownership may be expected. This leads us to project a massive increase in

[28] This back-of-the-envelope calculation also assumes that the price elasticity of gasoline demand remains constant despite increasingly lower gasoline consumption per car. It is likely that demand would become more inelastic as consumption declines, so these prices can be seen as a lower-bound on how high gasoline prices would need to go in order to stabilize consumption at current levels.

[29] Virtually all the population in these two countries is above the income threshold (with that share being slightly higher for Denmark), so this difference in ownership is not driven by differences in income.

the number of cars worldwide, from 0.6 billion in 2005 to 2.9 billion in 2050. In some respects, greater car ownership is to be welcomed, as it is closely associated to economic development and will add to the well-being of millions who are being lifted out of poverty. At the same time, such rapid take-off in car ownership has major implications both at the global level, for issues such as global warming, and at the national level, where countries will need to confront congestion, local pollution, and spending pressures for infrastructure provision. Of course, our projections assume 'business-as-usual' or 'current policies', and mass car ownership may trigger policy changes. Indeed, policy-makers currently face strategic decisions on whether to 'lean against the wind' of greater car ownership that will inevitably result from economic development, by promoting public transportation through appropriate infrastructure and the tax/subsidy mix, or whether to fully accommodate the demand for more roads and associated infrastructure. Regarding more specific policies, an increase in fuel taxes would seem a promising avenue to stem the increase in greenhouse gases, stringent standards on the quality of fuel and tailpipe emissions would help reduce local pollution, and time-varying 'cordon' tolls made possible by recent technological improvements have the potential to reduce congestion in some of the main cities. However, while these policies can play a useful role compared with a more laissez-faire approach, and are probably well worth implementing, they are unlikely to be able to avoid a massive increase in the undesirable by-products of car ownership and use. Much will ultimately depend on progress with respect to new technologies such as 'plug-in hybrids', or other breakthroughs that we are unable to foresee. Finally, it is important to place the case of automobiles in a broader perspective. Our study is motivated by an interest in analysing in detail one specific piece of a much broader puzzle. From the standpoint of keeping global warming in check, many other policies are probably even more crucial: these include – within the realm of transportation – a more general treatment of taxation of all oil products; and at the broadest level of energy taxation, would likely include a carbon tax, as argued for by a wide spectrum of economists. Other factors – notably emissions from coal-fired power stations (also prevalent in the emerging market giants) – have even greater implications for global warming. Nevertheless, the rapid projected increase in car ownership in emerging markets and worldwide will have major implications and merits early attention and policy action.

Discussion

Jonathan Temple
University of Bristol

This paper examines likely trends in global car ownership, using a combination of a cross-country panel data set, and household survey data for China and India. The findings are startling: even on a relatively conservative basis, the authors estimate that global car ownership will roughly double between 2005 and 2030, mainly driven by ownership growth in developing countries. To the limited extent that growth projections can be relied upon, their findings suggest even larger increases by 2050. The environmental implications are alarming.

Since the time of the presentation at the panel meeting, the issue has started to make headlines. Many of the world's major car manufacturers are working on low-cost cars, mainly with developing countries in mind. In January 2008, India's Tata Motors announced a car that would be priced at one *lakh*, or about $2500. This is roughly the same price as the DVD player in a Lexus. Tata's most basic model will be half the cost of the cars that were previously cheapest, China's Chery QQ3 and India's Maruti 800.

Steep increases in global car ownership would have far-reaching implications, so there is a real need for a careful empirical analysis, and the authors have met this requirement with a simple and elegant model. Their approach relates car ownership per capita to the (estimated) share of the population above a certain income threshold. The justification for this specification is that cars are expensive, indivisible goods. Ownership is rare at low-income levels, but increases rapidly with income, once an income threshold has been crossed. This represents a simplification of some of the ideas in a classic paper on car ownership by Farrell (1954).

The authors show that models based on an estimated income threshold perform well empirically. For example, despite its simplicity, a model using only the above-threshold population share can explain about 80% of the cross-section variation in car ownership across countries (Table 3). It is also impressive that the same specification explains 70–80% of the within variation in fixed-effect panel data models (Table 4). This is greater explanatory power than is the norm in cross-country panels in other contexts.

