Electric Two-Wheelers in India and Vietnam

Market Analysis and Environmental Impacts

ADB

Clean Air Initiative for Asian Cities

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ISBN 978-971-561-873-1
Publication Stock No. RPT091118

Cataloging-In-Publication Data

Asian Development Bank.
Electric two-wheelers in India and Viet Nam: market analysis and environmental impacts.
Mandaluyong City, Philippines: Asian Development Bank, 2009.

1. Transport. 2. Electric bikes. 3. Environmental effects. 4. India 5 Viet Nam.
I. Asian Development Bank.

This report was prepared by consultants based on results of the Technical Assistance on Rolling Out Air Quality Management in Asia, funded by the Swedish International Development Cooperation Agency and the Asian Development Bank (ADB).

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Contents

Abbreviations

BC	–	black carbon
C$	–	Canadian dollar
CARMA	–	Carbon Monitoring for Action
CO	–	carbon monoxide
CO_2	–	carbon dioxide
D	–	dong
e-bike	–	electric bike
e-scooter	–	electric scooter
GIS	–	geographic information system
MWTP	–	marginal willingness to pay
NASA INTEX-B	–	National Aeronautics and Space Administration Intercontinental Transport Experiment Phase B
NO_x	–	nitrogen oxide
OC	–	organic compound
PM_{10}	–	particulate matter 10
$PM_{2.5}$	–	particulate matter 2.5
PRC	–	People's Republic of China
Rs	–	rupee
SO_2	–	sulfur dioxide
VAT	–	value-added tax
VOC	–	volatile organic compound

Weights and Measures

cc	–	cubic centimeter engine displacement
D/100 km	–	Vietnamese dong per 100 kilometers
D/month	–	Vietnamese dong per month
km/h	–	kilometer per hour
kWh	–	kilowatt-hour
mg/km	–	milligram per kilometer
Rs/km	–	rupees per kilometer
W	–	watt

Acknowledgments

This report is part of Sustainable Urban Mobility in Asia, a program supported by the Asian Development Bank (ADB) through a grant from the Swedish International Development Cooperation Agency. It was prepared by Christopher Cherry and Luke Jones of the University of Tennessee.

The authors wish to thank Talat Munshi and Rutul Joshi from the Center for Environmental Planning and Technology in Ahmedabad, India for support on the project; Vu Tuan at the ADB Institute and Nguyen Ngoc Quang at the Hanoi University of Transport and Communications for their support on the Ha Noi element of this research; Michael Baechlin and the Swiss–Vietnamese Clean Air Program for data collection assistance and added funding; Sophie Punte, Herbert Fabian, and Sudhir Gota of the Clean Air Initiative for Asian Cities Center for their valuable comments in the refinement of this report; and Masami Tsuji of ADB for comments and overall guidance in the preparation of this report.

Executive Summary

Electric two-wheelers, which include vehicles ranging from electric bicycles to electric scooters, are becoming increasingly popular and important forms of urban transport in Asian cities, particularly in the People's Republic of China (PRC). While electric two-wheelers' popularity is evident in the PRC, their acceptance and adoption in other Asian countries is much more modest. The potential environmental benefit to Asian cities of electric two-wheelers could be significant, especially if electric two-wheelers replaced gasoline scooters and motorcycles. Electric two-wheelers in the PRC have been shown to have some of the lowest emission rates per kilometer compared to any motorized mode.

This report consists of three main analyses for two Asian cities, Ahmedabad, India, and Ha Noi, Viet Nam. The first is a market analysis of both cities, using disaggregate stated–preference choice modeling methods derived from user surveys to estimate the factors that influence electric two-wheeler purchase. Factors tested include vehicle price and performance characteristics, as well as variables like tax and licensing policy. The second analysis investigates electric two-wheeler emission rates based on electricity generation characteristics in Viet Nam and India. These analyses were conducted using two aggregate models to estimate primary pollutants and carbon dioxide (CO_2). The final section of this report combines the market models with the emission estimates to develop scenarios of vehicle adoption and the influence of those varied adoption rates on average emissions of the two-wheeler population in each of these cities.

Electric two-wheelers are much cleaner than their gasoline-powered two-wheeled counterparts on most metrics. Gasoline two-wheelers emit approximately double the CO_2, an order of magnitude more nitrogen oxides and particulate matter 10, and several orders of magnitude more volatile organic compounds and carbon monoxide. Particulate matter 2.5 and sulfur dioxide emissions are unknown for gasoline two-wheelers, but electric two-wheelers could have higher emission rates of these pollutants because of reliance on fossil fuel power plants. Electric two-wheelers in India have higher emission rates than those in Viet Nam because of India's higher reliance on coal power plants and higher electricity transmission loss rates. Viet Nam derives much of its electricity from natural gas power plants.

In Ha Noi, electric two-wheelers suffer from image problems and residents show a preference toward gasoline vehicles. Given the existing policy environment and technology, electric two-wheelers can be expected to fill up to 20% of the near future market. Given technological improvements, supportive tax policy, and increased gas prices, market shares can be expected to exceed 40% of the market. Respondents in the study were very sensitive to differential tax treatments, indicating that this could be a positive way to influence adoption. In Ahmedabad, electric two-wheelers suffer greater disfavor, with poor early experiences with the new technology tarnishing its reputation among users. Under current market scenarios, only about 6% of the near future market is expected to shift toward electric two-wheelers. Even with improved performance and price and increases in gas prices, only 14%–23% of the market can be expected to shift toward electric two-wheelers. Respondents in Ahmedabad were not sensitive to differential tax policy.

Coupling the market analysis with environmental emission rates, several technology and policy scenarios were developed. In Ha Noi, electric two-wheeler adoption could reduce average CO_2 emissions from all two-wheelers by 16%–21% depending on how aggressive supportive policy and technology improvements were. In addition, other primary pollutants show greater impacts from electric two-wheeler adoption, with reductions ranging from 33% to 42% in two-wheeler fleet emissions, depending on technology and policy support. In Ahmedabad, CO_2 emission reductions are more modest, with nearly undetectable reductions in emissions (up to 5%) under the least-aggressive scenario, and up to 11% reductions in CO_2 and 23% reductions in other primary local pollutants under more aggressive scenarios.

Electric two-wheelers have the potential to improve local air quality and greenhouse gas emissions compared to gasoline two-wheelers. They can also reduce noise pollution to the extent that they can compete in the market against gasoline two-wheelers. There are some fundamental performance issues that put them at a disadvantage, including speed, range, and recharging time. Their operating costs can be significantly lower, however, thus counteracting some of the performance issues. Early deployments in both Viet Nam and India have been somewhat unsuccessful due to unreliable vehicles and have created problems with the perception of this unproven technology. A strong preference for gasoline two-wheelers, regardless of price and performance, indicates that the electric two-wheeler industry and government and nongovernment organizations should engage in active marketing and public awareness, aside from developing supportive electric two-wheeler policy. In addition, supportive electric two-wheeler policy should be coupled with a robust battery manufacture and recycling policy that would support all transportation. Electric two-wheelers can provide low-cost, low-noise, and low-emission vehicles, but are currently competing in a difficult market against a more mature, but less environmentally friendly mode—gasoline two-wheelers. Working with the electric two-wheeler industry to improve their image, improve performance, and provide supportive policy could be the impetus to begin wide-scale adoption of electric two-wheelers in these large markets.

Introduction

Electric bike (e-bike) use has rapidly expanded in the People's Republic of China (PRC), in the process changing the mode split of many cities. Currently, the PRC produces over 20 million e-bikes yearly, up from a few thousand a decade ago.[1] E-bikes in the PRC are defined as electric two-wheelers with relatively low speeds and weights compared to a motorcycle. Both bicycle-style e-bikes (with functioning pedals) and scooter-style e-bikes (with many of the features of gasoline scooters) are classified as bicycles and are given access to bicycle infrastructure.

E-bikes have risen in popularity in the PRC due to restriction of gasoline motorcycles, extensive bicycle infrastructure, and increased car and public transit congestion. However, the rise in e-bikes in the PRC has not spread to the rest of Asia. In fact, few cities in other Asian countries have any presence of e-bikes. In countries with dominant gasoline two-wheeler mode split, replacing those vehicles with electric two-wheelers could improve air quality and reduce greenhouse gases.

This study focuses on market potential in Ahmedabad, India, and Ha Noi, Viet Nam. From these cities, the study estimates price, performance, and regulatory factors that can influence the adoption of electric scooters (e-scooters) in these countries. It also focuses on the tailpipe emission reductions that could occur if e-scooters were adopted. It is important to note that the study investigates the potential and relative benefits of substituting electric two-wheelers (e-scooters) for gasoline two-wheelers. This report does not investigate the potential shift to other modes, such as cars, mass transit, or nonmotorized transport, nor their impacts. It is expected that a shift from gasoline two-wheeler to e-scooter would result in environmental shifts, but that safety and mobility costs and benefits would not change much.

Figure 1: Typical Electric Scooter

Source: Authors.

[1] Jamerson, F.E., and E. Benjamin. 2007. *Electric Bikes Worldwide Reports—20,000,000 Light Electric Vehicles in 2007*. http://ebwr.com/index.php

Background

E-scooters are two-wheeled motorized vehicles that are similar to gasoline-powered scooters and motorcycles, except that they operate solely on battery power (Figure 1). As an alternative to the gasoline-powered scooter and motorcycle, the e-scooter offers efficiency gains and, as they have zero local tailpipe emissions and are virtually silent, air and noise pollution reductions.

E-scooters have become popular in the PRC, but because of regulations, their design has been limited to low-power (less than 500 watts [W]), light-weight (less than 60 kilograms [kg]), and low-speed models (less than 40 kilometers per hour [km/h]). These scooters do not provide the necessary performance to compete against gasoline scooters and motorcycles in other countries. Most Chinese e-bike producers do not have an incentive to develop larger models solely for the export market, given the strong domestic market for smaller models. Given this, existing e-scooters are generally unsuitable for the markets outside of the PRC. Some companies outside of the PRC are developing larger scale e-scooters that can compete against small displacement (<125 cc[2]) gasoline two-wheelers, but it is uncertain what factors consumers value or the real environmental impact of such a shift.

Ahmedabad, India

In most Indian cities, gasoline-powered two-wheelers (scooters and motorcycles) provide high mobility to households. While mode split varies by city, two-wheelers are a vital component of the transport system. Ahmedabad is the capital of Gujarat state in west India. Ahmedabad has a population of about 5 million. In 2007, 30% of all trips were made by a motorized two- or three-wheeler, 14% by bicycle, 22% by foot, 16% by public transport, and 17% by car. The average trip length of all modes was 6.2 km.[3] In 2000, motorized two-wheelers constitute 38% of vehicle kilometers traveled with an average trip length of 6.8 km.[4] Moreover, the average growth rate of the two-wheeler population in India is 10%.[5]

Interviews with a major e-scooter manufacturer indicate a generally negative public perception of e-scooters. This is based on early models that performed poorly, along with companies importing low-quality scooters from the PRC that cannot operate well in the Indian context and do not have strong after-sales support. Companies based in India are focusing on developing more powerful e-scooters to provide higher speeds and more load-carrying capacity.

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2 The unit "cc" means cubic centimeter engine displacement.

3 Government of India, Ministry of Urban Development. 2008. *Study on Traffic and Transportation Policies and Strategies in Urban Areas in India*. Delhi.

4 Ahmedabad Municipal Corporation. 2006. *Bus Rapid Transit System Ahmedabad.* www.egovamc.com/BRTS/BRTS.ASP

5 Meszler, D. 2007. *Air Emissions Issues Related to Two and Three-Wheeled Motor Vehicles.* San Francisco: International Council of Clean Transport.

Ha Noi, Viet Nam

In Viet Nam, private transport is dominated by gas-powered motorcycles. In 2005, there were 1.5 million registered motorcycles in Viet Nam's capital of Ha Noi for a population of 3 million people, with motorcycles comprising 65% of all vehicular trips.[6] Motorcycle ownership in Ha Noi and throughout Viet Nam continues to grow at an average annual rate of more than 14%.[7]

At the same time, motorcycles are the main contributor to Ha Noi's air quality issues, where levels of particulate matter exceed the national ambient air quality standards. Of all known local emissions of particulate matter, 40% originate from vehicular sources, and motorcycles have the largest share of vehicle emissions, emitting 43% of particulate matter and more than 54% of carbon monoxide (CO) and hydrocarbons.[8] In addition, motorcycles are the primary source of Ha Noi's urban noise pollution.

The prevalence of motorcycle use and the related environmental issues would make Ha Noi seem, like many cities in the PRC, a market primed for e-scooters. In Viet Nam, however, the transition from motorcycles to e-scooters has been the very opposite of that in the PRC, with e-scooters failing to make market penetration. In interviews conducted in Ha Noi, Vietnamese motorcycle riders conveyed a number of reasons that potentially explain why Viet Nam has not yet adopted e-scooters, including their inferior speed and range, but also the perceived greater comfort and style that is offered by a motorcycle. In the PRC, regulations against motorcycles are extensive and exclusive bicycle infrastructure make e-bikes and e-scooters particularly attractive.[9]

Despite Vietnamese riders' negative perception of them, e-scooters offer a potential solution to Ha Noi's air and noise pollution if adopted as a motorcycle alternative. Thus, it is valuable to explore what limits this adoption, and to understand the ability of technology and incentives such as sales tax breaks to overcome these impediments. Optimally, this investigation would be accomplished by observing the actual purchasing decisions and trade-offs of Vietnamese riders between e-scooters and motorcycles, but the nature of the problem in Ahmedabad and Ha Noi precludes the use of real purchasing data and instead requires the use of hypothetical choice data.

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[6] World Bank. 2006. Vietnam–Hanoi Urban Transport Development Project. World Bank report number AB2656 2006/11/22.

[7] Tuan, V.A., and T. Shimizu. 2005. Modeling of Household Motorcycle Ownership Behavior in Hanoi City. *Journal of Eastern Asia Society of Transportation Studies* 6; Meszler (2007).

[8] Schipper, L., et al. 2008. *Measuring the Invisible Quantifying Emissions Reductions from Transport Solutions: Hanoi Case Study*. EMBARQ–World Resources Institute; World Bank. 2008. *Attacking Air Pollution in Hanoi*. http://go.worldbank.org/9DFE1YV540

[9] Cherry, C., et al. 2009. *Electric Bikes in the People's Republic of China (PRC): Impact on the Environment and Prospects for Growth*. Asian Development Bank: Manila.

