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STUDYING CAR AND MOTORCYCLE OWNERSHIP LEVELS IN EVELOPING COUNTRIES USING INDIVIDUAL INCOME DISTRIBUTIONS

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STUDYING CAR AND MOTORCYCLE OWNERSHIP LEVELS IN DEVELOPING COUNTRIES USING INDIVIDUAL INCOME DISTRIBUTIONS

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ABSTRACT

Car and motorcycle ownership levels are expected to increase considerably in developing countries in the following decades, mainly as a result of increasing income levels and population growth, posing great challenges for developing countries in terms of urban transport sustainability. This paper proposes a model to study and forecast car and motorcycle ownership levels in regions of the developing world, quantifying the potential increase in motorization in the following decades. The model assumes that there exist minimum personal income thresholds for individuals to own a car or a motorcycle. Ownership levels can then be determined based on estimates of the individual income distribution and income thresholds. Forecasting is based on expected income growth and changes in vehicle purchase, ownership and use costs that affect the income threshold. The model is applied to Colombia in order to project car and motorcycle ownership levels up to 2040. These projections indicate an expected three-fold increase in the number of cars and a nine-fold increase in the number of motorcycles, underlining the importance of motorcycles as an urban transport mode in the following decades. We perform a sensitivity analysis that further supports this importance, showing a relatively low sensitivity of the forecasted motorcycle ownership levels with respect to different income growth and income threshold scenarios. Due to its low data requirements, the proposed model can be easily applied to other regions of the developing world.

Keywords: Car, motorcycle, ownership, motorization, developing countries, income distribution.

INTRODUCTION

In the previous decades, together with economic development and population growth, many developing countries have experienced an accelerated increase in the number of cars and motorcycles. However, according to the experience of developed countries, ownership levels (vehicles per inhabitant) will increase even faster in the following decades. For instance, the sustainable mobility project (World Business Council for Sustainable Development, 2004) projected a five-fold increase in the number of vehicles in China and Latin America by 2050.

Increasing motor vehicle ownership levels pose great challenges for developing countries in terms of sustainability in urban transport. The availability of a motor vehicle significantly affects several individual decisions related to transport, such as residential location, number of daily trips, destiny and, of course, mode. This usually implies that, as the number of motor vehicles increases, so does the number and distance of motorized trips. This increase generates most of the externalities associated with transport, such as congestion, pollution and road accidents. Moreover, car ownership is mostly concentrated in high-income households, which suggests that infrastructure investments to alleviate congestion may be socially regressive (unless it is properly charged to the main beneficiaries, which usually is not the case). Dimitriou and Gakenheimer (2011) and Gakenheimer (1999) provide a broad perspective of urban transport in developing countries, including specific analyses about the effects of fast-rising motorization.

The main objective of this paper is to propose a straightforward but insightful model to forecast vehicle ownership levels in developing countries in a medium- and long-term time framework. The forecasts are useful as indicators of the potential growth in motorization that developing countries may experience in the following decades, mainly as a result of increasing income levels. We apply this model to Colombia in order to forecast car and motorcycle ownership levels up to 2040. We consider that the model could be successfully applied to other regions of the developing world (countries, cities, districts, metropolitan areas or other geographical levels), obtaining useful estimates to help guide realistic public policies towards sustainability in urban transport. We consider the model especially suitable for developing countries given its underlying assumptions and the scarce data requirements for its application.

The remainder of this paper is organized in four sections. The following section describes the proposed model. Then, the model is applied to Colombia in order to forecast ownership levels up to 2040. A sensitivity analysis is performed next in order to obtain projections under different scenarios. The last section presents the main conclusions. Due to space limitations, we do not include an specific section on literature review of car and motorcycle ownership levels. However, the following section references the findings of literature that are most relevant and support the underlying assumptions of the proposed model, positioning this work relative to the existing state of knowledge. For a general review of car ownership models see De Jong et al. (2004).

THE MODEL

The model proposed to study vehicle ownership assumes that there exists a minimum personal income threshold for an individual to afford a vehicle. It further assumes that all individuals whose income is higher than this threshold, and whose age is above the minimum driving age, will own one vehicle. These assumptions imply that, knowing the individual income distribution of the region and its income threshold, the ownership level (vehicles per inhabitant) can be determined. Figure 1 illustrates this idea for car ownership.

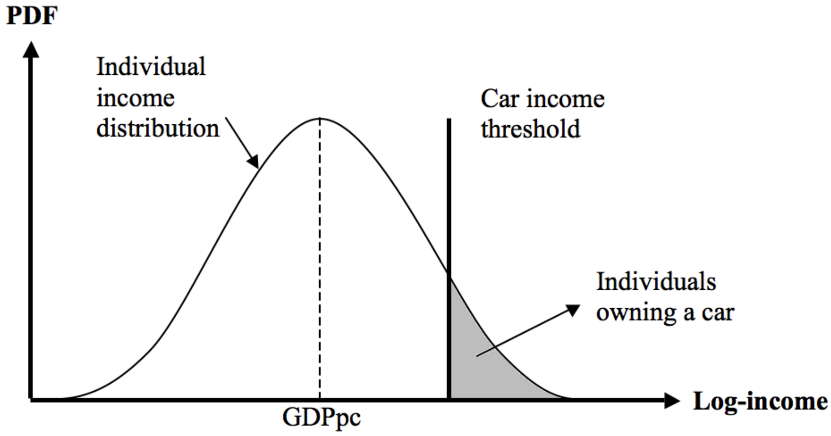

Figure 1 – Determination of the car ownership level

The horizontal axis in figure 1 represents the income level in logarithmic scale because income distributions generally follow a lognormal shape (Lopez and Servén, 2006). The average income is represented by the gross domestic product per capita (GDPpc), which does not necessarily coincide with the highest point of the distribution curve. The vertical axis represents the individual income distribution in terms of a probability density function (PDF), so the area under the distribution curve equals one. The car income threshold is placed to the right of the GDPpc, implying that less than half the population in the region has an income high enough to own a car, which is the case in most developing countries. The area to the right of the car income threshold and under the distribution curve (shaded in gray) represents the portion of the population whose income is high enough to own a car. The multiplication of this portion by the percentage of the population above the minimum driving age thus determines the car ownership level (cars per inhabitant).