Yet there are one or two signs that the simple threshold model is incomplete. In the panel data models, the impact on car ownership of the above-threshold population share increases quite strongly over time. In other words, the results imply that, over time, a higher and higher proportion of the 'potential' car owners are choosing to buy cars. The reasons for this increase remain something of a black box, which is a little problematic, not least when developing long-run projections of car ownership.

Initially, I thought the explanation might be a decline in the relative price of cars, but arguably that should lead primarily to a fall in the estimated income threshold, rather than a greater impact of crossing the threshold. It is not clear that we see this falling threshold in the data. Figure 5 in the paper suggests a different pattern, as do the regression-based tests in Appendix Table A1. The impact of crossing the threshold clearly increases over time.

There are some other possible hypotheses that might explain the instability in the estimated model. One might be changes in the quality of cars. A more speculative argument would appeal to changes in tastes, the role of social norms and trends as influences on consumer behaviour, and the rise of global media. Perhaps mass adoption of consumer goods follows a social diffusion process, along the lines envisaged by Reinstaller and Sanditov (2005).

All this suggests that, ideally, an empirical model for aggregate car ownership would be developed from a structural model of individual decisions. A structural model could give some insight into why an estimated income threshold might evolve over time, and why the effect of crossing the threshold might also change. It would also allow projections under a range of assumptions, so that it would be possible to explore the sensitivity of global car ownership to trends in the relative price of cars, and expectations about future running costs, including fuel prices. For policy evaluation, a density forecast for ownership would have significant advantages over a point forecast.

None of this underestimates the success of the reduced-form empirical models used in the paper, which help to indicate specific directions in which a structural approach could be developed. Taking the current analysis on its own terms, I have one final point. Since car ownership within a country is likely to be persistent, there is a case for estimating dynamic models, not least to control for some of the time-varying omitted variables that influence car ownership. Table A2 in the Appendix presents some models along these lines. In these specifications, the explanatory variables now determine a steady state, country-specific, level of car ownership that is gradually approached over time. I would have liked to see these dynamic models explored in slightly more detail. In particular, it would be interesting to know whether they help to overcome some of the problems with the static model discussed above.

Despite these reservations, it is worth emphasizing the achievement of the authors. Their empirical model is well designed and has high explanatory power, and the authors complement their cross-country study with informative use of household survey data for China and India. The headline findings deserve attention. The paper provides an unusually interesting analysis of a fundamental policy question, and is likely to be a major influence on future work in this area.

Christian Schultz
University of Copenhagen

This is a provocative and interesting paper, which engages in the daring task of predicting ownership of cars in the years ahead until 2050, worldwide and more detailed for China and India. Evidently, this is an important question, which certainly has not become less important with the growing concern for global warming and the stronger indications that indeed global warming is affected by human activity. More careful models from economists trying to predict the proliferation of major sources of CO_2 emissions seem highly topical. In this perspective, the current paper is most welcome.

The paper relies on the simple idea that car ownership is closely related to per capita GDP and a few other variables, notably the income distribution, urbanization, household size and population density. The authors argue that there is an S-shaped relation between car ownership and per capita GDP. They argue that this can be well explained by a simple approach, where car ownership is determined by the fraction of the population above an income threshold (US$5000 in 2000). With a bell-shaped income distribution this will indeed yield an S-shaped relation between car ownership and per capita GDP as the income distribution shifts to the right when per capita GDP increases. This is a simple, intuitive and economically appealing idea. The results are striking: growth in car ownership is massive. In 2030, 52% and in 2050, 70% of the world's fleet of cars will be in countries which today are developing countries.

Other papers have engaged in the task of making far ahead predictions of car ownership and other papers have noticed that there seems to be an S-shaped relation between GDP and car ownership. An important part of the contribution of the present paper is to try to root the predictions in the threshold-income distribution approach, so that one does not simply rely on some S-shaped functional form from the outset, but there is a more elaborate theory behind, which ideally gives more solid foundations for the predictions.

The paper progresses through a number of empirical exercises. First car ownership is estimated in a cross-section of 122 countries in 2000. The authors find that the fraction of population above the income threshold explains car ownership well (the preferred specification in Table 3, column 5). The optimal threshold is found by maximizing R^2 in the regression when varying over potential thresholds. Subsequently, a similar regression is made in a panel: here the preferred specification includes the threshold and an interaction term with time, reflecting that the threshold may move over time, as well as country fixed effects, the preferred specification is in Table 4, column 5.