Market Analysis

This study attempts to identify future market growth and potential for a new product with a significant amount of uncertainty related to energy prices and regulation of competing modes. A common method to analyze new product penetration is to conduct a stated-preference choice experiment.

Choice Experiment Survey Design

The choice experiment was designed to measure the effects of performance, cost, and policy variable attributes on the Vietnamese and Indian rider's decision to purchase an e-scooter over a gasoline motorcycle or scooter. In each decision question, buyers of two-wheeled motorized vehicles in Ha Noi and Ahmedabad were presented with three hypothetical vehicles. In Ha Noi, the choice set included a standard gasoline motorcycle, a large gasoline motorcycle, and an e-scooter. In Ahmedabad, the choice set included a standard gasoline motorcycle, a standard gasoline scooter, and an e-scooter. A standard gasoline scooter was included in Ahmedabad because of their relative popularity in India, whereas Ha Noi had very few scooters in the two-wheeler market. The three hypothetical vehicles varied in terms of their attributes, and respondents were instructed to indicate the vehicle they would most prefer to purchase, based solely on the attributes provided for each alternative.

Attributes and Levels

The number of attributes that can be tested in a choice experiment is limited by the ability of respondents to choose between complex alternatives. To minimize the cognitive burden on subjects in Ha Noi, alternatives varied along a limit of nine attributes. This meant that not all important choice attributes could be included in the experiment. In an attempt to control for the omission of relevant variables, subjects were instructed to assume that all unlisted attributes were the same for all of the hypothetical vehicles. In Ahmedabad, alternatives varied among 11 attributes, adding two attributes deemed important to India's population, but perhaps less important in Viet Nam's case.

The attributes included in the choice experiment were those deemed most critical based on the results of previous stated-preference studies for alternative vehicles and based on interviews with Vietnamese and Indian riders.[10] The entire set of

[10] Hensher, D.A. 1982. Functional Measurement, Individual Preference and Discrete-Choice Modeling: Theory and Application. *Journal of Economic Psychology*. 2(4). pp. 323–335; Calfee, J. 1985. Estimating the Demand for Electric Automobiles Using Fully Disaggregated Probabilistic Choice Analysis. *Transportation Research Part B*. 19(4). pp. 287–301; Bunch, D.S., et al. 1993. Demand for Clean-Fuel Vehicles in California: A Discrete-Choice Stated Preference Pilot Project. *Transportation Research Part A*. 27(3). pp. 237–253; Ewing, G., and

experimental attributes includes the following points:

(i) Purchase price: price of vehicle not including registration tax, sales tax, or value-added tax (VAT);

(ii) Refuel or recharge range: the number of kilometers that can be traveled on a full tank of gas or a full charge before needing to refuel or recharge;

(iii) Refuel or recharge time: the amount of time in minutes required to fill an empty gas tank or to recharge a battery from zero charge to full charge;

(iv) Fuel or electricity cost: operating cost stated in terms of Vietnamese dong per 100 kilometers (D/100 km) in Ha Noi and rupees per kilometer (Rs/km) in Ahmedabad;

(v) Maintenance cost: routine costs of maintenance such as battery replacement, measured as dong per month (D/month) in Ha Noi and Rs per 15,000 km in Ahmedabad;

(vi) Acceleration: measured relative to the standard motorcycle as a percentage, where the acceleration of the standard motorcycle is 0–40 km in 10 seconds in Ha Noi (In Ahmedabad, it is expressed as time to reach 30 km/h);

(vii) Top speed: fastest achievable speed in kilometers per hour;

(viii) License requirement: whether a license is required to operate the vehicle;

(ix) Sales and registration tax: combined sales and registration tax (independent of purchase price) expressed in millions of dong and owed upon purchase (In Ahmedabad, it is the VAT, expressed in Rs.);

(x) Transmission: manual or automatic transmission (not included in Ha Noi because most motorcycles have manual transmissions);

(xi) Carrying capacity, expressed in number of adults, which was explicitly included in the choice experiment in Ahmedabad since two-wheelers were considered important based on conversations with local experts.

Accurate values for the vehicle attribute levels were determined with the aid of transport engineers specializing in the study of motorcycles and e-scooters. The vehicle attribute levels were selected to reflect technology both current and in the foreseeable future. In particular, the ranges for the e-scooter attributes were constructed to contain values for the "average" e-scooter today, but also to contain plausible values for cutting-edge e-scooters that may emerge in the next few years; this allows for a better analysis of how technological developments may influence e-scooter demand.

Sarigollu, E. 2000. Assessing Consumer Preference for Clean-Fuel Vehicles: A Discrete Choice Experiment. *Journal of Public Policy and Marketing.* 19. pp. 106–118; Brownstone, D., and K. Train. 1999. Forecasting New Product Penetration with Flexible Substitution Patterns. *Journal of Econometrics.* 89. pp. 109–129; Chiu, Y.C., and G.H. Tzeng. 1999. *Transportation Research Part D*. 4 (2). pp. 127–146; Ewing, G., and E. Sarigollu. 1998. Car Fuel-Type Choice Under Travel Demand Management and Economic Incentives. *Transportation Research Part D.* 3. pp. 429–444; Dagsvik, J. et al. 2002. Potential Demand for Alternative Fuel Vehicles. *Transportation Research Part B.* 36. pp. 361–384; Potoglou, D., and P. Kanaroglou. 2007. Household Demand and Willingness to Pay for Clean Vehicles. *Transportation Research Part D*. 12. pp. 264–274.

The tax incentive attribute levels were chosen to vary around the status quo for a standard motorcycle, with zero tax as a lower bound. The nonzero value for the sales and registration tax was set to approximate 10% of the current purchase price for a standard motorcycle, 10% being close to the actual current value of combined sales and registration taxes. For the VAT, the nonzero value was set to approximate 20% of the current purchase price, representing an upper bound for tax incentive policies.

For most of the vehicle attributes, three levels were sufficient to cover the range of values. In Ha Noi, refuel or recharge time was assigned four levels to cover the range of recharge times for an e-scooter, which spans from 10 minutes to 6 hours. In Ahmedabad, refuel or recharge time was assigned three levels. Whether or not a license requirement exists for a particular vehicle was indicated as an important decision determinant in interviews with Vietnamese riders. Thus, a license requirement attribute was included in two levels: "Yes", a license is required; or "No", a license is not required. The standard motorcycle was taken to be the base case vehicle, and, as such, most of its attributes were set as constants, with the exception of sales and registration tax, which was allowed to vary to assess standard motorcycle tax policy. Some of the vehicle attributes for the large motorcycle were also fixed at constants in instances when doing so was intuitive. For example, the license requirement for a large motorcycle was fixed at "Yes," because current law requires an operating license, and there is no possibility in the foreseeable future of this licensing requirement being repealed. All attributes and their levels are presented in Table 1.

Choice Sets

Each choice set consisted of one of each vehicle type, with the attribute values of the alternatives set at particular levels. Varying the combinations of attribute levels generates different choice sets. In both cases, the full factorial design that includes all possible combinations of attributes would require billions of choice sets. To reduce the number of potential scenarios, a fractional factorial design was used to generate an orthogonal main-effects matrix consisting of 72 choice sets. This design allowed the main effect of each attribute level to be estimated without confounding.

The 72 choice sets were blocked into 12 sections of 6, and each respondent was presented with one of these blocks (answered 6 choice questions). The first respondent would face the first 6 choice sets; the second respondent would face the next 6 choice sets, and so forth; after the 12th respondent, the list of choice sets would recycle, with the 13th respondent facing the first 6 choice sets. Figure 2 presents an example of a choice question from the Ha Noi survey. Figure 3 presents an example of a choice question from the Ahmedabad survey.

Sampling

In both cases, future two-wheeler purchasers were targeted. In Ha Noi, this included almost every household as motorized two-wheeler ownership is over one vehicle per household on average and over 84% of households own at least one motorbike.[11] This is confirmed by 80% of the households surveyed, which stated that they are likely to purchase a motorized

[11] Schipper et al. 2008.

two-wheeler in the next 5 years. In Ha Noi, a household survey was conducted, stratified by population. Table 2 shows the stratification by district, with a total of 400 households surveyed. Table 3 shows the basic demographics of the sample.

Unfortunately, surveys for stratifying by household were logistically difficult in Ahmedabad. Instead, a stratified intercept approach was undertaken, sampling individuals at major trip generators in different sectors of the city. Figure 4 shows the sectors of the city, coupled with the population in those sectors. Different sections of Ahmedabad were sampled according to the population distribution, with a total sample size of 1,009 respondents.

Table 4 shows the sample characteristics of the Ahmedabad survey. Most striking is the disproportionate number of males surveyed, which is primarily explained by the cultural barriers of the predominately male survey team, coupled with the intercept sampling approach. In

Table 1: Experimental Attributes and Levels

Attributes (Ha Noi Underlined, *Ahmedabad in Italics*)	**Standard Motorcycle *Motorcycle***	**Large Motorcycle *Motor Scooter***	**Electric Scooter *Electric Scooter***
Purchase price (D million)	10	10, 15, 30	8, 12, 164
(*Rs*)	*38,400; 58,700; 79,000*	*32,000; 39,500; 47,000*	*15,000; 27,750; 40,500*
Refuel/Recharge range (km)	100 *560, 730, 900*	200 *225, 500, 775*	60, 120, 200 *45, 130, 215*
Refuel/Recharge time (min)	5 *5*	10 *5*	10, 15, 30, 360 *10, 240, 420*
Fuel/Electricity cost (D/100 km)	30,000	20,000; 30,000; 40,000	2,500; 5,000; 7,500
(*Rs/km*)	*0.7, 1.08, 1.45*	*0.87, 1.10, 1.33*	*0.02, 0.06, 0.11*
Maintenance cost (D/month)	20	20	70, 100, 140
(*Rs/15,000 km*)	*4,500*	*4,500*	*6,800; 7,750; 8,700*
Acceleration XX% different from standard motorcycle	0–40 km in 10 sec	20% slower than standard, same as standard, 20% faster than standard	20% slower than standard, same as standard, 20% faster than standard
0–30 km/h in XX sec	*2, 4, 6*	*2.5, 5, 7.5*	*3, 6, 9*
Top speed (km/h)	80 *65, 95, 125*	60, 80, 100 *60, 80, 100*	40, 50, 60 *30, 45, 60*
License Required	*Yes*	*Yes*	*Yes, No*
Sales and registration tax (D million)	0, 1.4, 2.8	0, 1.4, 2.8	0, 1.4, 2.8
(*Rs*)	*0; 4,750; 9,500*	*0; 3,600; 7,200*	*0; 1,600; 3,200*
Transmission (Ahmedabad only)	*Manual*	*Manual, Automatic*	*Automatic*
Carrying capacity (Ahmedabad only)	*2 adults, 3 adults*	*2 adults*	*1 adult, 2 adults*

D = dong, km = kilometer, km/h = kilometer per hour, min = minute, Rs = rupee, Rs/km = rupees per kilometer.

Source: Authors.

Figure 2: Sample Choice Question (Ha Noi)

Suppose the following three options are the only available alternatives for purchasing a two-wheeled motorized vehicle. Please indicate which vehicle you prefer by checking one of the boxes below.

	Standard Gas Motorcyle ☐	**Large Gas Motorcycle** ☐	**Electric Scooter** ☑
Purchase price (D million)	10	15	8
Refuel range (km)	100	200	120
Refuel/recharge time (min)	5	10	30
Fuel/Electricity cost (D/100 km)	30,000	30,000	5,000
Maintenance cost (D/month)	20,000	20,000	100,000
Acceleration	0–40 km/h in 10 seconds	20% faster than "standard motorcycle"	Same as "standard motorcycle"
Top speed (km/h)	80	80	50
License required	Yes	Yes	Yes
Sales/Registration tax (D million)	2.8	1.4	1.4

D = dong, D/100 km = dong per 100 kilometers, D/month = dong per month, km = kilometer, km/h = kilometer per hour, min = minute.

Source: Authors.

Figure 3: Sample Choice Question (Ahmedabad)

Suppose the following three options are the only available alternatives for purchasing a two-wheeled motorized vehicle. Please indicate which vehicle you prefer by checking one of the boxes below.

	Gasoline Motorcycle ☐	**Gasoline Scooter** ☑	**Electric Scooter** ☐
Purchase price (Rs)	58,700	32,000	27,750
Refuel range (km)	560	500	130
Refuel/Recharge time (min)	5	5	240
Fuel/Electricity cost (Rs/km)	1.45	1.10	0.06
Maintenance cost (Rs/15,000 km)	4,500	4,500	7,750
Acceleration	0–30 km/h in 4 seconds	0–30 km/h in 5 seconds	0–30 km/h in 6 seconds
Top speed (km/h)	95	80	40
Carrying capacity (adults)	2	2	1
Transmission	Manual	Manual	Automatic
License required	Yes	Yes	No
Sales/Registration tax (Rs)	4,750	7,200	0

km = kilometer; km/h = kilometer per hour; min = minute; Rs = rupee; Rs/15,000 km = rupees per 15,000 kilometers; Rs/km = rupees per kilometer.
Source: Authors.

Table 2: Population and Target Sample per District
(Ha Noi)

District Name	Population (1,000 persons)	Sample Size	District Name	Population (1,000 persons)	Sample size
Urban core and urban fringe districts			*Suburban and rural districts*		
Ba Dinh	231	30	Tu Liem	262	25
Hoan Kiem	179	25	Thanh Tri	165	20
Hai Ba Trung	312	40	Soc Son	266	10
Dong Da	372	45	Dong Anh	288	10
Tay Ho	108	15	Gia Lam	212	30
Thanh Xuan	196	40			
Cau Giay	171	40			
Hoang Mai	236	30			
Long Bien	186	40			
Total	**1,991**	**305**	**Total**	**1,193**	**95**

Source: Nguyen, Q. 2007. Integration of Transport and Land Use in Hanoi: Can We Relieve Traffic Congestion by Relocating Some Major Land-Uses? Master's thesis. International Institute for Geo-information Science and Earth Observation. Enschede, The Netherlands.

