Factors Influencing Demand for Buses Powered by Alternative Energy Sources

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Abstract

Transit buses consume high amounts of fossil fuels, with the consequent release of greenhouse gases into the atmosphere. In recent decades, much effort has been concentrated on the development of cleaner fuels to mitigate this externality. However, market shares for cleaner-fueled buses are still modest, which is why it is relevant to evaluate the aspects influencing their acceptance. This article presents an econometric model to evaluate factors influencing demand for transit buses in Colombia powered by cleaner fuels. For this purpose, a stated preference survey was applied to public transportation entrepreneurs. Results suggest that the target population considers acquisition cost and operating cost as the most important variables when choosing fuel technology for their fleets. The power offered by the bus engine was relevant for some alternative fuel alternatives, but not the full range.

Keywords: *Transit equipment, alternative-fueled buses, Colombian public transportation*

Introduction

Diesel fuel and gasoline traditionally have been used as the main energy sources for buses. In particular, diesel fuel is massively used for transit buses in Colombia (UPME 2012), as well as worldwide. The burning of fossil fuels involves gas emissions resulting from the combustion process such as CO₂, CO, NO_x and SO_x. These gases are associated with global warming and the greenhouse effect (IPCC 2007). Environmental concern about air quality has motivated the development of cleaner energy technologies for public transportation systems.

Although development of vehicles powered by alternative energy sources is a dynamic research topic, their level of acceptance and market penetration is still too small when compared with traditional technologies. Consequently, proposing policies or strategies to increase demand for cleaner buses requires a better understanding of consumer behavior (i.e., transportation companies) and the variables influencing their buying decisions. This paper aims to identify the factors underlying the purchase decision for transit vehicles powered by clean energy sources. A demand model for buses powered

by alternative fuel technologies was calibrated using data gathered from Colombian transit entrepreneurs and following the discrete choice modeling approach.

Discrete choice models are widely used in demand studies and consumer behavior analysis because they allow the forecasting of market shares for real or hypothetical alternatives. Observed decisions and information about attributes describing technological alternatives (i.e., commonly collected through revealed or stated preference surveys) are used to calibrate the models and, consequently, to analyze the importance of attributes in the choice decision process.

This paper is structured as follows: in the next two sections previous studies related to the research topic are reviewed and the context of public transportation in Colombia is explained. Then, the methodological approach used is presented. After that, a complete description of the data and the main results are shown. Finally, the most relevant conclusions and guidelines for future research are listed.

Background

The transportation sector is responsible for 13.1% of global greenhouse gas (GHG) emissions and nearly 95% of the world's energy used for moving people and goods proceeds from petroleum-based fuels (mostly gasoline and diesel) (EPA 2013). This fact demonstrates that road transportation, including public services, is one of the largest emitters of GHGs. Governments and international organizations around the world have proposed using alternative energy sources, seeking alternatives to mitigate this externality. They have proposed the use of electric power, hydrogen fuel cells, and hybrid technologies that could be a combination of conventional and non-conventional energy sources (Caultfield, Farrell, and McMahon 2010; Litman and Delucci 2006). Compressed natural gas (CNG) is another fuel suggested as an alternative to conventional fuels. Some authors claim that CNG produces a significant reduction in GHG emissions compared to conventional fossil fuels such as diesel and gasoline (Hekkert et al. 2005; Yeh 2007).

Several models and approaches have been used to study buying preferences, most of them focused on private cars. The most popular econometric approaches to study demand for alternative-fueled cars are linear regression, multinomial logit (MNL), ordered logit, ordered probit, and Poisson regression (Potoglou and Kanaroglou 2008). In Colombia, Soto, Cantillo, and Arellana (2014) estimated hybrid choice models to evaluate demand for alternatively-fueled cars incorporating explicitly-observed and latent factors that could affect the next vehicle purchase.