As economic development spread its benefits in many developing countries, as it has done in the last decades, GDPpc rises over time and the income distribution curve shifts to the right, increasing the portion of the population to the right of the threshold (assuming that the threshold remains constant), and hence the car ownership level. This relationship between the GDPpc and the car ownership level agrees with the sigmoidal shape found empirically in many countries and frequently used to analyse ownership levels (Dargay and Gately, 1999; Ingram and Liu, 1997; Button, Ngoe and Hine, 1983 – Figure 2). According to the proposed model, the car ownership level increases more rapidly as the middle-income population (generally the most populous as development spreads) go past the threshold. Additionally, the saturation level, usually assumed in the sigmoidal relationship between GDPpc and car ownership, corresponds in the model to the percentage of the population above the minimum driving age. Since in the last decades most countries have been experiencing an ageing population, this percentage has generally increased. This fact agrees with Ingram and Liu (1999) who observed that the estimated saturation levels tended to increase over time. The model also implies that changes in the income distribution may affect the car ownership level, even if GDPpc remains unchanged. When the income threshold is higher than the average income, a reduction in income inequality (a narrower distribution curve) would reduce car ownership, and vice versa. Kutzbach (2009) also recognized this effect of inequality on motorization.

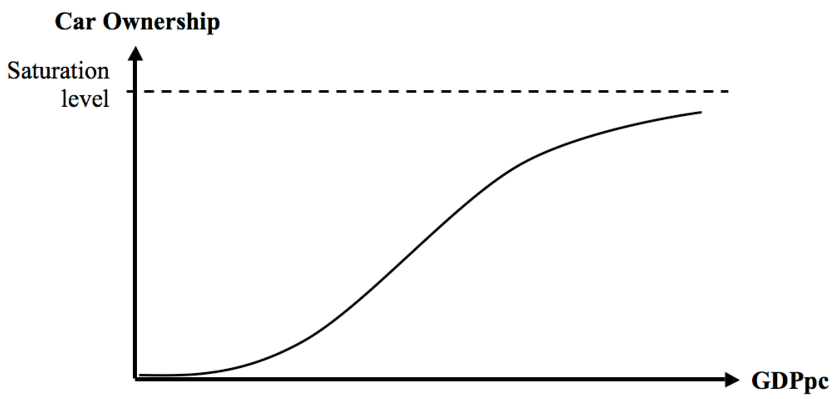

Figure 2 – Empirical relationship between the GDPpc and the car ownership level

The model assumption that the income threshold marks a cut off point between not owners and owners is clearly a simplification. In reality, ownership levels simply increase for higher income population. However, in order to take this into consideration, disaggregate ownership and income data would be required. Previous studies on the disaggregate modelling of car ownership in developing regions have found income to be the major driving force of motorization (Gómez and Obando, 2013; Zegras and Hannan, 2012; Yang and Zegras, 2010). Similarly, Gakenheimer (1999) found that in developing countries the income of the top 20% of the population might be a better explanatory variable for car ownership than overall income.

Given the assumption that personal income (as compared to the income threshold) is the only relevant decision variable for car ownership, the model is more suitable to analyse and project vehicle ownership in developing countries. In developed nations, other factors, such as the availability of public transport and residential location, may also play an important role in determining the ownership level (see for instance Potoglou and Kanaroglou, 2008).

Another important characteristic of the model is that it operates at the individual level, rather than at the household level. It could be argued that car ownership decisions may be better represented with households as the decision-maker unit, so the model could be proposed based on the household income distribution and a household income threshold. However, this approach faces a critical drawback: household size would be a factor as important, or perhaps more important, as income to determine the number of cars in the household. In other words, household differentiation by income would not be a good predictor of the number of cars in the household because household size would also have to be considered. Furthermore, it would not be right to assume that a household can own maximum one car, as it is assumed in the model for individuals. This implies that at least a second threshold would have to be added to the model in order to differentiate households with two or more cars. It is important to notice that the individual approach implies that a household with a very high income would own as many cars as the number of household members above the minimum driving age.

The income threshold

The minimum income threshold for an individual to own a car theoretically depends on purchase, ownership and use costs. These costs may be expressed in terms of a monthly expenditure as follows. Purchasing a car generally requires borrowing, which causes a monthly purchase expenditure. This expenditure depends on the car price, the interest rate and the payment period. With respect to ownership, the monthly expenditure is generally related to fixed costs such as taxes, parking and maintenance (assuming that parking is paid on a monthly basis). Finally, the monthly out-of-pocket expenditure depends mainly on fuel costs, which can be computed as the product of the number of kilometres travelled per month, fuel efficiency and fuel price.

In order to determine the minimum monthly income that an individual requires to afford the monthly expenditure associated to car purchase, ownership and use costs, a maximum percentage of income that individuals are willing to spend in transport must be established. Following the constant travel money budget theory (Zahavi, 1982), this percentage is quite regular among different regions in the world. Figure 3 illustrates the theoretical process to determine the minimum monthly income threshold based on purchase, ownership and use costs, as explained above.