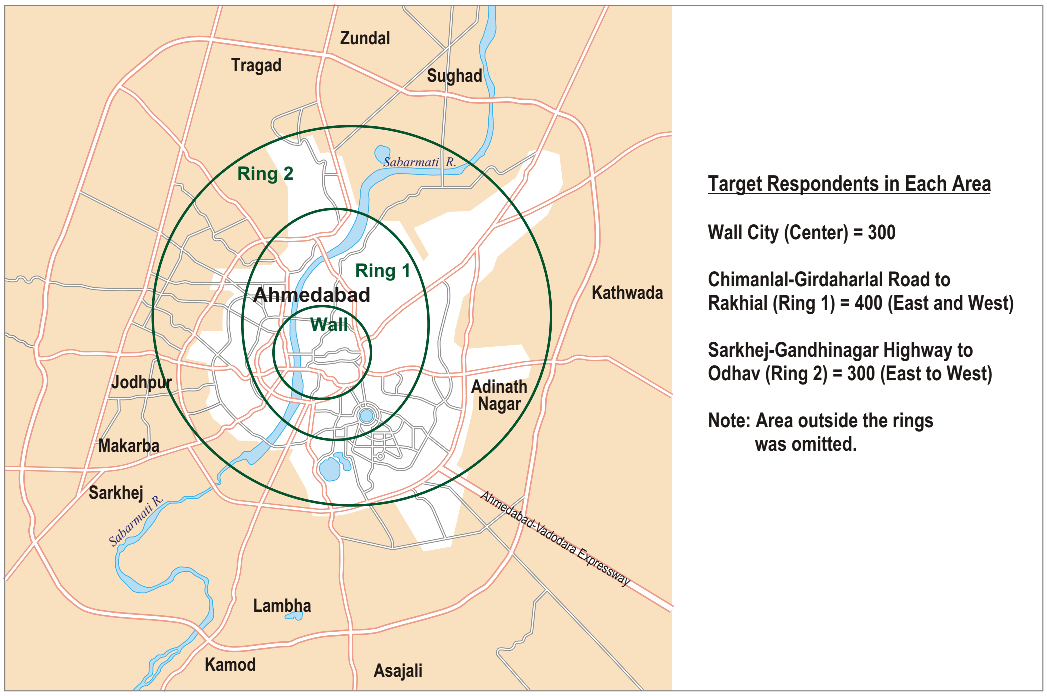
Table 3: Sample Characteristics
(Ha Noi)

Gender	Female	46%
	Male	54%
Mean age of household head		41.3
Number of vehicles in average household	Cars	0.15
	Motorcycles	1.91
	Bicycles	0.93
	E-scooters	0.09
Household income (D million/month) (%)	Less than 3	17%
	3–6	40%
	6–9	24%
	9–20	16%
	More than 20	3%
Purchase motorized 2-wheeler in next 5 years	Definitely	39%
	Very likely	18%
	Likely	24%
	Unlikely	14%
	No chance	6%

D = dong, e-scooter = electric scooter.

Source: Authors.

Figure 4: Geographic Sampling Scheme (Ahmedabad)



Source: Authors.

Table 4: Sample Characteristics (Ahmedabad)

Gender	Female	2%
	Male	98%
Mean age of respondent		39.6
Number of vehicles in average household	Cars	0.11
	Bicycles	0.31
	Motorcycles	1.02
	E-scooters	0.01
	Motor scooters	0.52
Household income (Rs/month)	Less than 2,500	0%
	2,501–7,500	3%
	7,501–15,000	41%
	15,001–30,000	44%
	30,000 or more	11%
Purchase motorized 2-wheeler in next 5 years	Definitely	17%
	Very likely	16%
	Likely	59%
	Unlikely	2%
	No chance	6%

e-scooter = electric scooter, Rs = rupee.

Note: Values in parentheses are average preference scores.

Source: Authors.

Ahmedabad, 94% of the respondents stated that they were likely or more than likely to purchase a two-wheeler in the next 5 years, indicating a strong future two-wheeler market.

Vehicle Choice and Respondent Preferences

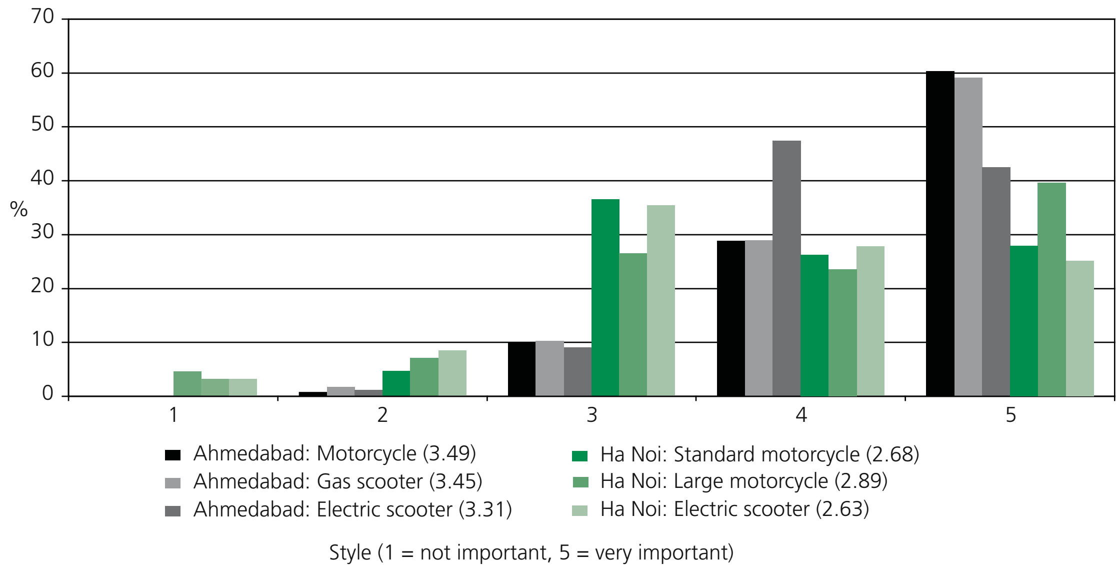
In the choice experiment, a limited number of vehicle-specific parameters were included to determine the effects of varying vehicle attributes on vehicle choice, and to ultimately calibrate choice models that estimate market shares. However, several factors could not be included for the sake of model efficiency and variable type. In the questionnaire portion of the survey (outside the context of the choice experiment), respondents were asked a series of Likert Scale questions, rating the importance of various vehicle parameters from 1 to 5, with 1 being not important and 5 being very important. These factors could explain some of the unobserved preference that is captured in the model's alternative specific constants (see Market Estimation Results section) where respondents subconsciously prefer vehicles based on perceptions that are not easily tested in traditional choice modeling frameworks. Figures 5–13 show the results of these questions in both Ahmedabad and Ha Noi, expressed as a frequency of responses separated by vehicle choice. If a respondent chose a particular type of vehicle, the choice would be categorized with his or her rating to develop these figures. Ha Noi respondents were not asked to rate helmet requirements or availability of recharging or refueling infrastructure. In addition to each of the charts, a preference score is applied to each of the factors, by city and vehicle choice. This score is calculated by assigning a weight of 1 to "not important" up to 5 for "very important" and assumes that the strength of preference is linear from 1 to 5. The scores are weighted by the proportion of the responses and allow direct comparison between values of respondents who chose different modes. For instance, in Figure 5, an Ahmedabad respondent who chose an e-scooter in the choice experiment (preference score 3.49) values "style" less than a respondent who chose a gasoline motorcycle (preference score 3.49). The factors that vary most between modes in the same city are style, cargo-carrying capacity, and replacement part availability, with e-scooter choosers valuing style and cargo-carrying capacity less than their counterparts, and valuing replacement part availability more. Interestingly, there were no significant differences between vehicle choosers on many of the metrics, including environmental performance, safety, and reliability of the vehicle.

Market Estimation Results

Ha Noi, Viet Nam

The model is estimated with sampling weights for the 14 strata, and reports robust standard errors. The explanatory variables in the model include alternative-specific constants and the experimental attributes. The alternative-specific constants, labeled "standard motorcycle" and "large motorcycle," capture the influence of the type of vehicle on the choice decision, independent of the other explanatory factors. The omitted alternative-specific variable "e-scooter" was selected as the reference alternative, and thus the coefficients for "standard motorcycle" and "large motorcycle" are interpreted relative to the e-scooter alternative. Acceleration and license requirement were treated as categorical,

Figure 5: How Do You Rate Style in Vehicle Purchase Choice?

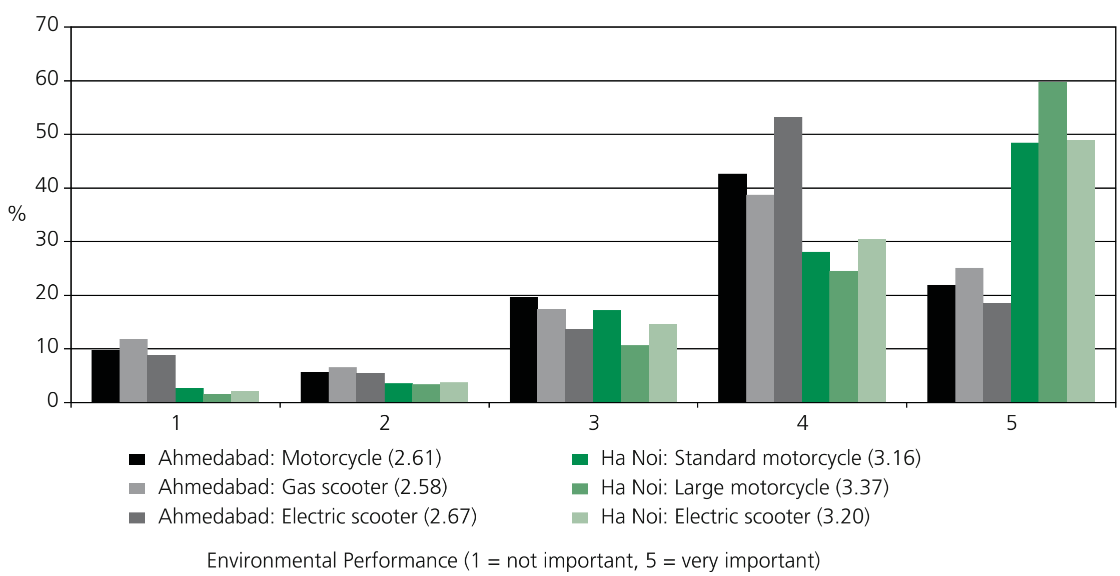


e-scooter = electric scooter.

Note: Values in parentheses are average preference scores.

Source: Authors.

Figure 6: How Do You Rate Environmental Performance in Vehicle Purchase Choice?

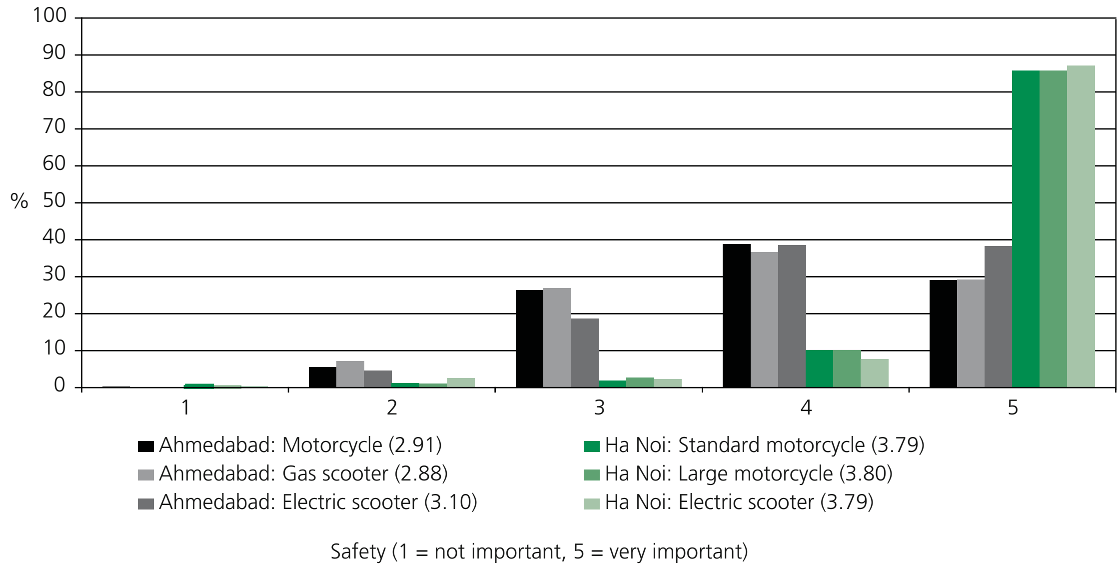


e-scooter = electric scooter.

Note: Values in parentheses are average preference scores.

Source: Authors.

Figure 7: How Do You Rate Safety in Vehicle Purchase Choice?

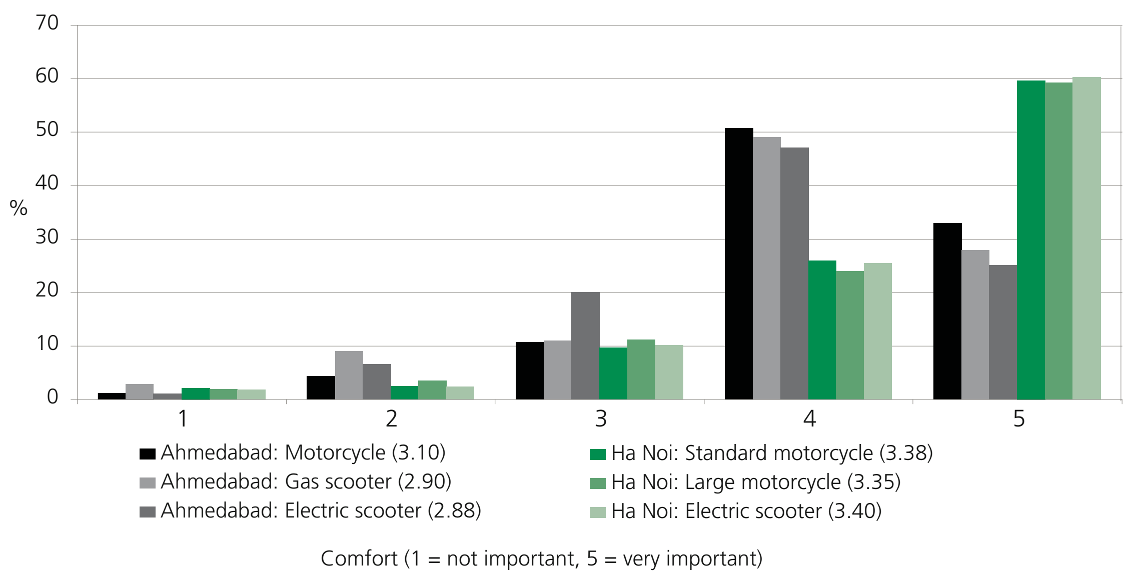


e-scooter = electric scooter.