The paper then turns to China and India and reports results from household surveys among urban households. The Chinese survey covers approximately 21 000 households in 10 municipalities in 2005. A probit and a non-parametric regression is performed, which relates household car ownership to income. For a given income distribution this gives a relation between per capita income and car ownership. Assuming that the shape of the income distribution is constant in the future, so that increasing per capita GDP comes about through a shift of the income distribution to the right, and assuming that the relation between household income and car ownership is stable, this gives predictions for future car ownership. The same method is used on Indian data. It goes without saying that such estimates are to be considered as informed guesses.

The paper is well written and the subject is fascinating, but of course the long-term projections require some faith. There is a big leap of faith in believing that the estimates obtained here are valid also in the year 2050. Perhaps this is so self-evident that it is not a real problem: All readers will realize it is the case. However, we are making predictions very far ahead in time. In all fairness, the authors also present predictions for years before 2050, perhaps the predictions for 2030 are more interesting – they are probably more reliable.

I am sympathetic to the paper's mission, but as a discussant, it needs to be remarked that a large part of the paper is 'very macro'. One may argue that it is to have a very parsimonious approach. However, although the threshold approach is intuitive, there is no real model behind it. It represents common sense. Box 1 in the paper motivates the idea. Using the fact that a car is an expensive indivisible good, the box argues that for a given household utility function there is a threshold income, such that the household only buys a car if its income is above the threshold. This is well taken, but there is the usual aggregation problem. A threshold at the household level does not necessarily produce one at the aggregate level if households are heterogeneous. Furthermore, two-car households seem to proliferate in rich countries. The authors acknowledge the problem, but take confidence in that the approach seems to work in the empirical implementation. Nevertheless, it would be good in future work to try to improve the foundations of the approach.

At the macro level, the paper considers that there are many factors influencing car ownership. While the simple approach is parsimonious, there is the risk that it overly simplifies matters. There are many important features, which are not taken account of in the 'theory' of the box: Politics comes to mind as a candidate for first order effects.

The paper briefly discusses the effect of availability of roads and railways. Clearly these factors influence car ownership. As the authors rightly notice this is not easily taken account of. There may be an endogeneity problem when running regressions over the time span considered where road grid is used to explain car ownership. It may well be that the development of the road grid itself depends on the number of cars. It would nevertheless be an interesting venue for further research to take the effect of the road grid and railways into consideration. The effects here may be rather intricate, and it is not obvious to this reader that one would end up with a simple theory as in the aforementioned box.

The paper offers some policy relevant considerations. It appears that an important policy question for countries over the longer span exactly is the development of the infrastructure. Although it is outside the confines of the present paper, it would be interesting to see models and empirical work that consider the interaction between political decisions on infrastructure and the proliferation of car ownership in the electorate. At an intuitive level, it seems like there can be reinforcing effects: a larger road grid and smaller railways lead to more car ownership, which expands the electoral base for more roads and so forth. I would welcome research on such issues.

Although the authors do include a number of controls some obvious factors influencing car demand are left out of the analysis. Coming from one of the countries in the world with the highest car taxes, I am not surprised to see that Denmark has a strikingly low degree of car ownership despite being one of the richest countries in the world. Of course this is to some degree captured in the fixed effects estimation; still, one has the feeling that progress could be made by including taxes as a control.

A good paper provides new knowledge and induces thoughts about possibilities of further research. This paper does both; it provides a refreshing look at an important issue, which is certainly not going to be less relevant in years to come.

Panel discussion

Omer Moav acknowledged that the findings are very interesting, as well as the policy discussion about congestions, but stressed that it is not clear in the paper how estimates are related to actual policy implications.

Allan Drazen wondered what should be done from a policy-making perspective, since it seems likely that there will be a crisis, and that some major policy change will be triggered. This argument implies that a simple extrapolation is not a realistic forecast, as it does not account for the effect of policies that are likely to be implemented over the next years, such as the adoption of alternative energy sources.