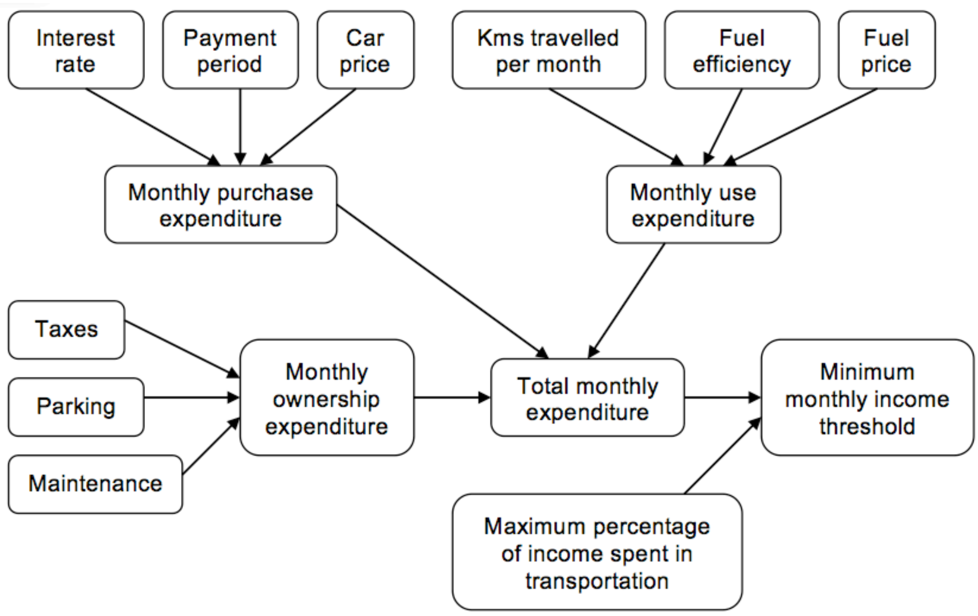

Figure 3 – Determination of the minimum monthly income threshold

If the income threshold decreases (i.e., shifts to the left), the population to the right of the threshold increases and so the car ownership level. This relationship determines how changes in car purchase, ownership and use costs can affect the car ownership level in the model. It is important to clarify that this is a theoretical proposition, which has to be corroborated by empirical studies. Whelan, Wardman and Daly (2000), for instance, found that purchase costs have a stronger bearing on car ownership levels than do operating costs.

Motorcycle ownership

In several developing countries the increasing motorization rate is not only related to cars but also to motorcycles (Pongthanaisawan and Sorapipatana, 2010). The motorcycle ownership level for a region can be determined in the model considering a minimum income threshold for an individual to own a motorcycle. In this case, the hypothesis is that the individuals with motorcycles are those whose income is higher than the motorcycle threshold but lower than the car threshold. As the individual income goes past the car threshold, the person prefers to sell the motorcycle and buy a car. Figure 4 illustrates this idea. As pointed out before, the assumption of a cut off point between motorcycle and car owners is a simplification. In reality, there may be a region with overlapping ownership.

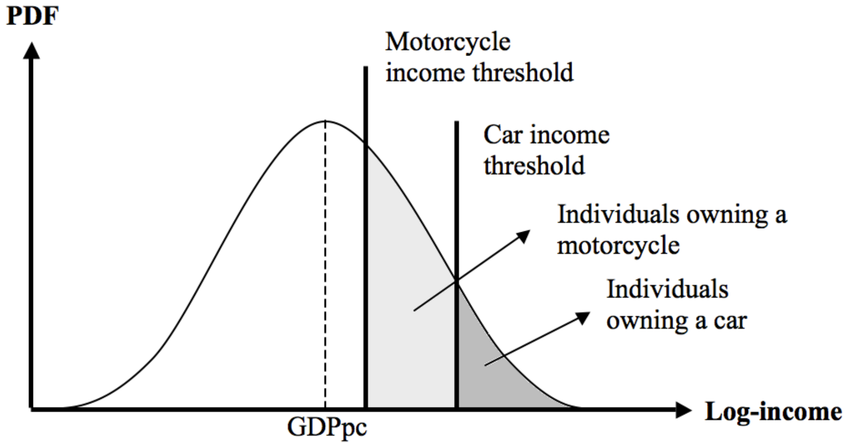

Figure 4 – Determination of the car and motorcycle ownership levels

As the income distribution shifts to the right (GDPpc growth), the motorcycle ownership level initially increases. However, it will eventually decrease, when most of the population can afford a car. This relationship agrees with previous research findings indicating that after personal income grows up to a certain level, people will shift from motorcycle to car ownership (Pongthanaisawan and Sorapipatana, 2010). Figure 5 illustrates the relationship between GDPpc and car and motorcycle ownership levels according to the model. There are still very few empirical studies about the relationship between car and motorcycle ownership levels in developing countries, which is clearly an important area for future research (Senbil, Zhang and Fujiwara, 2007).

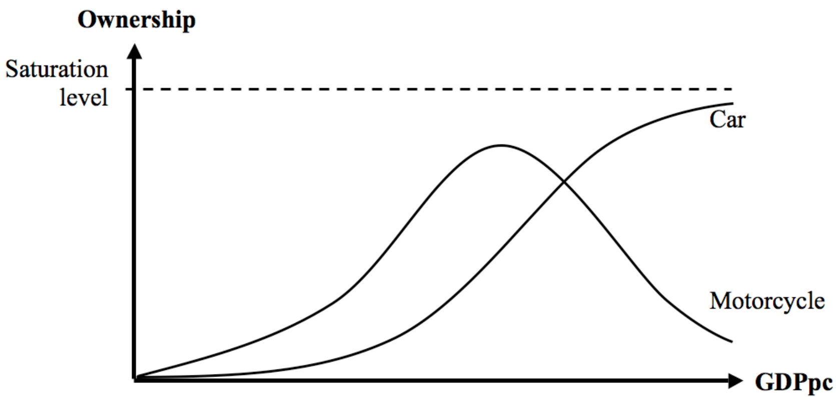

Figure 5 – Relationship between the GDPpc and the car and motorcycle ownership levels

The motorcycle income threshold can be determined following the process described in figure 3, based on motorcycle purchase, ownership and use costs. However, one would expect that other factors, such as climate, gender and age, might also play an important role in the individual decision to own a motorcycle (Anastasopoulos et al., 2012). In this respect, the assumption that all individuals whose income is between the car and motorcycle thresholds, and whose age is above the minimum driving age, will own a motorcycle, may be an overstatement for some regions of the developing world. In these cases, the assumption could be modified indicating that, for instance, only males aged below 60 years are prone to own a motorcycle.