Note: Values in parentheses are average preference scores.

Source: Authors.

Figure 8: How Do You Rate Comfort in Vehicle Purchase Choice?

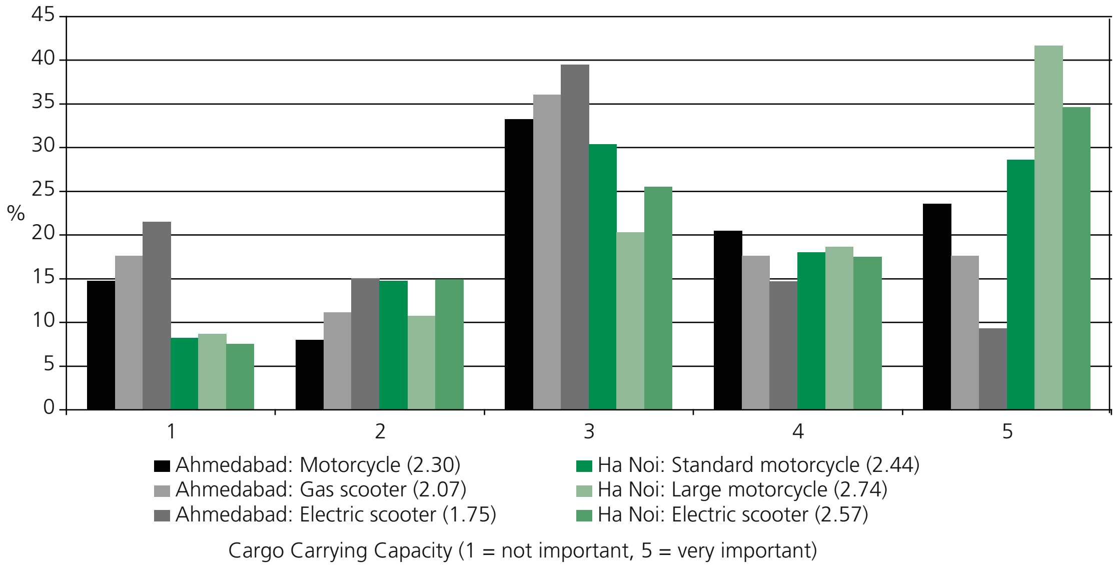


e-scooter = electric scooter.

Note: Values in parentheses are average preference scores.

Source: Authors.

Figure 9: How Do You Rate Cargo-Carrying Capacity in Vehicle Purchase Choice?

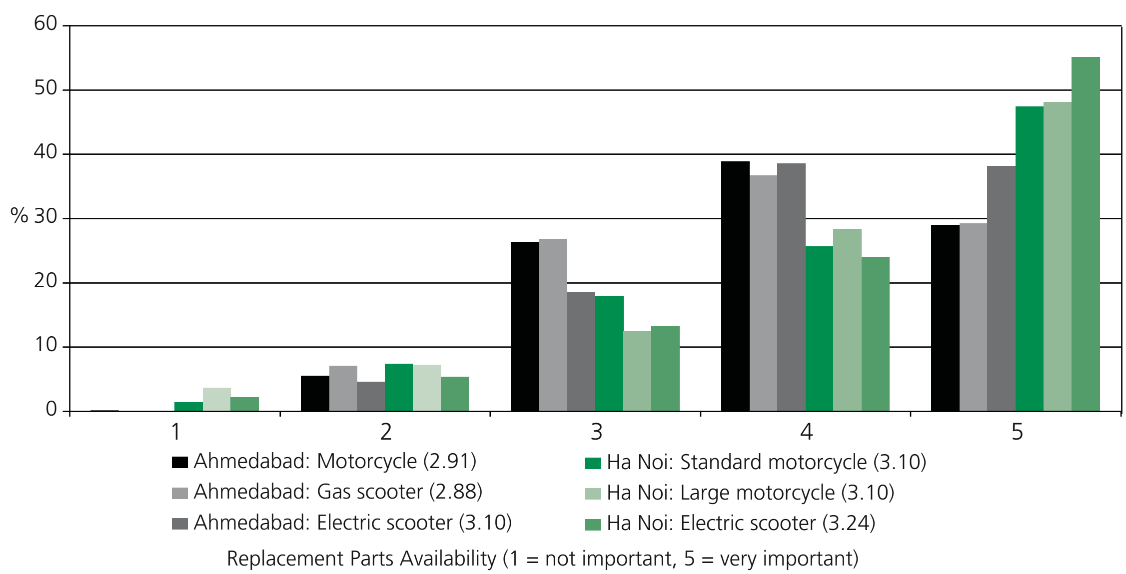


e-scooter = electric scooter.

Note: Values in parentheses are average preference scores.

Source: Authors.

Figure 10: How Do You Rate Replacement Parts Availability in Vehicle Purchase Choice?

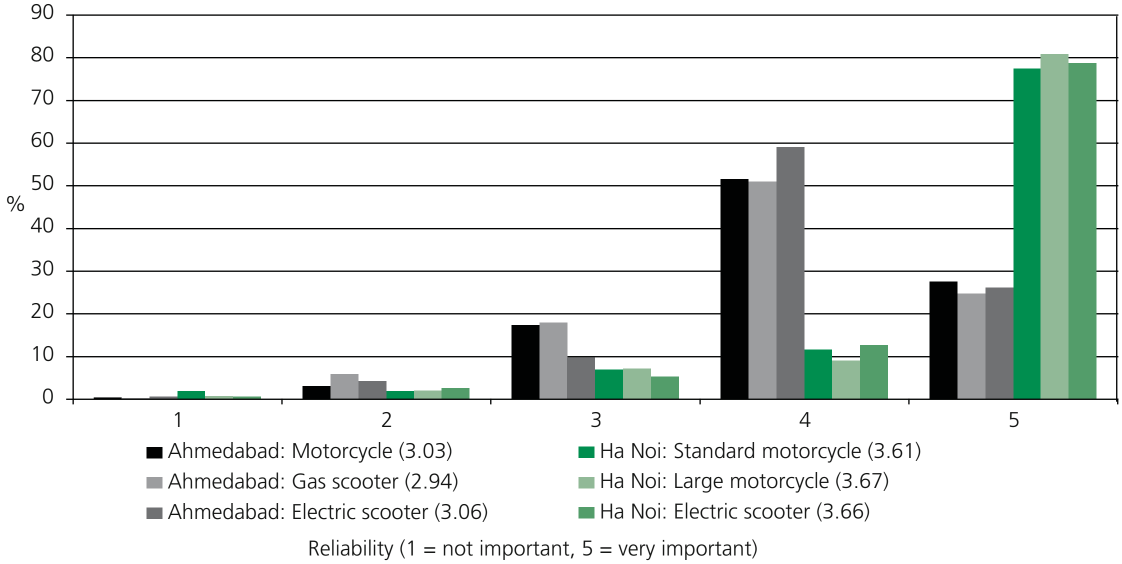


e-scooter = electric scooter.

Note: Values in parentheses are average preference scores.

Source: Authors.

Figure 11: How Do You Rate Reliability in Vehicle Purchase Choice?

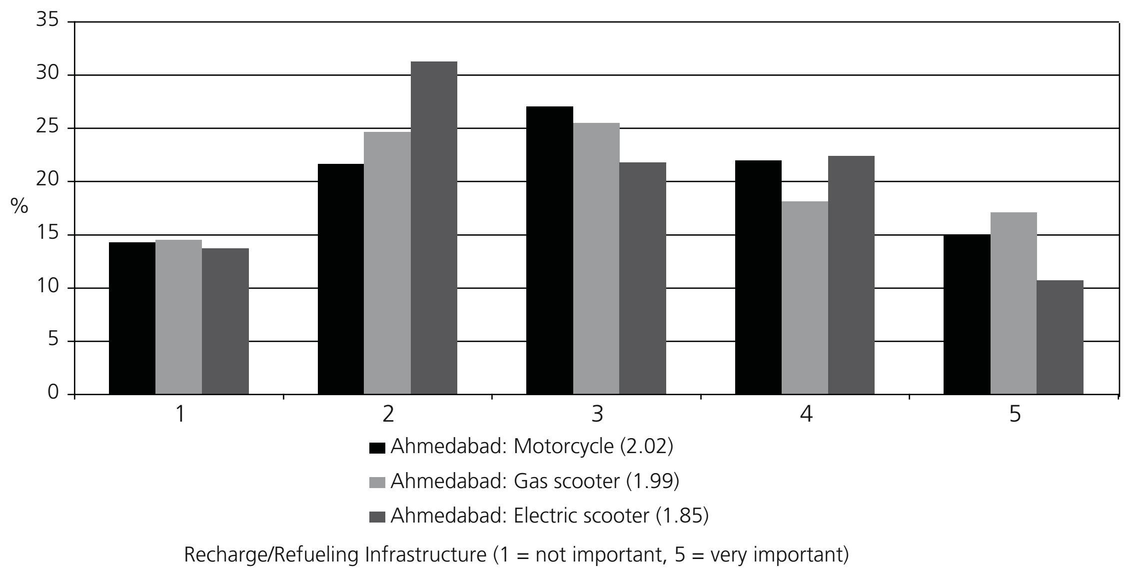


e-scooter = electric scooter.

Note: Values in parentheses are average preference scores.

Source: Authors.

Figure 12: How Do You Rate Recharging and Refueling Infrastructure in Vehicle Purchase Choice?

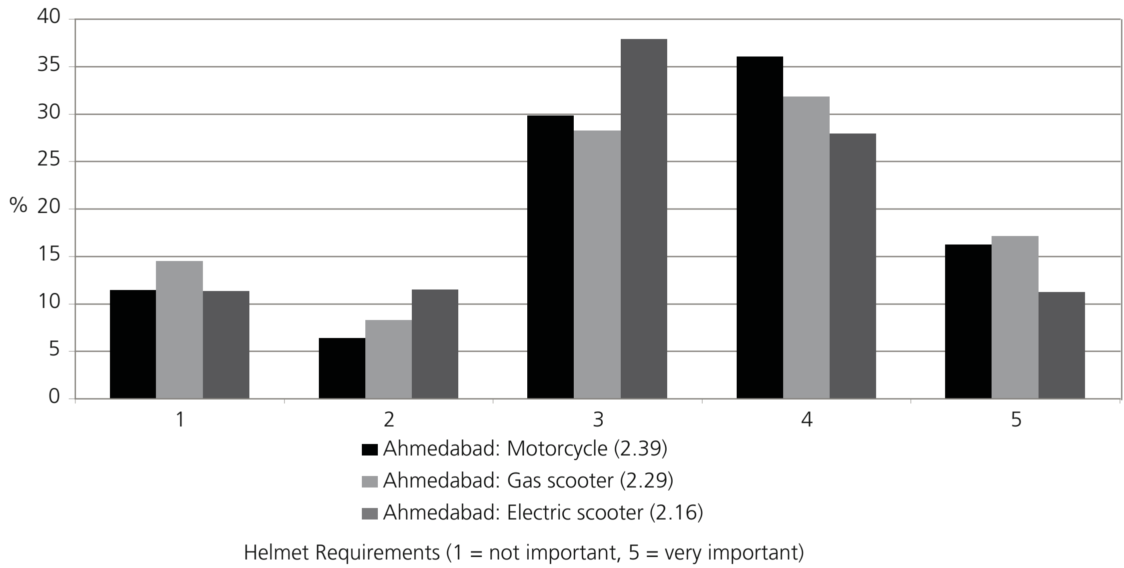


e-scooter = electric scooter.

Note: Values in parentheses are average preference scores.

Source: Authors.

Figure 13: How Do You Rate Helmet Requirements in Vehicle Purchase Choice?



e-scooter = electric scooter.

Note: Values in parentheses are average preference scores.

Source: Authors.

and effects codes were generated for these variables.

Given that previous research found gender to influence preferences over motorbikes and e-scooters, three gender-attribute interaction variables were created: range x male; top speed x male; and price x male.[12] These variables capture the joint effects of being male combined with refuel or recharge range, top speed, and price, and were included as explanatory variables along with the alternative-specific constants and experimental attributes. The model estimates are shown in Table 5.

All experimental attributes have the anticipated signs, and all are at least significant at the 95% level. Purchase price, refueling or recharging time, fuel or electricity cost, maintenance cost, slower acceleration, license requirement, and tax all had negative effects on choice, while range, faster acceleration, and top speed had positive effects. The coefficients for the alternative-specific constants are both positive, while only the standard motorcycle alternative-specific constant is significant (p = 0.04), which indicates that after taking all other explanatory factors into account, respondents demonstrate a preference for a standard motorcycle relative to an e-scooter. The result that respondents prefer motorbikes to e-scooters, all else being equal, is most likely attributable to omitted factors that are associated with vehicle type, e.g., style, comfort, luggage space, safety, reliability, ease of finding replacement parts, and environmental

[12] Chiu and Tzeng 1999.

Table 5: Parameter Estimates of the Conditional Logit Model
(Ha Noi)

Variable	Coefficient	Standard Error	*p*-value
Purchase price (D million)	(0.0928811)	0.0099441	0
Refuel or recharge range (km)	0.004173	0.0010179	0
Refuel or recharge time (min)	(0.0007025)	0.0003317	0.034
Fuel or electricity cost (D/100 km)	(0.0000155)	0.00000594	0.009
Maintenance cost (D/month)	(0.00000384)	0.00000167	0.021
20% faster acceleration[a]	0.119782	0.0467819	0.01
20% slower acceleration[a]	(0.0978936)	0.0474261	0.039
Top speed (km/h)	0.006553	0.0022026	0.003
License required	(0.0937764)	0.0482465	0.052
Sales and registration tax (D)	(0.1496249)	0.0241181	0
Top speed x male	0.004764	0.0022562	0.035
Range x male	(0.002061)	0.0010027	0.04
Price x male	0.0286288	0.0124639	0.022
Standard motorcycle	0.4413562	0.215009	0.04
Large motorcycle	0.0886192	0.2193426	0.686
N Obs	7,140		
Log-likelihood (0)	(2403.7281)		
Log-likelihood	(2371.7839)		
Wald chi-square	223.29		0

( ) = negative, D = dong, D/100 km = dong per 100 kilometers, D/month = dong per month, km = kilometer, km/h = kilometer per hour, min = minute, N Obs = number of observations, sec = second.