According to José Tavares the paper provides very interesting insights by stating that there exists a threshold and that, in large countries, the bulk of the population is approaching it. He asked whether there could be an echo effect as the first buyers replace their cars and a second-hand car market for less rich people develops. Furthermore, he suggested dealing with relevant issues related to policies on infrastructures and policies that are going to affect the size of the households, and with people's expectations about whether the government is going to impose taxes on car properties. Interestingly, policies that may reduce the demand for cars have to trade off control and democracy instances; for instance, China and India likely will have different approaches to taxation, given differently democratic regimes.

Alessandro Turrini wondered whether, since projections are based on real GDP, it might be important to account for feedbacks from cars' demand to real income growth, to the extent that cars are produced locally.

APPENDIX: TESTING THE SIGNIFICANCE OF CHANGES OVER TIME IN THE REGRESSIONS

To test the patterns suggested in Figure 6, we estimate a specification that allows the income threshold and its associated 'elasticity' to be a linear function of time. This is the specification:

$$\textit{threshold}_t = b_4 + b_5 t,$$

$$\textit{cars per thousand population}_t = b_0 + b_1 t + 1000(b_2 + b_3 t)(1 - g(\textit{threshold}_t;\ \textit{GDP}_t,\ \textit{Gini}_t)) + \varepsilon_t,$$

where $g(\bullet;\ GDP,\ Gini)$ is the cumulative distribution of the income given per capita GDP and Gini coefficient. Because of the non-linearity of g, we estimate the specification

Table A1. Time varying patterns in impact of income crossing threshold on car ownership rates

	Balanced 1975–2002 (1)	Balanced 1995–2002 (2)	Unbalanced 1963–2003 (3)
Constant	−15.57	13.47	11.03
	(8.97)	(7.32)	(2.75)**
Constant time trend	−0.57	−0.17	0.34
	(0.59)	(2.64)	(0.14)*
Elasticity	465.28	423.89	425.52
	(9.78)**	(10.24)**	(4.96)**
Elasticity time trend	7.02	9.62	3.28
	(0.67)**	(3.75)*	(0.37)**
Threshold	4747.02	4082.55	4167.25
	(264.88)**	(215.50)**	(119.27)**
Threshold time trend	−20.61	29.81	−128.22
	(21.64)	(81.00)	(11.74)**
Observations	952	496	3255
Adjusted R-squared	0.859	0.822	0.844

Notes: Standard errors in parentheses.

* significant at 5%; ** significant at 1%.

using non-linear least squares. These estimates are presented in Table A1. We are not able to reject the hypothesis of a trend in income threshold and in the regression intercept, but do reject it for the null of no trend in its semi-elasticity.

Dynamic adjustment model

Table A2 presents the results from a dynamic model where the lagged car ownership rate is included as a control. Specification (1) includes only the share of the population above the income threshold, whereas specification (2) also includes its interaction with a trend. That interaction term has a small and not statistically significant coefficient. Thus, the rising ownership rates over time (for a given population share above the threshold) are being captured by the lagged dependent variable. Also, the effect of the increase in income is very persistent in all specifications. Therefore, the long-run effect of an increase in the threshold variable is much larger than its short-term effect. This dynamic model suggests a relatively slow adjustment. For example, in specification (1), a 1% permanent increase in the population with income above $4500 will only increase car ownership in the current period by 0.027 percentage points. Even after ten years, that change will increase the ownership by 0.23 percentage points, which is 27% of the long-run effect, 0.85 percentage points. The rapid take-off in ownership rates in countries such as China and India today or the advanced countries in earlier decades suggests a more rapid adjustment process, leading us not to use this dynamic model for our baseline results.

Table A2. Determinants of car ownership in a panel of countries

	(1)	(2)	(3)
I(Optimal threshold)	27.18**	26.97**	26.70**
	(3.57)	(4.83)	(4.92)
I(Optimal threshold) × (year-2000)		−0.0108	−0.0824
		(0.11)	(0.098)
Lagged cars/1000 people	0.968**	0.969**	0.976**
	(0.0044)	(0.012)	(0.0096)
I(Optimal threshold) × Log(new US car price)			
Urbanization			0.0157
			(0.018)
Household size			0.913
			(0.78)
Population density			0.000181
			(0.0043)
Constant	−1.985**	−2.078**	−7.927**
	(0.91)	(1.02)	(3.89)
Estimated optimal threshold	4500	4500	4500
Observations	3133	3133	2874
R-squared	0.98	0.98	0.99

Notes: Robust clustered (by country) standard errors in parentheses. *R*-squared is adjusted *R*-squared for no fixed effects, and within *R*-squared for fixed effects. See Data Appendix for sources.