MODEL APPLICATION TO COLOMBIA

In this section, the model is applied to Colombia in order to forecast car and motorcycle ownership levels up to 2040. The application process can be divided into four steps:

1. Estimation of individual income distributions
2. Estimation of population above the minimum driving age
3. Estimation of income thresholds
4. Forecasting of ownership levels and number of vehicles based on the results of steps 1, 2 and 3.

Estimation of individual income distributions

The starting point in estimating an individual income distribution is the income per capita (Sala-i-Martin, 2005). As a measure of total income, we will use the gross domestic product (GDP). The GDP per capita (GDPpc) will be used as the mean of the income distribution.

Historical information on annual GDPpc in Colombia is reported by the official National Department of Statistics (DANE, 2012). Between 1990 and 2011, the annual GDPpc in Colombia increased from COL$8,03 millions to COL$12,51 millions in constant terms of 2010 (approximately US$8.670 in parity purchase prices). This implies an average annual increase of 2,13%.

The International Monetary Fund (IMF) provides a projection of GPDpc in Colombia up to 2017. We followed this estimate, which implies an average annual increase in GDPpc of 3,29% in real terms between 2011 and 2017. In order to project further to 2040, we assumed a constant annual increase of 3,27%, which is the increase in the last year of the IMF projections.

Once we have the mean of the distribution, we use information on decile income shares in order to approximate the income per capita for each population decile. Historical information on decile income shares in Colombia is obtained from the UNU-WIDER compilations (UNU-

WIDER, 2008), using only data at the individual level (not at the household level). Unfortunately, information on decile income shares is not available for every year. In order to estimate the missing years, we used a simple linear interpolation. The data shows that income inequality increased considerably during the 1990's and then decreased slightly over the last decade. In 2011, the richest decile earned about 44,4% of total income, while the poorest decile earned only 1,07%.

Considering the trend of the previous decade and the progressive and persistent government policies to focus expenditures and services in low-income population, income shares are projected assuming a moderate reduction in income inequality. This projection implies that by 2040 the richest decile will earn 41,67% of total income, while the poorest decile will earn 2,04%.

Based on the annual income per capita for each decile, we estimate the individual income distribution using kernel density estimation (Sheather, 2004). This method does not impose specific functional forms on distributions. Instead, the method is based on approximating a density distribution around each observation (the kernel) and then adding up to estimate the overall distribution. We use a Gaussian kernel. One important parameter that needs to be specified is the bandwidth or smoothing parameter of the kernel, which relates to its standard deviation. We use the common approximation proposed by Silverman (1986).

Figure 6 shows the results obtained for the individual income distributions between 1990 and 2040. The distribution curves exhibit three humps, which correspond to high, middle and low-income populations. As pointed out previously, as GDPpc rises over time, the distribution curve shifts to the right. Also, as a result of the assumed inequality reduction, the middle-income class becomes more populous (i.e. the middle hump is higher).

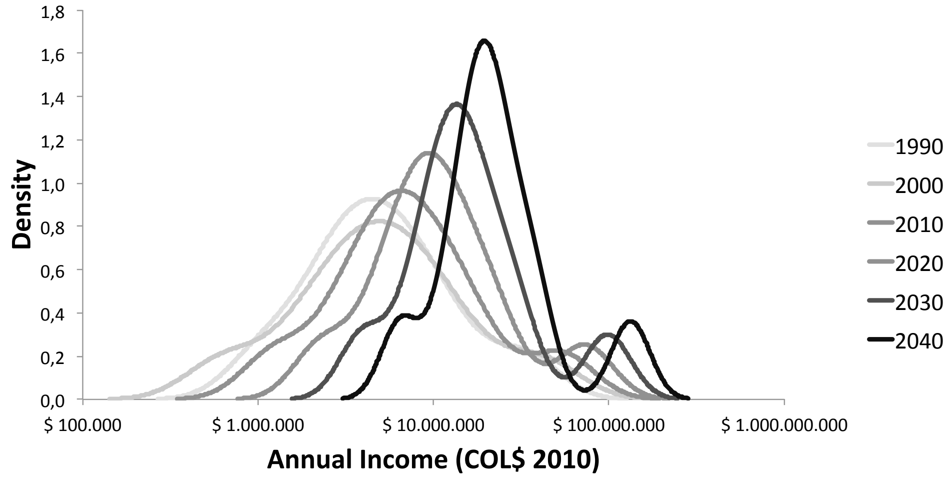

Figure 6 – Individual income distribution in Colombia 1990-2040

Population above the minimum driving age

Between 1990 and 2011, total population in Colombia increased from 34,1 to 45,5 million inhabitants. This implies an average annual growth rate of 1.45%. In this same period, the percentage of the population above the minimum driving age, 16 years, increased from 62,1% to 69,9%. This caused the population above the minimum driving age to increase at a higher average annual rate of 2,02%.

The National Department of Statistics of Colombia (DANE, 2012) provides projections of the total population and the percentage of population above the minimum driving age by 2020. We followed this projections, which estimate a total population of 50,9 millions and a percentage above the minimum driving age of 72,9% in 2020. In order to estimate population growth by 2040, we followed the medium variant of the world population prospects made for several countries by the United Nations (United Nations, 2010). These projections result in a total population of 58,6 millions and a percentage above the minimum driving age of 79% by 2040.

Determination of income thresholds

In order to determine the annual income thresholds, we could use the approach illustrated in figure 3. However, this approach requires average data that is not readily available in Colombia to an acceptable level of confidence. Instead, we calculated the past thresholds based on historical car and motorcycle ownership data and the past distribution curves estimated previously. In other words, we computed the required thresholds for the model to replicate the historical ownership levels in Colombia from 1990 to 2010. Historic data on the number of cars and motorcycles registered in Colombia were obtained from the Ministry of Transport of Colombia (MT, 2011). Figure 7 shows the evolution of ownership levels in this period and figure 8 presents the estimated income thresholds.