[a] Relative to standard motorcycle: 0–40 km in 10 sec.

Source: Authors.

friendliness; however, it may also be the case that, even controlling for omitted factors, Vietnamese riders have a bias against e-scooters due to perceived poor quality or performance.

An examination of the gender-attribute interactions reveals that, as found in previous research, gender is an important decision determinant for e-scooters and motorbikes.[13] All three gender-attribute interaction variables are at least significant at the 0.05 level. The parameter for "range x male" is negative, meaning that, relative to females, males show a lower preference for being able to travel an extended range before needing to refuel or recharge. "Top speed x male" is positive, which indicates that males demonstrate greater preference than females for a high vehicle speed. "Price x male" is positive as well; the interpretation is that higher purchase prices have less of a dissuasive effect on males than

[13] Chiu and Tzeng 1999.

they do on females (the male-demand curve is more inelastic). This gender-specific information is particularly valuable for e-scooter manufacturers, as it indicates that a worthwhile marketing strategy may be to produce lines of e-scooters geared to each gender. For example, relative to a female-line of e-scooters, manufacturers could modify the male-line by increasing its top speed in favor of cruising range, and any net increase in production costs could be more readily absorbed in the purchase price by the inelastic male-demand curve.

Willingness to Pay Estimates and Tax Effects

Up to this point, discussion has centered on the estimated parameter values. To provide meaningful interpretations for the magnitudes of these parameters, and particularly to assess the impact of tax incentives on the demand for e-scooters, parameters are converted into monetary values. Within the random utility maximization framework, each parameter represents a marginal utility.[14] The coefficient on price can thus be interpreted as the marginal utility of money, and multiplying any other attribute's coefficient by the negative inverse of the price coefficient yields the marginal rate of substitution between that attribute and the price, which is the marginal willingness to pay (MWTP) for that attribute.[15] Following this procedure and using the parameter estimates from the full model, the MWTP for selected attributes were computed.

The MWTP for the tax is –1.61 million dong for each million dong increase in the tax. Stated differently, a respondent would have to be compensated D1.61 million to incur a D1 million tax increase and have his/her utility remain unchanged; or stated another way, a respondent would be willing to pay D1.61 million extra on the price of a vehicle to avoid a D1 million increase in the sales tax.

With the units of change in the attributes defined as in the choice experiment, the tax has the largest willingness to pay estimate of all significant variables. In particular, the effect of the tax is larger than the effect of the purchase price, which provides some evidence that a rider's cognitive response to an explicit tax incentive is different from the response to an equivalent change in price. The fact that the estimated MWTP for tax is different from 1 (in magnitude) highlights the value of explicitly including the tax as an attribute in the choice experiment, because the different coefficients on the purchase price and the tax generate differing MWTP estimates. Using the coefficient on price to infer the demand effects of a tax incentive could lead to spurious conclusions. Following the method of price inference, Ewing and Sarigollu concluded that, although a tax incentive showed promise to boost the adoption of alternative cars, its effect was smaller than the effects of vehicle performance attributes.[16] In contrast, explicitly including a tax as an experimental attribute and observing its large marginal influence (greater than the

[14] Given an additively separable linear specification of indirect utility (Holmes, P., and W. Adamowicz. 2003. Attribute-Based Methods. In Champ, P., K. Boyle, and T. Brown, eds. *A Primer on Nonmarket Valuation.* Dordrecht, The Netherlands: Kluwer Academic Publishers.).

[15] Holmes and Adamowicz 2003.

[16] Ewing and Sarigollu 2000.

marginal influence of price), this study concludes that the incentive effect of a tax is *larger* than the effects of vehicle performance attributes.

In line with the current findings, Potoglou and Kanaroglou also obtained large MWTP estimates for sales tax (between C$2,000 and C$5,000); however, although their study explicitly included tax as an attribute, their results are not directly comparable to those in the present investigation. The tax was presented to respondents as a "no purchase tax" incentive, and the actual amount of the tax in the absence of this incentive was left open to respondent interpretation. Thus, in specifying the MWTP for this incentive, the actual monetary change in tax that would elicit a C$2,000–C$5,000 MWTP is left uncertain.[17] In the design for this study, all possible values of the tax were controlled and specified explicitly in the experiment, thus allowing for more precise interpretations of MWTP.

It is also worth noting the large MWTP for acceleration and for license required, two variables not included in previous research on e-scooter demand.[18] Respondents would pay D1.29 million for a 20% increase in acceleration from the base level of 0–40 km in 10 seconds, and would pay D1.05 million to avoid a 20% decrease. Requiring a license for a vehicle is equivalent to increasing that vehicle's purchase price by D1.01 million.

Market Share Predictions

In this section, the results from the conditional logit model are used to estimate market shares for standard motorcycles, large motorcycles, and e-scooters in Ha Noi, given various states of technology and policy. The market shares are derived by computing probabilities as nonlinear combinations of the estimated coefficients, with the experimental attributes set at given values and the dummy variable for "Male" held at the sample mean of 0.54.

The analysis examines three different states of e-scooter technology: current, upgraded, and cutting-edge. Each state is combined with both low and high gasoline price scenarios. Each combination of e-scooter technology and gasoline price scenario is combined with two different sales tax policies, one that reflects the current taxation of e-scooters, and one that provides tax incentives for e-scooters. Market shares are calculated for each combination of technology, gasoline price, and tax policy.

Table 6 presents the attribute values that were selected for the three different states of technology in the low gasoline price scenario without an e-scooter tax incentive.

The upgraded state of technology implements mid-level enhancements in e-scooter technology, relative to the current technology, without associated increases in price or operating costs. The e-scooter refuel range increases from 60 km to 120 km; the recharging time falls from 360 minutes to 30 minutes; acceleration increases from being 20% slower to the same as a standard motorcycle's; and the top speed rises from 40 km/h to 50 km/h.

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[17] Potoglou and Kanaroglou 2007.
[18] Chiu and Tzeng 1999.

The cutting-edge state of technology posits even further improvements in refuel range, recharging time, and top speed, relative to the upgraded technology, while assuming these improvements to be accompanied by associated increases in price and operating costs. Refuel range increases to 200 km; recharging time falls to 10 minutes; and top speed increases to 60 km/h. The e- scooter purchase price rises from D10 million to D16 million. The electricity costs increase from D5,000/100 km to D7,500/100 km, reflecting higher energy requirements and also the capital costs of supercharging devices required for rapid recharging. Finally, the maintenance costs rise from D100,000/month to D140,000/month to account for the greater expense of enhanced batteries.

In the low gasoline price scenario, fuel costs are set at D30,000/100 km for both the standard and large motorcycles. These calculations are based on a gasoline price of D15,000 per liter and a specification of 50 km per liter for standard and large motorcycles. In late July 2008, the Government of Viet Nam cut back on fuel subsidies and raised the price of retail gasoline by 31% to approximately D20,000 per liter. Market share predictions based on the high gasoline price scenario reflect this increase in the price of gasoline, and using the above specification for kilometers per liter, the fuel costs are set at D40,000/100 km for both the standard and large motorcycles in the high gasoline price scenario.

Examining the taxes in Table 6, the sales tax for each of the three vehicles is set at 10% of the purchase price in the absence of the e-scooter tax incentive. These sales taxes are set to approximate the current policy in Ha Noi. For the market share predictions based on the implementation of an e-scooter tax incentive, the sales tax for the e-scooter is set to 0%, while the sales taxes for the standard and large motorcycles each remain at 10%. Table 7 shows the market share predictions for each state of technology under both low and high gasoline price scenarios, with and without the e-scooter tax incentive.

Under the current technology with low gasoline price and no e-scooter tax incentive, the e-scooter is predicted to hold the smallest share of the market for two-wheeled motorized transport at 20%, with the large motorcycle holding 33%, and the standard motorcycle holding the largest share with 47%. Moving to a high gasoline price while remaining with the current technology and without an e-scooter tax incentive increases the predicted e-scooter market share to 23%. In general, for a given state of technology and a given tax policy, moving from a low to high gasoline price results in a 3% increase in the predicted e-scooter market share.

An examination of the posited technological improvements reveals an influence on the predicted market shares. Without the e-scooter tax incentive, switching from the current state of technology to the cutting-edge state of technology results in a 13% increase in the predicted e-scooter share of the market under either gasoline price scenario, from 20% to 33% in the low gasoline price scenario, and from 23% to 36% in the high gasoline price scenario. Similarly, when the e-scooter tax incentive is in place, switching from current technology to cutting-edge technology increases e-scooter market share from 23% to 38% with low gasoline prices, and from 26% to 42% with high gasoline prices.

Table 6: Low Gasoline Price without Electric Scooter Tax Incentive
(Ha Noi)

Attribute	Cutting-Edge Technology	Upgraded Technology	Current Technology
Purchase price (D million)			
Standard motorcycle	10	10	10
Large motorcycle	15	15	15
E-scooter	16	12	12
Refuel range (km)			
Standard motorcycle	100	100	100
Large motorcycle	200	200	200
E-scooter	200	120	60
Refuel/Recharge time (min)			
Standard motorcycle	5	5	5
Large motorcycle	10	10	10
E-scooter	10	30	360
Fuel/Electricity cost (D/100km)			
Standard motorcycle	30,000	30,000	30,000
Large motorcycle	30,000	30,000	30,000
E-scooter	7,500	5,000	5,000
Maintenance cost (D/month)			
Standard motorcycle	20,000	20,000	20,000
Large motorcycle	20,000	20,000	20,000
E-scooter	140,000	100,000	100,000
Acceleration[a]			
Standard motorcycle	same as common	same as common	same as common
Large motorcycle	20% faster	20% faster	20% faster
E-scooter	20% faster	same as common	20% slower
Top speed (km/h)			
Standard motorcycle	80	80	80
Large motorcycle	80	80	80
E-scooter	60	50	40
License			
Standard motorcycle	Yes	Yes	Yes
Large motorcycle	Yes	Yes	Yes
E-scooter	No	No	No
Sales tax (D million)			
Standard motorcycle	10%	10%	10%
Large motorcycle	10%	10%	10%
E-scooter	10%	10%	10%

D = dong, D/100 km = dong per 100 kilometers, D/month = dong per month, e-scooter = electric scooter, km = kilometer, km/h = kilometer per hour, min = minute, sec = second.

[a] Relative to standard motorcycle: 0–40 km in 10 sec.

Source: Authors.

Table 7: Market Share in Ha Noi—Varying Tax, Fuel Price, and Technology

	Market Share Predictions for Alternative Technologies without Tax Incentive					
	Low Gasoline Price			High Gasoline Price		
	Current Technology	Upgraded Technology	Cutting-Edge Technology	Current Technology	Upgraded Technology	Cutting-Edge Technology
Standard motorcycle	0.47 (0.03)	0.41 (0.03)	0.40 (0.04)	0.46 (0.03)	0.39 (0.03)	0.38 (0.04)
Large motorcycle	0.33 (0.03)	0.28 (0.03)	0.27 (0.02)	0.32 (0.03)	0.27 (0.05)	0.26 (0.02)
E-scooter	0.20 (0.04)	0.31 (0.04)	0.33 (0.04)	0.23 (0.05)	0.34 (0.05)	0.36 (0.05)

	Market Share Predictions for Alternative Technologies with Tax Incentive					
	Low Gasoline Price			High Gasoline Price		
	Current Technology	Upgraded Technology	Cutting-Edge Technology	Current Technology	Upgraded Technology	Cutting-Edge Technology
Standard Motorcycle	0.46 (0.03)	0.39 (0.03)	0.37 (0.04)	0.44 (0.04)	0.36 (0.03)	0.34 (0.04)
Large motorcycle	0.31 (0.03)	0.27 (0.03)	0.25 (0.02)	0.30 (0.03)	0.25 (0.03)	0.24 (0.02)
E-scooter	0.23 (0.04)	0.35 (0.04)	0.38 (0.04)	0.26 (0.05)	0.38 (0.05)	0.42 (0.05)

e-scooter = electric scooter.

Note: Values not enclosed in parentheses are the coefficients, while values within parentheses are the standard errors. As a result of rounding, the market shares for some alternatives may not sum to 1.

Source: Authors.

For a given state of technology and given gasoline price scenario, the e-scooter tax incentive increases the predicted market share of e-scooters by 3% to 6%. Among the scenarios examined, the e-scooter market share reaches its highest level of 42% under cutting-edge technology, high gasoline price, and e-scooter tax incentive.

Ahmedabad, India

Not all experimental attributes in the Ahmedabad survey were significant or had the expected sign. There are a number of possible explanations for this, including lack of importance of the attribute in the choice decision. However, it could also be that respondents did not read the choice questions carefully or had a preconceived bias against electric two-wheelers. This is evidenced in the high alternative specific constants for gasoline scooters and motorbikes. It could be the case that individuals chose those modes considering attributes that were not included in the choice experiment. Alternatively, individuals may have chosen based on the attributes in the choice experiment, but may have had preconceived notions of those attributes as opposed to the levels provided; or individuals may simply value gas scooters solely for the fact that they are powered by gas and not electricity.

Table 8 shows the parameter estimates for the conditional logit model estimated in Ahmedabad. The alternative specific constants

Table 8: Parameter Estimates of the Conditional Logit Model (Ahmedabad)

Variable	Coefficient	Standard Error	*p*-value
Purchase price (Rs)	(0.0000291)	1.57E-06	0
Refuel or recharge range (km)	0.0001977	0.0001042	0.058
Refuel or recharge time (min)	(0.0019452)	0.0002849	0
Fuel or electricity cost (Rs/km)	(0.7535194)	0.0797702	0
Maintenance cost (Rs/15000 km)	0.000057	0.0000623	0.36
Top speed (km/h)	0.0022291	0.0011376	0.05
Acceleration (0–30 km in X sec)	(0.0127484)	0.0113414	0.261
VAT + registration tax (Rs)	4.40E-06	5.85E-06	0.452
Caplow (1 passenger)	(0.5077588)	0.0678198	0
Caphigh (3 passengers)	0.314273	0.050005	0
Transmission	(0.0016645)	0.0277165	0.952
License	(0.0577002)	0.046505	0.215
Price x female	(0.0000323)	0.0000119	0.007
Speed x female	0.0206921	0.0069034	0.003
Caplow x female	1.190801	0.3827393	0.002
Caphigh x female	(1.252734)	0.3179304	0
Maintenance x female	(0.0009319)	0.0004108	0.023
Motorcycle alternative specific constant	2.078798	0.1689444	0
Motor scooter alternative specific constant	2.073141	0.1416126	0
N Obs	16,962		
Log-likelihood (0)	(5060.6495)		
Log-likelihood	(4947.4576)		
Wald Chi-Square	556.80		

( ) = negative, km = kilometer, km/h = kilometer per hour, min = minute, N Obs = number of observations, Rs = rupee, Rs/km = rupees per kilometer, Rs/15,000 km = rupees per 15,000 kilometers, sec = second.