* significant at 5%; ** significant at 1%.

DATA APPENDIX

Data on car ownership rates by country is available from the various issues of *World Road Statistics* by the International Road Federation (IRF). There are some gaps in the car ownership data in IRF. Since that is a relatively slow-moving stock variable, we interpolate the missing observations (the results presented are robust, and do not hinge on this interpolation). For regression tables, Hong Kong SAR and Singapore are dropped because they are small economies, and outliers which distort the results. They are included for the forecasts.

Only for Figure 3 we used various sources to obtain longer time series than IRF data. For the United States and Japan, we used the following national sources: US Department of Transportation, 'Highway statistics', various issues, and Japan Ministry of Land, Infrastructure and Transport, 'Jidoushya-yusou-toukei-chousa', various issues and Ministry of Land, Infrastructure and Transport, 'Rikuun-toukei-youran', various issues. For the European countries, we used various issues of 'Annual Bulletin of Transport Statistics for Europe and North America' by the United Nations Economic Council of Europe.

Gasoline prices are drawn from an international survey (*International Fuel Prices*, 2005 edition) conducted in 172 countries between 1991 and 2004 (but with several gaps in coverage) by the German Technical Cooperation agency GTZ. Due to the volatile nature of that variable we chose not to interpolate missing observations.

The main explanatory variable we focus on is the share of population above a certain income. Since cars are a tradable good, our income measure is based on GDP in constant 2000 US dollars, which, as appropriate, does not make PPP adjustments. The data after 1970 is available from World Development Indicators (WDI) published by the World Bank. It is extended back in time (prior to 1970) using the growth rates from Maddison (2003). In order to estimate the share of a country's population above that threshold income level, we follow the approach used in Dollar and Kraay (2002). That consists of assuming a log-normal income distribution whose mean is given by the level of GDP per capita. The second moment of that distribution is estimated based on the Gini coefficient.

Unfortunately, Gini coefficients are notoriously difficult to estimate correctly. Our main data source is the UNU/WIDER World Income Inequality Database V 2.0a. That is a collection of inequality measures from different surveys. These surveys differ in methodology (actual household survey or estimates from aggregated data) and unit of observation (household level or individual level, income or consumption). We controlled the characteristic by using the predicted value if all surveys have the same 'standard' characteristics. Also, if we have multiple observations in a year, we calculated the weighted average of surveys. The weights are the quality measure assigned by UNU. Gini coefficients are linearly interpolated when necessary. Once we have estimated those moments we can easily obtain the share of the population above the income threshold.

The other explanatory variables considered include demographic characteristics (e.g. share of the population aged 18–65 and average household size), population density and a measure of urbanization. All of them are obtained from WDI. They are linearly interpolated when necessary.

Our forecasts for future car ownership are based on GDP forecasts from the International Monetary Fund World Economic Outlook (WEO) database, the Economist Intelligence Unit (EIU) (2006), Goldman Sachs (Wilson and Purushothaman, 2003), PricewaterhouseCoopers (2006) and Intergovernmental Panel on Climate Change (IPCC) (2000). Since multiple datasets have forecasts for the same country-year pair, we use the datasets in the order above to choose the preferred forecasts. That is, we always use the WEO first (giving 5-year ahead forecasts). We then use forecasts from the EIU extending to 2020, and so on. IPCC is different from the other four datasets because it only provides a regional average growth rate. We used it when no other data provides country-specific forecasts. IPCC classified countries as advanced economies based on their 1990 situation. We assumed that their growth rate is the same as in OECD countries if no other dataset provides the growth information. Population estimates are from the UN Population Division. Gini coefficients are assumed to stay constant.

The WEO definition of 'Advanced economies' contains Australia, Austria, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Hong Kong SAR, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and United States. Developing economies are all other countries.

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