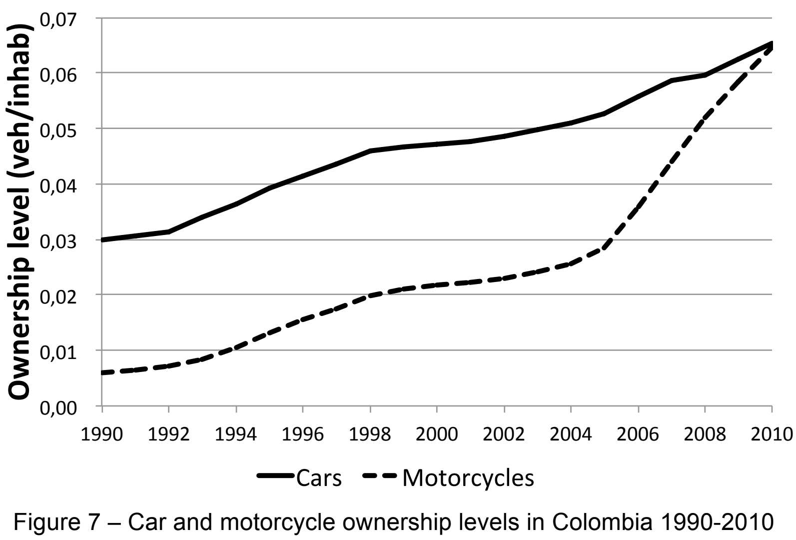

Figure 7 – Car and motorcycle ownership levels in Colombia 1990-2010

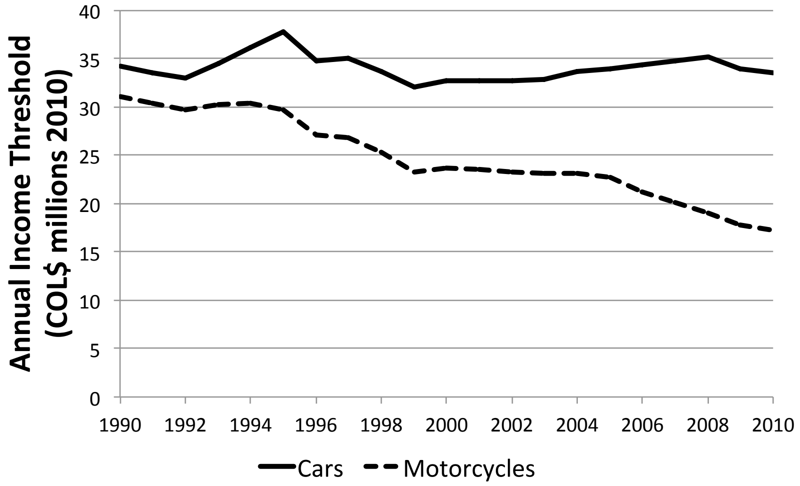

Figure 8 – Annual car and motorcycle income thresholds in Colombia 1990-2010

The car ownership level in Colombia more than doubled between 1990 and 2010, rising from 0,03 to 0,065 at a steady rate. On the other hand, the motorcycle ownership level increased by a factor of ten in the same period, rising from 0,006 to 0,065. Remarkably, most of this increase occurred between 2005 and 2010, which suggests a significant increase in the number of motorcycles in the upcoming years.

The annual income threshold for cars remained fairly stable between 1990 and 2010. According to the model, during this period an individual required an annual income of approximately COL$33,5 millions of 2010 (US$24.300 in parity purchase prices) to afford a car. The faster increase in the number of motorcycles is explained in the model by the steady decrease of the income threshold for motorcycles between 1990 and 2010. During this period, this threshold halved from COL$31,1 millions to COL$17,2 millions of 2010 (US$12.480 in parity purchase prices). This reduction was probably the result not only of falling international prices for motorcycles and increased assembling factories of these vehicles in Colombia, but also of far easier access to personal credits to purchase a motorcycle (lower red tape, lower interests rates and longer payment periods), which decreased the required monthly purchase expenditure.

In order to forecast ownership levels to 2040, car and motorcycle income thresholds must be forecasted. Given the relative stability of the level of the car threshold in the previous years, we assumed a constant threshold to 2040 equal to COL$33,5 millions of 2010. This assumption implies that car purchase, ownership and use cost will remain stable over the following three decades. This assumption may be regarded as strict. However, the following sections present a sensitivity analysis with respect to different income threshold assumptions. The motorcycle threshold showed a decreasing tendency over the past two decades. We assumed that this tendency is going to continue over the coming years, until the annual threshold reaches an assumed minimum equal to COL$12 millions of 2010, which is reached in 2017. After this year, we assume the motorcycle threshold will remain constant.

Computation of ownership levels and number of vehicles

Based on the projections of income distribution, population and income thresholds, the process to compute ownership levels and number of vehicles is straightforward. The process to estimate car and motorcycle ownership levels only involves measuring the corresponding areas under the distribution curves (figure 4) multiplied by the percentage of population above the minimum driving age. To obtain the total number of cars and motorcycles, these ownership levels have to be multiplied by the total population.

Figure 9 illustrates the distribution curves between 2010 and 2040, together with the income thresholds. This figure shows that by 2040 the car income threshold would still be higher than the mean income, indicating the significant potential for car ownership growth that would remain beyond 2040. Additionally, the figure determines that by 2040, middle-income people would be the main owners of motorcycles.