Note: *p*-value<0.05 indicates a >95% confidence that the parameter estimate is not equal to zero.

Source: Authors.

indicate a strong disposition toward gasoline-powered two-wheelers. A notable insignificant variable is VAT + Registration tax. The implication here is that Indian vehicle purchasers are less sensitive to taxes than purchasers in Viet Nam. This could also indicate that the respondents did not conceptualize the effect of the tax on their purchase choice, an inherent challenge with stated-preference choice experiments.

There was difficulty including gender-attribute interactions because females were undersampled. Unfortunately, the predominately male survey team had difficulty collecting data from females, which creates estimation problems in the model. Still, price, speed, capacity, and maintenance costs interacted with gender-influenced choice. The interpretation of the negative sign on maintenance cost and purchase price variables, interacted with females, indicates that females are more price-sensitive than males. Females are also less concerned with capacity as an important variable in their decision. Surprisingly, speed, interacted with female gender, is positive, indicating that females prefer faster vehicles than males, contrary to findings in the Ha Noi model or in Chiu and Tzeng.[19]

Willingness to Pay Estimates

The MWTP of various attributes is important to understand the substitution patterns of potential e-scooter purchasers. Again, the MWTP is expressed as the amount of money one would pay for a marginal increase or decrease in another parameter and is calculated as the quotient of the vehicle purchase price parameter estimate and the parameter of the variable in question. Notably, the alternative specific constants were dominant in the MWTP estimates, about Rs71,000, just for having a gasoline two-wheeler instead of an electric. This exceeds the purchase price in many cases, yielding a strong prevalence away from electric two-wheelers. Speed is important, and respondents were willing to pay Rs76 per km/h top speed increase. Similarly respondents would pay Rs438 per second reduced to reach 30 km/h (for instance, respondents would pay Rs438 more for a two-wheeler that accelerated from 0 to 30 km/h in 5 seconds, compared to the same two-wheeler that accelerated from 0 to 30 km/h in 6 seconds). Interestingly, capacity proved important as individuals were willing to pay Rs10,000 for a scooter with an additional person-carrying capacity. Regarding cross-price sensitivity, individuals were willing to pay Rs26,000 to save Rs1/km on fuel costs. Over the reasonable life of a vehicle (80,000 km), this fuel savings from additional investment in a fuel economy would pay for itself threefold. To put it another way, a vehicle purchaser will only pay an up-front cost of about 1/3 of the expected fuel cost savings over the life of the vehicle. Considering maintenance costs, respondents were willing to pay about Rs2 to save Rs1/15,000 km in maintenance costs. Again, assuming a vehicle lifespan of 80,000 km, the up-front willingness to pay for an expected gain is about 1/3 of the expected savings.

Market Share Predictions

The results of the conditional logit model specification are used to estimate market shares for Ahmedabad, creating several classes of vehicles and estimating the future market potential of each class of vehicle. Similar to the Ha Noi model, the analysis examines three different states of e-scooter technology: current, upgraded, and cutting-edge. Each state is combined with low and high gasoline price scenarios. Since taxes did not enter significantly in the model, they were not included as a determinant of market share. Market shares are calculated for each combination of technology and gasoline price.

Table 9 presents the attribute values that were selected for the three different states of technology in the low gasoline price scenario. Again, the upgraded state of technology implements mid-level enhancements in e-scooter technology, relative to the current technology, without associated increases in price or operating costs.

[19] Chiu and Tzeng 1999.

The two states where market share is analyzed are low and high gasoline price scenarios. The low gasoline price scenario reflects the current market conditions, while the high gasoline price scenario reflects a 33% price increase. This price increase is consistent with increases in fuel prices seen around the world and could be a result of taxation policy or market forces.

Considering the high and low fuel prices, coupled with different performance and price attributes of current and future generation e-scooters, market shares are estimated as shown in Table 10. In Ahmedabad, e-scooter market potential is much lower than in Ha Noi. In the low gasoline price scenario, the current technology e-scooter is estimated to penetrate only 6% of the market. With an upgraded technology (performance), this value increases to 19%. Interestingly, the market share drops in the cutting-edge technology case, to about 11%. The explanation of this drop is that the operating costs increase given higher energy requirements and more expensive maintenance costs, which outweigh the performance improvements. The implication here is that consumers might not be willing to pay for higher performing batteries and power, in exchange for improved performance. Increasing gasoline prices by 33% results in a 2–3 percentage point increase in market share for all three e-scooter classes.

Table 9: Market Estimation Attribute Values
(Ahmedabad)

Attribute	Cutting-Edge Technology	Upgraded Technology	Current Technology
Price (Rs)			
Motor scooter	39,500	39,500	39,500
Motorcycle	58,700	58,700	58,700
E-scooter	37,000	27,750	27,750
Range (km)			
Motor scooter	100	100	100
Motorcycle	200	200	200
E-scooter	200	120	60
Recharge time (min)			
Motor scooter	5	5	5
Motorcycle	10	10	10
E- scooter	10	30	360
Fuel/electricity cost (Rs/km)			
Motor scooter	1.08	1.08	1.08
Motorcycle	1.08	1.08	1.08
E-scooter	0.09	0.06	0.06
Maintenance cost (Rs/15,000 km)			
Motor scooter	7,500	7,500	7,500
Motorcycle	7,500	7,500	7,500
E-scooter	10,850	7,750	7,750
Acceleration (0–30 km in XX sec)			
Motor scooter	5	5	5
Motorcycle	4	4	4
E-scooter	4	5	6
Speed (km/h)			
Motor scooter	80	80	80
Motorcycle	80	80	80
E-scooter	60	50	40
Capacity high (# adults)			
Motor scooter	2	2	2
Motorcycle	2	2	2
E-scooter	2	2	1
Transmission			
Motor scooter	Automatic	Automatic	Automatic
Motorcycle	Manual	Manual	Manual
E-scooter	Automatic	Automatic	Automatic

continued on next page...

Table 9 continued

Attribute	Cutting-Edge Technology	Upgraded Technology	Current Technology
License			
Motor scooter	Yes	Yes	Yes
Motorcycle	Yes	Yes	Yes
E-scooter	No	No	No
VAT + registration tax			
Motor scooter	3,600	3,600	3,600
Motorcycle	4,750	4,750	4,750
E-scooter	1,600	1,600	1,600

km = kilometer, km/h = kilometer per hour, Maint = maintenance, min = minute, Rs = rupee, Rs/15,000 km = rupees per 15,000 kilometer, Rs/km = rupees per kilometer, sec = second.

Source: Authors.

Table 10: Market Share in Ahmedabad—Vary Fuel Price and Technology

	Low Gasoline Price			High Gasoline Price		
	Current Technology	Upgraded Technology	Cutting-Edge Technology	Current Technology	Upgraded Technology	Cutting-Edge Technology
Motorcycle	0.32 (0.02)	0.28 (0.02)	0.30 (0.02)	0.31 (0.02)	0.26 (0.02)	0.29 (0.02)
Motor scooter	0.62 (0.02)	0.53 (0.02)	0.59 (0.03)	0.60 (0.02)	0.50 (0.02)	0.57 (0.03)
E-scooter	0.06 (0.01)	0.19 (0.02)	0.11 (0.03)	0.08 (0.02)	0.23 (0.03)	0.14 (0.04)

e-scooter = electric scooter.

Note: Values not enclosed in parentheses are the coefficients, while values within parentheses are the standard errors. As a result of rounding, the market shares for some alternatives may not sum to 1.

Source: Authors.

Environmental Impacts

Although e-scooters can be referred to as zero-emission vehicles, they do in fact emit pollution from power plants. Additionally, they emit lead from battery manufacturing and recycling. A study in the PRC showed that electric two-wheelers emit up to 30% of the mass of a battery over its life cycle. Electric vehicles also tend to emit more sulfur dioxide (SO_2) pollution than conventional gasoline vehicles because of reliance on coal power plants.[20] Because electric two-wheelers are competing against gasoline scooters and motorcycles in India and Viet Nam, e-scooter-style vehicles will likely be required to attain market share. E-scooters have higher energy requirements than smaller e-bikes so e-scooters could have higher emissions during the use phase. In this section, use-phase emissions of e-scooters were estimated and compared against gasoline two-wheelers. Lead pollution was also estimated based on regional efficiencies of the lead battery production and recycling industries in India and Viet Nam.

Ultimately, e-bike emission rates depend on emissions from the power sector. Both Viet Nam and India have a high reliance on thermal power sources and, as demand grows, thermal power continues to constitute a high proportion of new capacity. In 2006, 16% of India's power was supplied by hydropower, 2% by nuclear and about 81% by thermal power, 86% of which is coal-based.[21] Viet Nam relies much more heavily on hydropower sources, although thermal power sources are a large share. In 2004, 52% of power was generated by thermal power while 48% was produced by hydropower. Only 12% of power was generated by coal, while the remainder was generated by natural gas and other thermal sources.[22]

Several studies have quantified motorcycle emission rates worldwide. A recent, comprehensive study identified emission rates of two-stroke and four-stroke motorcycles. In both India and Viet Nam, four-stroke motorcycles are quickly replacing two-stroke motorcycles, with four-strokes constituting 70% of new motorbike sales in India in 2004.[23]

E-bikes vary by country and region. E-scooter emissions in the PRC, with 85% reliance on fossil fuel electricity generation, are also shown in Table 11 for comparison. Notably, emission rates from gasoline motorcycles are at least an order of magnitude higher for most pollutants, compared to e-scooters.

[20] Cherry et al. 2009.

[21] US Energy Information Administration. 2009. *Country Analysis Briefs–India*. www.eia.doe.gov/emeu/cabs/India/Electricity.html

[22] US Energy Information Administration. 2009. *Country Analysis Briefs–Vietnam*. www.eia.doe.gov/emeu/cabs/Vietnam/Electricity.html

[23] Meszler, D. 2007. *Air Emissions Issues Related to Two and Three-Wheeled Motor Vehicles.* San Francisco: International Council of Clean Transport.

Table 11: Motorcycle Emission Rates
(g/km)

	Exh VOC	Evap VOC	Total VOC	CO	NO_x	PM	CO_2	Max CO_2	N_2O	CH_4	SO_2
Two-stroke	15.5	1.25	16.75	18	0.05	0.5	40	118	0.002	0.15	…
Four-stroke	1	1.25	2.25	12.5	0.15	0.1	55	77	0.002	0.2	…
E-scooter, PRC	…	…	0.007	0.02	0.06	0.017	21.5	…	…	…	0.13

... = not available, CH_4 = methane, CO = carbon monoxide, CO_2 = carbon dioxide, e-scooter = electric scooter, Evap = evaporative emissions, Exh = exhaust emissions, g/km = gram per kilometer, max CO_2 = maximum CO_2 emissions carbon dioxide, N_2O = nitrous oxide, NO_x = nitrogen oxide, PM = particulate matter, PRC = People's Republic of China, SO_2 = sulfur dioxide, VOC = volatile organic compound.

Source: Meszler, D. 2007. *Air Emissions Issues Related to Two and Three-Wheeled Motor Vehicles.* San Francisco: International Council of Clean Transport; Cherry, C., et al. 2009. *Electric Bikes in the People's Republic of China (PRC)—Impact on the Environment and Prospects for Future Growth.* Asian Development Bank: Manila.

Impact Estimation Methodology

E-scooters in India and Viet Nam, to compete directly against gasoline motorcycles and scooters and become more widely used, will demand higher energy and thus more electricity generation with concomitant pollution per kilometer, compared to a smaller e-bike on the same grid. In this analysis, three classes of e-scooters are analyzed for environmental emissions:

(i) The first class is the same estimated in Cherry and Weinert et al., a lower power (350–500 W) scooter with a maximum speed of 30 km/h. These scooters are technologically mature and very common in the PRC. The electricity requirements at the plug are 1.8 kilowatt-hours per 100 km (kWh/100 km).[24]

(ii) The second class is an intermediate scooter, with mid-range motor power (750 W) and a maximum speed of 45 km/h. This class of scooter is not widely manufactured in the PRC because of regulatory pressure to develop slower and lighter vehicles. The electricity requirements at the plug are 2.3 kWh/100 km.

(iii) The third class is a more advanced e-scooter, with motor power greater than 1,000 W and maximum speeds of over 55 km/h. There are few of this class developed in Asia. The electricity requirements at the plug of this class are estimated to be 3.1 kWh/100 km.

Transmission losses require more electricity to be generated at the plant than is delivered to the outlet—10% more in Viet Nam, 14% more in the PRC, and 34% more in India. The higher the transmission loss, the more electricity must be generated per kilometer to power electric vehicles.[25]

[24] Cherry et al. 2009.

[25] Lawrence Berkeley National Laboratory. 2004. *China Energy Databook 6.0.* http://china.lbl.gov/research/china-energy-databook; WebIndia123.com. 2009. *Steps Will Be Taken to Bring Down Transmission Loss: Balan.* 14 June. http://news.webindia123.com/news/Articles/India/20090614/1275122.html; Vietnam News. 2009. *EVN Wants Cap on Power Losses.* 10 July. http://vietnamnews.vnagency.com.vn/showarticle.php?num=03ECO190509

Once plug-to-wheel and plant-to-plug energy use is estimated, one can estimate the total electric energy use requirements per kilometer. First, one has to estimate the emission intensity of electricity generation, expressed as grams of pollutant per kilowatt-hour. Emission rates from the power sector, per kilowatt-hour of generated electricity, are estimated using two databases. For CO_2 emissions, the Carbon Monitoring for Action (CARMA) database is used to estimate the intensity of CO_2 emissions per kilowatt-hour of electricity generation, averaged over the country. Conventional pollutant emission rates are estimated by summing aggregate emission inventories in the power sector, estimated by the National Aeronautics and Space Administration Intercontinental Transport Experiment Phase B (NASA INTEX-B), and dividing by the total electricity generation in each country provided by the CARMA database.[26] Each of these analyses was conducted using a geographic information system (GIS) to spatially estimate emissions. In all cases, aggregate emissions from the power sector were averaged, rather than plant-specific emission rates. The pollutants estimated include CO_2, black carbon (BC), CO, NO_X, organic compounds (OC), particulate matter 10 (PM_{10}), particulate matter 2.5 ($PM_{2.5}$), SO_2, and volatile organic compounds (VOC).