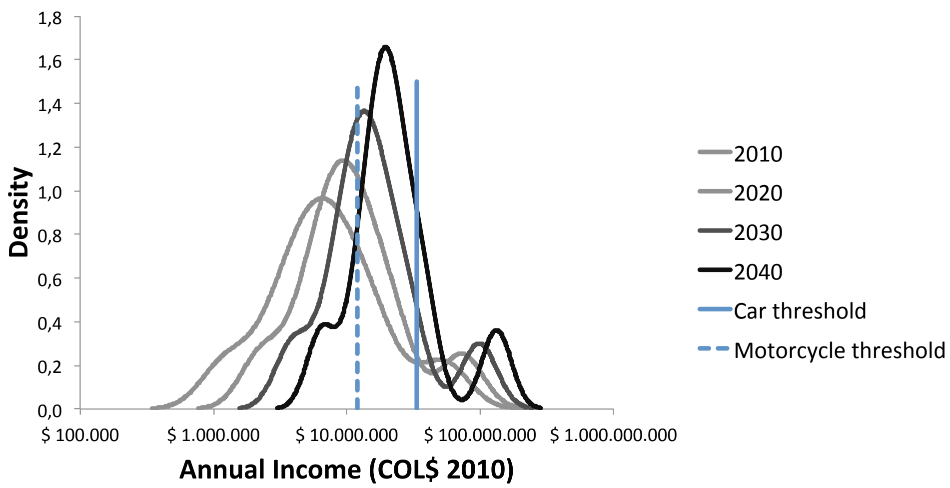

Figure 9 – Individual income distribution and income thresholds in Colombia 2010-2040

Figure 10 and table I show the projections of ownership levels and the total number of vehicles up to 2040 respectively. The most remarkable result is the accelerated increase that is expected in the number of motorcycles in the country. The results indicate that this number would increase nine-fold, from about 3 millions in 2010 to over 27 millions in 2040, a 7,8% average annual increase. This underlines the urgency for Colombia to adopt public policies aimed at either preventing the expected increase in the number of motorcycles, such as higher purchase, ownership or use taxes and much better public transport, or alleviating its impact on traffic flow, such as building exclusive lanes.

The number of cars is expected to increase at an average annual rate of 4,3% between 2010 and 2040, rising from nearly 3 millions to over 10 millions. Even though this increase is not as rapid as that of motorcycles, it would certainly worsen the already serious problems of congestion and pollution in the biggest cities of Colombia.

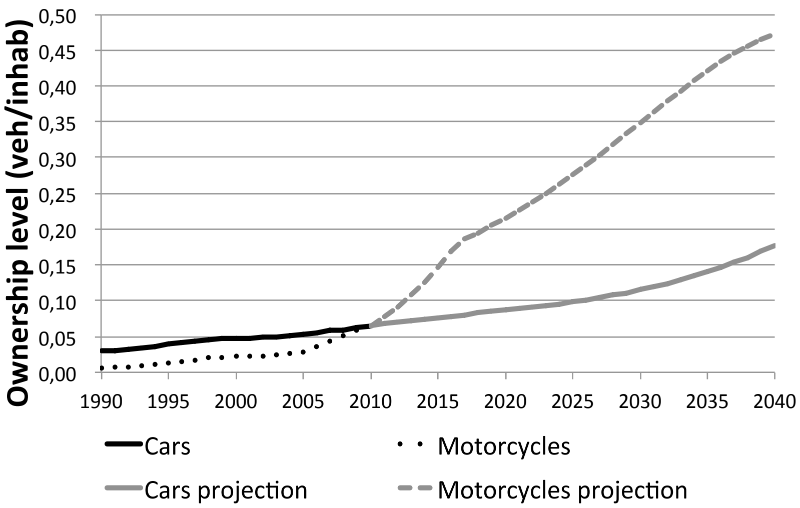

Figure 10 – Projection of car and motorcycle ownership levels in Colombia 2010-2040

Table I – Projection of total number of cars and motorcyles in Colombia 2010-2040

Year	Population (millions)	Cars		Motorcycles	
		Ownership (cars/inhab)	Number of cars (millions)	Ownership (moto/inhab)	Number of motorcycles (millions)
2010	45,5	0,065	2,97	0,065	2,94
2015	48,2	0,077	3,70	0,147	7,07
2020	50,9	0,087	4,40	0,215	10,93
2025	53,4	0,098	5,25	0,275	14,69
2030	55,5	0,115	6,38	0,348	19,33
2035	57,2	0,140	8,03	0,421	24,08
2040	58,6	0,177	10,40	0,472	27,64

SENSITIVITY ANALYSIS

The proposed model can be easily adapted to different assumptions about future income distribution, population and income thresholds. In this section we present a sensitivity analysis of the forecasted ownership levels with respect to different income growth rates beyond 2017 and changes in income thresholds.

Changes in income growth

The projections of car and motorcycle ownership levels presented previously were based on a constant annual income increase of 3.27% beyond 2017. We consider this an optimistic scenario. Figures 11 and 12 show the forecasted car and motorcycle ownership levels assuming annual income growth rates of 2.6% (medium growth) and 2% (low growth), together with the previous projections (3.27%, high growth).

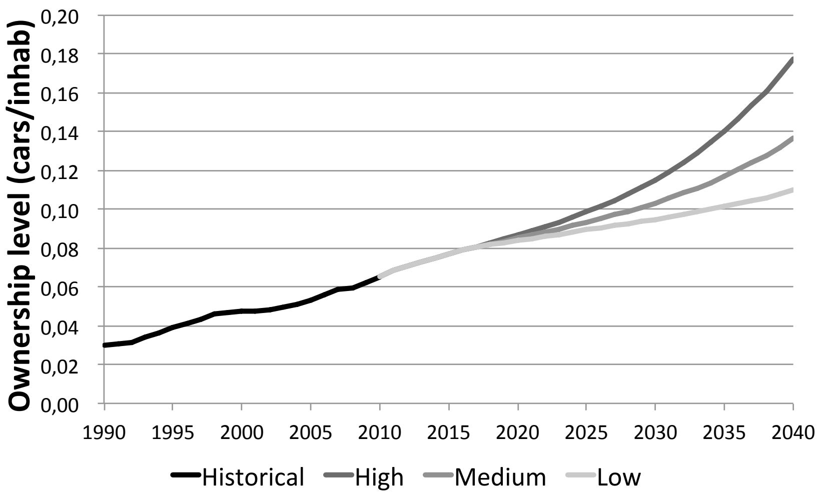

Figure 11 – Projection of car ownership levels in Colombia 2010-2040 under different income growth scenarios

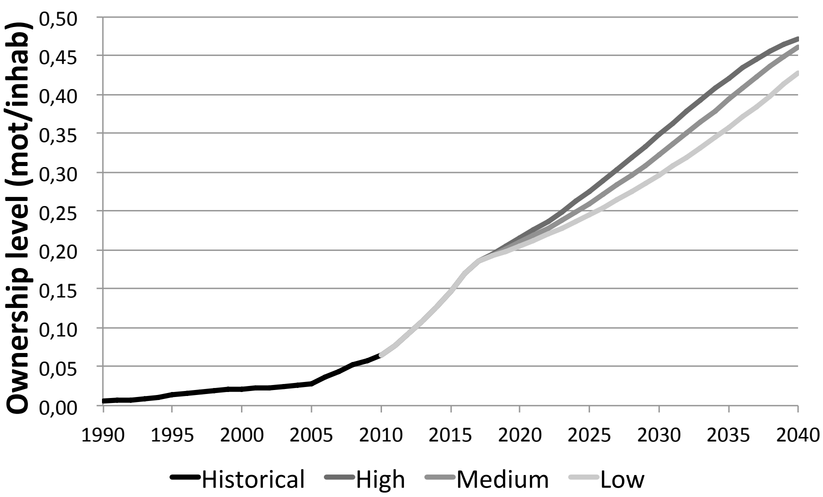

Figure 12 – Projection of motorcycle ownership levels in Colombia 2010-2040 under different income growth scenarios

The results show that car ownership has greater sensitivity than motorcycle ownership with respect to different income growth scenarios. The average annual increase of the car ownership level between 2017 and 2040 is 3,49%, 2,31% and 1,34% for the high, medium and low income growth scenarios respectively. These rates imply that by 2040 there would be 10,40, 7,99 or 6,42 million cars. On the other hand, the average annual increase of motorcycle ownership, during the same period and under the same income growth scenarios, is 4,13%, 4,03% and 3,68%. These rates imply that by 2040 there would be 27,64, 27,02 or 25,01 million motorcycles. Clearly, the variation in car ownership projections is considerably higher than in motorcycles. The reason for this difference lays in the fact that in the high income growth scenario the motorcycle ownership level starts to reach its maximum (illustrated in figure 5) around 2040, hence its accelerated increase reduces. The low sensitivity of the expected increase in motorcycles reinforces the urgency for Colombia to adopt public policies with respect to these vehicles.

Changes in income thresholds

The initial projections were based on the assumption that the car income threshold would remain constant up to 2040. This assumption implies that car purchase, ownership and use costs will not change considerably over this period. However, different circumstances may increase or decrease this threshold. On the one hand, Colombia is aggressively promoting free trade agreements that will probably reduce the price of cars by lowering tariffs. Additionally, new car technologies are being developed around the world that may considerable reduce its purchase cost. On the other hand, rising fuel prices may increase use costs.

In order to evaluate the sensitivity of vehicle ownership with respect to changes in the car threshold (i.e. changes in car costs), we made projections for two additional scenarios: one where the car threshold increases at a constant rate from COL$33,5 millions in 2010 until it is 20% higher in 2040 (rising threshold scenario), and another one where it decreases at a constant rate until it is 20% lower in 2040 (falling threshold scenario). It is important to notice that due to the way in which the motorcycle ownership level is computed in the model (the portion of the population between the two thresholds), changes in the car threshold not only affect car ownership but also motorcycle ownership. Figures 13 and 14 present the results for the different car threshold scenarios. These scenarios were computed under a high income growth condition.

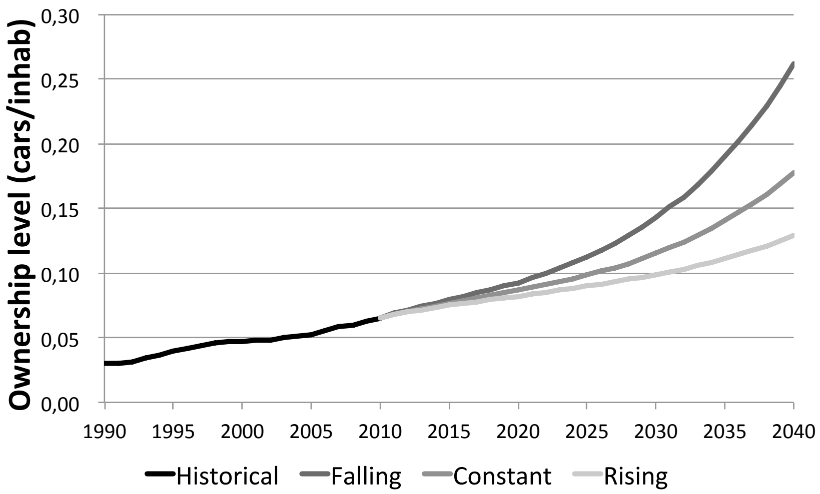

Figure 13 – Projection of car ownership levels in Colombia 2010-2040 under different car income threshold scenarios

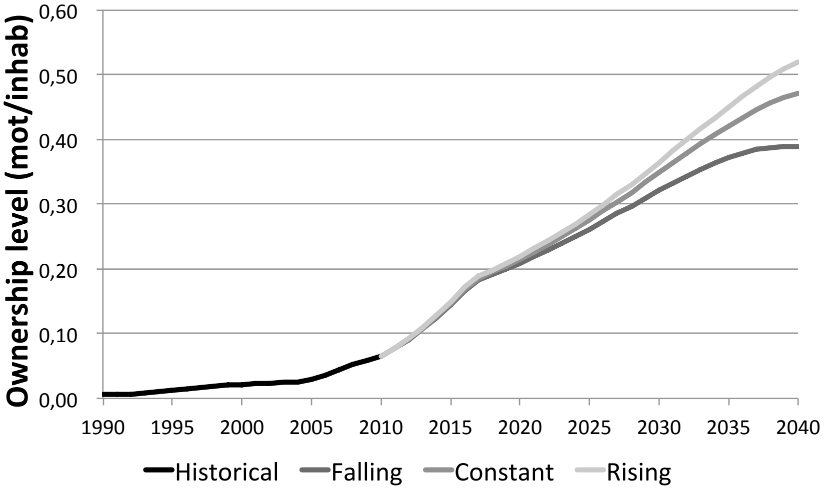

Figure 14 – Projection of motorcycle ownership levels in Colombia 2010-2040 under different car income threshold scenarios