Regionally, emission rates could vary depending on the electricity generation fuel mix in each specific grid. In the PRC, regional variations can account for some regions having up to six times higher emissions per kilowatt-hour than "cleaner" grids for some pollutants. Viet Nam has one continuous power grid, so it was assumed that each unit of electricity generation has the same emission intensity. India has five distinct power grid networks, but grid-specific emission rates were not estimated because of the lack of region-specific power generation locations. Given this, national emission rates for India were estimated. The calculation method is shown in Appendix 2.

Emission Rates of Electric Scooters in India and Viet Nam

Using the above methodology, the emission rates for the three vehicle classes are estimated and presented in Table 12. Because of the structure of Viet Nam's energy and lead processing industry and resources, e-scooter emission rates are significantly lower than India's for most pollutants. Still, compared with gasoline two-wheelers, e-scooters have much lower emission rates on almost all pollutants in both countries.

Importantly, on a per-kilometer basis, e-scooters can reduce CO_2 emissions by one-third to one-half of a motorcycle's emissions. CO is practically undetectable compared to a motorcycle's emissions. The only pollutant that has a potentially higher emission rate during the use phase is SO_2, whereas SO_2 emission rates of vehicles using unleaded gasoline are often undetectable. There are some important differences to note between using an e-scooter in India and Viet Nam. Particularly, the CO emission rate in Viet Nam is orders of magnitude higher than CO emissions in India. On the other hand, the OC emission rate is several orders of magnitude higher in India than the OC emission rate in Viet Nam. This is likely because of a different fuel mix for electricity generation.

[26] Argonne National Lab. 2006. *2006 Asia Emissions for INTEX-B*. 7 June. http://www.cgrer.uiowa.edu/EMISSION_DATA_new/index_16.html; CARMA. 2009. Carbon Monitoring for Action. July 1. http://carma.org

Table 12: Emission Rate of Electric Scooters in India and Viet Nam

	India			Viet Nam			India and Viet Nam
	Class I Low Power E-scooter	Class II Mid Power E-scooter	Class III High Power E-scooter	Class I Low Power E-scooter	Class II Mid Power E-scooter	Class III High Power E-scooter	4-Stroke Two-wheeler
CO_2 (g/km)	21.9	28.0	37.8	16.1	20.5	27.7	55
BC (mg/100 km)	27.3	34.8	47.0	0.8	1.0	1.4	–
CO (mg/100 km)	0.03	0.04	0.05	31.5	40.2	54.2	1,250,000
NO_X (g/100 km)	4.8	6.2	8.3	1.3	1.7	2.3	15
OC (g/100 km)	92.8	118.6	159.8	0.4	0.5	0.6	–
PM_{10} (g/100 km)	4.5	5.8	7.8	0.3	0.4	0.6	10
$PM_{2.5}$ (g/100 km)	2.8	3.6	4.9	0.2	0.3	0.4	–
SO_2 (g/100 km)	8.1	10.3	13.9	1.9	2.4	3.3	–
VOC (g/100 km)	0.4	0.5	0.6	0.0	0.1	0.1	225

– = no data available, BC = black carbon, CO = carbon monoxide, CO_2 = carbon dioxide, e-scooter = electric scooter, g/100 km = gram per 100 kilometers, g/km = gram per kilometer, mg/100 km = milligram per 100 kilometers, NO_x = nitrogen oxide, OC = organic compound, PM_{10} = particulate matter 10, $PM_{2.5}$ = particulate matter 2.5, SO_2 = sulfur dioxide, VOC = volatile organic compound.

Source: Authors; Meszler, D. 2007. *Air Emissions Issues Related to Two and Three-Wheeled Motor Vehicles.* San Francisco: International Council of Clean Transport.

Environmental Impacts of Electric Scooter Adoption

While e-scooters have lower emission rates than gasoline scooters, their impact can only be realized with high adoption rates. Coupling e-scooter scenarios developed in the market analysis section with environmental emission rates can show reductions in transportation-related emissions, in terms of both local pollutants and greenhouse gases. The market scenarios developed in Tables 7 and 9 are extended below in Tables 13 and 14, coupled with the weighted emission rate of two-wheelers in the country by scenario. These tables present several scenarios of e-scooter adoption, based on improved performance and economic incentive. Based on these scenarios, the impact of e-scooters can be estimated through an average two-wheeler emission rate that takes into account the proportions of the fleet comprising gasoline and electric two-wheelers. This weighted emission rate includes the appropriate e-scooter class and weights the emissions by the proportion of the two-wheeler market that the e-scooter captures. This assumes that as e-scooters replace gasoline two-wheelers, e-scooter users use gasoline two-wheelers in the same way. For instance,

Table 13: Two-Wheeler Average Emission Rate Impacts of Electric Scooter Market Penetration—Ha Noi

		No Tax Incentive				Tax Incentive			
		Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Pollutant[a]	Current State[b] 0% E-scooters	Low Gas Price Class III E-Scooter 33% E-scooters	% Change (compared to 100% gas two-wheeler)	High Gas Price Class III E-Scooter 36% E-scooters	% Change (compared to 100% gas two-wheeler)	Low Gas Price Class III E-Scooter 38% E-scooters	% Change (compared to 100% gas two-wheeler)	High Gas Price Class III E-Scooter 42% E-scooters	% Change (compared to 100% gas two-wheeler)
CO_2 (g/km)	55	46.0	(16)	45.2	(18)	44.6	(19)	43.5	(21)
CO (g/100km)	1,250	838	(33)	800	(36)	775	(38)	725	(42)
NO_X (g/100km)	15	10.8	(28)	10.4	(30)	10.2	(32)	9.7	(36)
PM_{10} (g/100km)	10	6.9	(31)	6.6	(34)	6.4	(36)	6.0	(40)
SO_2 (g/100km)[c]	0	1.1	New emissions	1.2	New emissions	1.2	New emissions	1.4	New emissions
VOC (g/100km)	225	151	(33)	144	(36)	140	(38)	131	(42)

( ) = negative, CO = carbon monoxide, CO_2 = carbon dioxide, e-scooter = electric scooter, g/100 km = gram per 100 kilometers, g/km = gram per kilometer, NO_X = nitrogen oxide, PM_{10} = particulate matter 10, SO_2 = sulfur dioxide, VOC = volatile organic compound.

[a] Some pollutants were omitted from this table because they were not consistently reported across data sets.

[b] From Meszler 2007.

[c] SO_2 is unreported in Meszler 2007. It is assumed that the emission rate is zero for gasoline two-wheelers since this is an important new emission from electric vehicles.

Source: Authors; Meszler, D. 2007. *Air Emissions Issues Related to Two and Three-Wheeled Motor Vehicles*. San Francisco: International Council of Clean Transport.

Table 14: Two-Wheeler Average Emission Rate Impacts of Electric Scooter Market Penetration—Ahmedabad

		Low Gasoline Price				High Gasoline Price			
		Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Pollutant[a]	Current State[b] 0% E-scooters	Class II E Scooter 19% E-scooters	% Change (compared to 100% gas two-wheeler)	Class III E-Scooter 23% E-scooters	% Change (compared to 100% gas two-wheeler)	Class II E-Scooter 11% E-scooters	% Change (compared to 100% gas two-wheeler)	Class III E-Scooter 14% E-scooters	% Change (compared to 100% gas two-wheeler)
CO_2 (g/km)	55	50.0	(9)	48.7	(11)	52.0	(5)	51.2	(7)
CO (g/100 km)	1,250	1,016	(19)	960	(23)	1,113	(11)	1,075	(14)
NO_X (g/100 km)	15	13.4	(11)	13.0	(14)	14.0	(6)	13.8	(8)
PM_{10} (g/100 km)	10	9.2	(8)	9.0	(10)	9.5	(5)	9.4	(6)
SO_2 (g/100 km)[c]	0.0	1.9	New emissions	2.4	New emissions	1.1	New emissions	1.4	New emissions
VOC (g/100 km)	225	183	(19)	173	(23)	200	(11)	194	(14)

( ) = negative, CO = carbon monoxide, CO_2 = carbon dioxide, e-scooter = electric scooter, g/100 km = gram per 100 kilometers, g/km = gram per kilometer, NO_X = nitrogen oxide, PM_{10} = particulate matter 10, SO_2 = sulfur dioxide, VOC = volatile organic compound.

[a] Some pollutants were omitted from this table because they were not consistently reported across data sets.

[b] From Meszler 2007.

[c] SO_2 is unreported in Meszler 2007. It is assumed that the emission rate is zero for gasoline two-wheelers since this is an important new emission from electric vehicles.

Source: Authors; Meszler, D. 2007. *Air Emissions Issues Related to Two and Three-Wheeled Motor Vehicles.* San Francisco: International Council of Clean Transport.

a 33% shift toward e-scooters will result in a 33% replacement of vehicle kilometers traveled. There are two potentially counterbalancing forces that could produce biased results from this assumption: (i) since the marginal cost of travel is lower, there could be more induced travel by e-scooter owners; and (ii) e-scooters generally have a lower range than their gasoline counterparts, so e-scooter owners might make shorter trips on average.

It should be noted that emission rate reductions are compared to the average emission rate of the gasoline two-wheeler, and do not suggest that ambient air quality will improve by this percentage in urban areas. It is uncertain what effect e-scooters will have on ambient air quality in populated areas for two reasons.

Gasoline two-wheelers are responsible for much, but not all air pollution in urban areas. For instance, gasoline two-wheelers are responsible for about 80% of transport-related CO pollution in Ha Noi. By displacing 33% of gasoline two-wheelers with e-scooters, total transport-related CO emissions could be reduced by 26%. On the other hand, gasoline two-wheelers are only responsible for 20% of transport-related PM emissions (dominated by heavy-duty diesel vehicles), so by displacing 33% of gasoline two-wheelers with e-scooters, transport-related PM emissions will be reduced by 6% (20% times 31%).[27]

Gasoline two-wheelers emit pollution directly into the urban environment, impacting local ambient air quality directly. E-scooters emit pollution from sometimes remote power plants, impacting ambient air quality in different regions. This could result in significantly improved public health through reduced exposure efficiency of air pollution.[28]

Although e-scooters do emit slightly more SO_2, there are very clear advantages of promoting e-scooters in Viet Nam and India. In fact, subsidizing e-scooter adoption could be a more cost-effective method of reducing CO_2 emissions than many competing alternatives. Moreover, e-scooter adoption will likely result in much greater local air pollution improvement.

E-scooters have the potential both to improve local air quality and reduce greenhouse gas emissions derived from the transport sector. In fact, they can be very cost effective at both. For instance, in Ha Noi, 12 billion passenger-kilometers were traveled by motorbike in 2005, or about 8,000 km per year per motorbike.[29] This analysis shows that 33% of the future market could choose e-scooters with little government intervention, assuming that the best technology is developed and marketed by industry. Assuming that 33% of the 12 billion passenger-kilometers are taken by e-scooters in the future, the total emissions would be 552,000 metric tons of CO_2 yearly. E-scooter market adoption could increase to 38% if e-scooters were exempt from registration tax (10%) and gasoline two-wheelers were still subject to that tax, resulting in a 5-percentage-point increase in adoption. This market penetration would result in total

[27] Schipper et al. 2008.
[28] Heath et al. 2006.
[29] Schipper et al. 2008.

two-wheeler CO_2 emissions of 535,200 tons, or a 16,800 ton reduction per year. If an e-scooter's lifespan is 6 years, on average, each e-scooter that replaces a gasoline scooter would reduce CO_2 emissions by 1.3 tons.[30] This would cost about D1 million per e-scooter, or about $48/ ton. While this is more expensive than some alternatives, the co-benefits of improved air quality could justify public subsidy of this mode.

The potential improvements are more modest in Ahmedabad for two reasons. The first is that e-scooters have a negative perception, even with price and performance advantages. This results in a low market adoption, impeding policy attempts to influence market demand. The second reason is that India's electricity generation emission rates are relatively high, reducing the net benefit of a shift from gasoline two-wheelers to e-scooters. With effective marketing campaigns, public perception could shift toward e-scooters; however, current consumers seem unresponsive to direct price incentives, like VAT reduction.

Lead Pollution

Lead pollution is a significant concern when considering e-scooter adoption. Lead acid batteries are still the dominant battery technology adopted by e-scooter manufacturers in Asia, with over 95% of electric two-wheelers using them.[31]

In addition, Asia has a relatively poor record for battery production and recycling efficiency. In the PRC, lead pollution rates from e-scooters are about 420 milligrams per kilometer (mg/km), compared to about 32 mg/km for a gasoline two-wheeler.[32] All of these emissions occur during the mining and smelting, battery manufacture, and recycling phases.

Estimating lead pollution of e-scooters in India and Viet Nam is complicated since a large portion of lead batteries are imported from the PRC. Mao and Dong et al. estimate regional emission rates of lead from battery production and recycling.[33] For the most part, regional rates are discussed, but given India's size, the authors calculate India-specific loss rates. India has one of the lowest lead-loss rates in Asia, 10.9% of lead output, while Asia's average is 19.6% of lead output. Battery life is related to both recharge cycles and weather. Battery life can deteriorate significantly in hot or cold temperatures.[34] Since e-scooters are new vehicles, it is difficult to estimate how many kilometers one might travel before replacing a battery. Additionally, batteries for larger, faster e-scooters are significantly larger than batteries in most Chinese e-scooters. Table 15 shows battery size, weight, and lead emissions for different e-scooter classes and mileage assumptions.

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30 This is a calculation of the total amount of CO_2 reduction over the life of vehicle. CO_2 reduction (in grams) = 8,000 km/yr*6 (55gCO_2/km-27.7g CO_2), where 55g/km is the assumed emission rate of gasoline motorcycles and 27.7g/km is the average CO_2 emission rate of electric scotters.