As expected, the results show that higher car income thresholds reduce car ownership and increase motorcycle ownership. Between 2010 and 2040, the average annual increase of the car ownership level is 4,73%, 3,39% and 2,30% for the falling, constant and rising car threshold scenarios respectively. These rates imply that by 2040 there would be 15,31, 10,40, or 7,56 million cars. Conversely, the average annual increase of the motorcycle ownership level is 6,16%, 6,85% or 7,20%, implying 22,73, 27,64 or 30,48 million motorcycles in 2040 respectively.

Changes in the car income threshold may not only be the result of general circumstances, such as free trade agreements, but also the result of public policies purposely designed to increase the cost of car ownership and use, such as congestion charges or tax increases. In this respect, the previous results indicate that such policies may have the unintended consequence of increasing motorcycle ownership and use, unless the cost of motorcycles is also properly increased (i.e. motorcycles are also subject to congestion charges or tax increases).

Finally, the initial projections were also based on the assumption that the motorcycle income threshold would decrease to a minimum of COL$12 millions of 2010. Figure 15 presents the forecasted motorcycle ownership levels assuming minimum thresholds of COL$14 million and COL$10 million of 2010. These forecasts were calculated under a high income growth scenario and with a constant car ownership threshold. The results of the car ownership level are not computed since changes in the motorcycle threshold do not affect them.

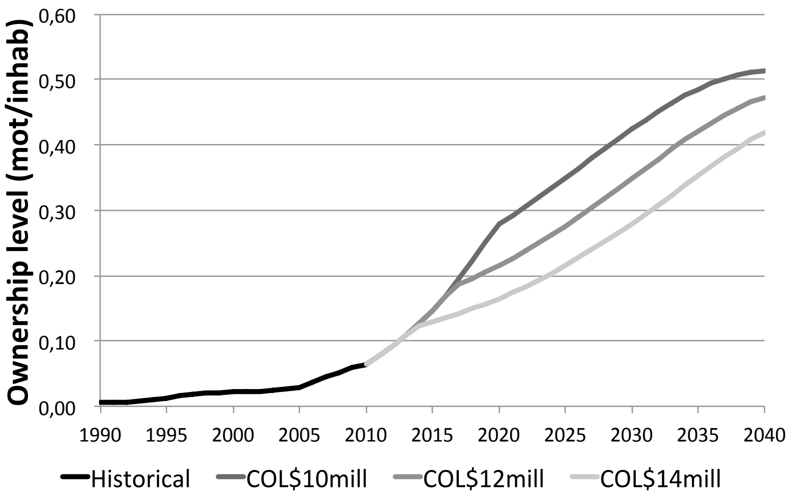

Figure 15 – Projection of motorcycle ownership levels in Colombia 2010-2040 under different minimum motorcycle income threshold scenarios

The results show again a relatively low sensitivity of motorcycle ownership levels to minimum income thresholds. In the evaluated scenarios, the total number of motorcycles by 2040 ranges from 24,50 to 30,05 millions. This low sensitivity indicates that in order to control the expected growth in motorcycle ownership to a considerable extent, significant cost increases would have to be implemented.

CONCLUSIONS

This paper proposes a straightforward but insightful model to study and forecast car and motorcycle ownership levels in developing countries, quantifying the potential increase in motorization in the following decades. The model assumes that there exist minimum personal income thresholds for individuals to afford a car or a motorcycle. All individuals whose income is higher than the car income threshold, and whose age is above the minimum driving age, will own one car. Similarly, all individuals whose income is higher than the motorcycle income threshold but below the car income threshold, will own one motorcycle.

These assumptions imply that, knowing the individual income distribution of the region and its income thresholds, the ownership levels (cars and motorcycles per inhabitant) can be determined. Due to the usual lognormal shape of income distribution, the model indicates a sigmoidal relationship between average income and car ownership, as found in many empirical studies.

The model is applied to Colombia in order to forecast car and motorcycle ownership levels up to 2040. The results show an expected average annual increase in the number of cars of 4,3% between 2010 and 2040, rising from approximately 3 millions to over 10 millions. Remarkably, the number of motorcycles in this same period is expected to increase at an average annual rate of 7,8%, rising from nearly 3 millions to over 27 millions. This accelerated increase highlights the urgency for Colombia to adopt public policies with respect to these vehicles.

A sensitivity analysis was performed for these results with respect to different income growth scenarios. This analysis shows a relatively lower sensitivity in the expected increase of motorcycles, strengthening the importance that this mode will play in the future of urban mobility in Colombian cities. Also, a sensitivity analysis was performed with respect to different projections of income thresholds (i.e. different projections of car and motorcycle purchase and use costs). The main conclusion of this analysis is that public policies aimed at increasing car costs in order to reduce its ownership and use, may have the unintended consequence of increasing motorcycle ownership and use, unless motorcycles costs are also properly increased.

Due to its low data requirements (population, average income, income distribution and vehicle ownership levels), the proposed model can be easily applied to other regions of the developing world, helping guide realistic public policies towards sustainability in urban transport. In order to be able to study the impact of specific public policies that affect car and motorcycle purchase, ownership and use costs, the income thresholds must be calibrated following a theoretical approach. Such an approach is proposed in this paper, but it is not employed due to insufficient data availability. The approach considers the monthly expenditure associated to purchasing, owning and using a motor vehicle and a maximum percentage of income that individuals are willing to spend in transport. Future work with respect to the proposed model should aim at calibrating the income thresholds in order to estimate the specific impact of different public policies that affect car and motorcycle costs.

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