31 Jamerson and Benjamin 2007.

32 Cherry et al. 2009.

33 Mao, J. et al. 2008. A Multilevel Cycle of Anthropogenic Lead: II. Results and Discussion. *Resources, Conservation and Recycling*. 52 (8–9). pp. 1050–1057.

34 Weinert, J.X. et al. 2007. Lead-Acid and Lithium-Ion Batteries for the Chinese Electric Bike Market and Implications on Future Technology Advancement. *Journal of Power Sources*. 172 (2). pp. 938–945.

Table 15: Average Emissions from Lead Acid Batteries

	India			Viet Nam		
	E-scooter Class I	E-scooter Class II	E-scooter Class III	E-scooter Class I	E-scooter Class II	E-scooter Class III
Battery capacity (Ah)	20	30	40	20	30	40
Lead content (kg)	18	29	40	18	29	40
Lead loss rate (% of output)[a]	10.9	10.9	10.9	19.6	19.6	19.6
Mileage over battery life[b]	15,000	15,000	15,000	15,000	15,000	15,000
Average emission rate (mg Pb/km)	131	211	291	235	379	523

Ah = amp-hour, e-scooter = electric scooter, kg = kilogram, km = kilometer, mg Pb/km = milligram lead per kilometer.

[a] From Mao and Dong et al. 2008. India-specific rate of 10.9% used for India and Asia average rate or 19.6% used for Viet Nam.

[b] Emission rate per kilometer is very sensitive to battery life since all production and recycling emissions are averaged over the life cycle of the battery. Estimates vary on the amount of mileage one can achieve per battery, but most makers report 10,000–15,000 km.

Source: Authors; Mao, J. et al. 2008. A Multilevel Cycle of Anthropogenic Lead: II. Results and Discussion. *Resources, Conservation and Recycling*. 52(8–9). pp. 1050–1057.

Conclusions

E-scooter adoption is dependent on a number of variables, including purchase price, operating costs, maintenance cost (battery purchase), performance, and regulation. In both Ahmedabad, India, and Ha Noi, Viet Nam, individuals valued various attributes differently, illustrating the need for location-specific policies. For instance, removing license requirements is "worth" about D1 million on average in Ha Noi, whereas they are not important in Ahmedabad. One of the common themes among survey respondents and other transport experts in both cities is that e-scooters suffer a perception problem. Individuals seem skeptical of their reliability or perceive them to be low-power, low-performance vehicles whose quality is not proven. In fact, a poor reputation for quality is likely a significant factor. If given accurate information related to e-scooter performance and price, individuals have some likelihood of choosing them over gasoline two-wheelers. However, many individuals do not have adequate knowledge to make this decision in the marketplace. It is incumbent upon industry and the government to increase public awareness to adequately market the performance and price characteristics of e-scooters, in an environment where gasoline two-wheelers are ubiquitous and their performance well known.

The air quality improvement and CO_2 reductions will be significant if e-scooters can replace gasoline two-wheelers. Each e-scooter that replaces a gasoline two-wheeler reduces CO_2 emissions by 1.3 tons per vehicle over its lifespan in Ha Noi. Moreover, almost all local air pollutants are reduced, with the likely exception of SO_2. In Ahmedabad, the direction of the impact is the same on all pollutants, but more modest since the power generation sector is more emission intensive and the likelihood of wide-scale adoption seems lower, based on the surveys.

Lead pollution is a serious concern that needs to be avoided through adoption of cleaner lithium-ion and/or nickel-metal hydride battery technologies or vastly improved recovery and recycling processes. Some of the more advanced lead production, battery manufacture, and recycling processes have quite low loss rates, in the order of 5% of the final lead mass of the battery. Moreover, steps can be taken to assure containment of emissions to improve environmental and occupational health. Both India and Viet Nam have begun adoption of an environmental certification program, Better Environmental Sustainability Targets, which focuses on reducing negative impacts associated with lead battery manufacture.

Instruments to Improve Electric Scooter Adoption

There are many ways to support e-scooter adoption, including removing fuel subsidies for gasoline two-wheelers and subsidizing clean battery technology, preferential taxation and registration fees. While operating costs (electricity) are very low, the up-front cost of batteries is prohibitive for many consumers, even though the average cost over time could be significantly lower than that of a gasoline two-wheeler. Alternative financing models could potentially overcome this problem, like leasing or financing batteries, but these models are unproven in this context. Without marketing to inform the public and address negative perceptions of e-scooters, or shifts in the economics of vehicle choice (like major gasoline price shifts), e-scooters will only constitute a small portion of vehicles on the street. As technology advances and prices drop, coupled with improved performance, e-scooters can begin to become more widely used. Until then, government intervention to improve the economic advantage of e-scooters relative to gasoline two-wheelers could be a cost-effective pollution mitigation strategy.

Role of Policy Makers

Policy makers have a few tools that they can use to improve the market of e-scooters. In general, preferential taxation policy is shown to factor in increasing market share. This policy could include raising sales taxes and registration fees at the point of purchase for gasoline two-wheelers, while simultaneously reducing e-scooter fees. In Ha Noi, a D1 million tax differential is worth about a D1.6 million purchase price advantage toward e-scooters. This tax preference could be near term, until adoption rates are reasonable and the technology proven. Removing licensing requirements also encourages adoption in Ha Noi, although this could have safety consequences. While it is difficult for the government to reduce operating costs (fuel primarily), a more country-level response would include reducing gasoline subsidies, effectively increasing gasoline prices. Unfortunately, this broad-brush approach does not target gasoline two-wheelers specifically, but will increase operating costs of gasoline vehicles and thus increase the operating cost advantage of electric vehicles.

Two main components of the success of e-bikes in the PRC are infrastructure availability and somewhat draconian bans on gasoline two-wheelers in many cities. The current e-scooter technology is comparable in performance to a gasoline two-wheeler in an urban environment, so e-scooters do not necessarily require exclusive infrastructure. Increasing regulation against gasoline two-wheelers, although difficult, is one of the most effective ways to promote e-scooters.

Role of Industry

The models presented in this report identify many performance characteristics that will improve the overall marketability of e-scooters, in addition to price components that are largely in the hands of the industry. Several factors were deemed important, including top speed, range, acceleration, and purchase and operating costs. It is the responsibility of the companies and industry associations to improve the performance of e-scooters so that they can compete on a similar level as gasoline two-wheelers. The disadvantage of e-scooters is the battery system that must be purchased up-front. This makes the purchase price significantly more expensive and consumers are only willing to pay one-third the expected lifetime savings at the time of purchase. This is a significant hurdle, but research and development are resulting in improved e-scooter performance at lower prices. Unfortunately, because of the relatively modular e-scooter industry, weak intellectual property protection, and low barriers to entry, e-scooter companies have little incentive to innovate.[35]

One of the biggest hurdles is negative perceptions and misconceptions. An industry association that regulates the quality of vehicles and effectively markets e-scooters is important to overcome persistent, if unwarranted, negative perceptions, many of which are based on some bad early experiences of the e-scooter industry.

Joint Role

To increase e-scooter adoption, government and industry must join to develop marketing strategies for e-scooters. Government can also serve as an early adopter for agencies and employees to create an initial market and overcome negative perceptions. Government can also provide direct subsidy to overcome higher-quality battery price barriers, which simultaneously improves performance and reduces environmental impacts. Finally, because of the fragmented nature of the e-scooter industry, government or nongovernment research and development can improve the technology, which can be shared with industry.

Final Remarks

E-scooters have potential to improve air quality and reduce greenhouse gas emissions in Viet Nam and India. This research developed several models to estimate the effects of policy measures and technological improvements on vehicle choice and, ultimately, air quality. The application of these models can test a number of policy and technology scenarios, of which a few are presented in this report. Future work can apply these models to specific policies or improvements in performance or price. Notably, the models do not estimate all of the factors that could influence choice, as evidenced by the "alternative specific constants" for gasoline two-wheelers. These constants include many factors that vary between vehicle types but are unobserved, and likely include issues related to perception. E-scooter adoption can increase with a combination of increased performance, reduced price, regulations favoring e-scooters (or harming gasoline two-wheelers), improved infrastructure, and effective marketing. These are all difficult to achieve, but the benefits could supplant other strategies toward reducing environmental problems.

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[35] Weinert, J.X. et al. 2008. The Future of Electric Two-Wheelers and Electric Vehicles in China. *Energy Policy*. 36 (7). pp. 2544–2555.

Appendix 1: Logit Modeling Formulation

The data analysis applies the conditional logit model based on the theory of random utility.[1] Let the indirect utility associated with vehicle *k* be given by:

$$V_k = f\left(d_k, X_k; \alpha, \beta\right) + \varepsilon_k,$$

where $k = 1,\ldots,m$ (m alternatives)

f = deterministic component of utility

ε_k = stochastic component of utility reflecting researcher uncertainty

X_k = sector of attributes for option k

β = vector of attribute parameters to be estimated

α = the parameter on d_k to be estimated

$$y_{ji} = \begin{cases} 1 & \text{if } j \text{ chose } i \\ 0 & \text{otherwise} \end{cases}$$

where $k = 1$ denotes the reference alternative.

Now assume an additively separable linear indirect utility function:

$$V_k = \alpha d_k + \beta X_k + \varepsilon_k$$

Furthermore, assume $\varepsilon_\kappa \sim iid$ that across all alternatives as a Type I Extreme Value Distribution. It can be shown that, as a result of the properties of Type I Extreme Value Distribution random variables, the probability of choosing alternative *i* from choice set *C* is given by:

$$P(i/C) = \frac{exp(\alpha d_i + \beta X_i)}{\sum_{k=1}^{m} exp(\alpha d_k + \beta X_k)}$$

Let the subscript *j* denote the *j*th respondent for $j = 1,\ldots,N$

and let

$$y_{ji} = \begin{cases} 1 & \text{if } j \text{ chose } i \\ 0 & \text{otherwise} \end{cases}$$

Then the log-likelihood to be maximized is specified as follows:

$$\log L = \sum_{j=1}^{N} \sum_{k=1}^{m} y_{ji} \log \left[\frac{\exp(f_i)}{\sum_{k=1}^{m} \exp(f_k)} \right]$$

[1] McFadden, D. 1974. Conditional Logit Analysis of Qualitative Choice Behavior. In Zarembka, P. ed. *Frontiers in Econometrics*. New York: Academic Press.

Appendix 2: Electric Vehicle Emission Rate Estimation

Once emission intensities are estimated, one can estimate emission rates of electric vehicles per kilometer as follows:

$$EmissionRate\ (g/km) = e \times (1 + tl) \times \frac{\sum_{powerplants} E}{\sum_{powerplants} G}$$

where *EmissionRate* = emission rate of a certain pollutant from an e-scooter

e = electricity requirement from the plug to wheel

tl = transmission loss rate

$\sum_{powerplants} E$ = total emissions of a certain pollutant from all power plants

$\sum_{powerplants} G$ = yearly electricity generation of all power plants.

Appendix 3: Market Analysis

Stated-preference experiments are frequently used in marketing for forecasting new product demand and in recent years the methodology has been applied by transport and economic researchers to assess the demand for new "green" vehicles. Most of this stated-preference research on electric cars and alternative fuel vehicles has focused on the effects of price and vehicle performance attributes on the purchase decision; relatively few studies have examined the effect of economic instruments on this decision.

Potoglou and Kanaroglou examined the ability of economic incentives to encourage clean vehicle adoption, using a stated-preference internet survey in Hamilton, Canada.[1] Their experiment involved the choice between an alternative fuel vehicle, a conventional gas vehicle, and a hybrid electric vehicle based on class/size, purchase price, annual fuel cost, annual maintenance cost, fuel availability, and acceleration. The authors made incentives explicit attributes in the experiment, which included access to high occupancy vehicle (HOV) lanes, exemption from parking/meter fees, and exemption from sales tax.

Potoglou and Kanaroglou found that the probability of adopting an alternative fuel vehicle or a hybrid electric vehicle increased in the presence of a tax free option.[2] In particular, their analysis indicated that all else being equal, respondents would pay an additional C$2,000 to C$5,000 for a vehicle that was exempt of sales tax.

Relative to the number of studies on prefer ences for four-wheeled alternative vehicles, the research that has been conducted to assess the market potential for two-wheeled alternative vehicles is quite limited. Only one paper to date (that the authors know of) has used the stated-preference method to dissect the choice decision for e-scooter purchases. Chiu and Tzeng examined the demand for e-scooters in Taipei,China.[3] Their random sample of households in Taipei,China was used to evaluate the choice between a large-engine motorcycle, a small-engine motorcycle, and an electric motorcycle based on purchase price, top speed, emission level, operating cost, cruise range, style, and environmental friendliness.

Chiu and Tzeng's investigation revealed that motorcycle preferences differed between male and female riders, and thus they estimated a segmented multinomial logit model for males and females.[4] The authors found purchase price and speed to be significant choice determinants for all riders, and found that education and the number of motorcycles per household member had positive effects on choosing an electric motorcycle. Their results confirmed gender-specific effects for operating costs, range, and style. Cruising range was positive and significant

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1 Potoglou and P. Kanaroglou. 2007. Household Demand and Willingness to Pay for Clean Vehicles. *Transportation Research Part D*. 12. pp. 264–274.

2 Potoglou and Kanaroglou 2007.

3 Chiu Y.C., and G.H. Tzeng. 1999. *Transportation Research Part D*. 4(2). pp. 127–146.

4 Chiu and Tzeng 1999.

for all males, while operating costs were important to older males. Females showed a preference for a scooter-style bike over a traditional style, most likely because the scooter-style is lightweight and is more comfortable. Economic incentives were not explicitly considered, although increasing e-scooter subsidies were offered as a way to stimulate adoption.

Electric Two-Wheelers in India and Vietnam—Market Analysis and Environmental Impacts

While the use of electric two-wheelers has increased in the People's Republic of China (PRC) in the past decade, such unparalleled growth has not extended beyond the PRC's borders to countries, such as India and Viet Nam, where environmentally detrimental gasoline motorcycles dominate. This report documents market conditions in Ahmedabad, India, and Ha Noi, Viet Nam, to explain why this is so, and analyzes the potential environmental impact of electric two-wheelers to show how they could chart a path toward sustainable transport in these and other countries in the region.

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ISBN 978-971-561-873-1

9 789715 618731

Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org
ISBN 978-971-561-873-1
Publication Stock No. RPT091118

Printed in the Philippines