Although related literature on private alternative-fuel vehicle choice can be used as a reference to approaching alternative-fuel bus acquisition, the decision choice processes that lead to the purchase of a personal car vs. a bus are different. A car for an individual represents a personal use good, whereas a bus for a transit company represents working equipment that has to be profitable.

There are few demand studies on alternative-fuel buses around the world, with the exception of CNG buses. The reason is that the market success of other alternative

technologies is marginal, and urban buses running on non-CNG alternative fuels are not available in many countries worldwide.

The first research studies related to alternative-fuel commercial vehicles are those conducted by manufacturers and transportation companies in the early 1990s, with studies mainly focused on trucks. Their main objective was to find the importance of some attributes in the choice of fuel technology for that kind of vehicle. Golob et al. (1997) estimated logit models using stated preference (SP) data collected in 1995: a total of 2,000 truck fleet operators were asked to choose among vehicles running on electricity, CNG, methanol, and gasoline based on operational characteristics and their acquisition costs. Parker, Fletchall, and Pettijohn (1997) presented a descriptive analysis of the perceptions of truck operators about the use of alternative fuels. They concluded that the most important decision variables when choosing truck fuel technology were capital costs, availability of charging stations, and operating costs.

Other authors have focused on determining the main barriers and factors that encourage market acceptance of alternative fuels for buses and trucks. SP surveys were applied in Hong Kong to evaluate the acceptance of public light buses (PLB) among operators for using alternative fuels (Loo, Wong, and Hau 2006). The SP experiment presented two alternatives: diesel and liquefied petroleum gas (LPG). Collected data were used to calibrate multinomial logit models (MNL). Results showed that PLB operators were not inclined to switch from conventional diesel buses to LPG. Vehicle price was not a significant attribute for PLB operators in Hong Kong, possibly because there is a subsidy from the government for the purchase of public transportation buses.

Mattson (2012) described motivating factors and deterrents for adoption of alternative fuels for buses, using the experience of different transit agencies. He examined factors such as costs, maintenance, reliability, and overall satisfaction between those agencies that have used alternative fuel vehicles and those that have not, as well as differences between rural and small urban areas. The author concluded that the size of a transit agency is important at the time of adopting new fuel technologies. Mattson (2012) also found that larger agencies were more suitable to using alternatively-fueled vehicles. In addition, agencies considered cost savings as one of the most important factors when deciding the type of vehicle to buy. They also were worried about fuel supply and costs associated with infrastructure.

Wang and Gonzalez (2013) evaluated the feasibility of electric buses for small and medium-size cities based on qualitative and quantitative data available from diverse sources such as literature reviews and manufacturers' information. An electric alternative was compared with diesel, diesel-hybrid, and CNG. Results suggested that the operation of electric buses is ideal for small and medium-size communities because of their zero emissions and low noise. However, electric buses indirectly affect the environment due to the amount of energy consumption and present some acquisition barriers because their purchase cost is higher than that of CNG and hybrid alternatives.

Finally, some authors have focused their research on the attitudes of bus and truck operators toward alternative fuels and their environmental impact. Saxe, Folkesson, and Alyfors (2007) found that safety concerns related to new hydrogen fuel cell buses is not

an issue among drivers and that operators were pleased with the reliability of the buses. Schweitzer, Brodrick, and Spivey (2007) evaluated attitudes of truck drivers towards technologies for idling reduction as a way to decrease emissions and fuel consumption and concluded that costs of technology and fuel are the key factors affecting the adoption of idle-reduction technologies. Meanwhile, Gota, Gosu, and Anthapur (2014) studied three leading bus companies in India to assess their attitudes and strategies on fuel economy and emission reduction, concluding that the assessed companies do not have a commitment to ensuring improvement in fuel efficiency nor have they implemented strategies to reduce emissions.

The Colombian Public Transportation Context

Public transportation services in Colombia are regulated by the national government through the Ministry of Transportation, which issues general guidelines for transit operations. However, city governments are responsible for issuing local regulations, assigning bus routes, and defining schedules, frequencies, and fleet sizes of bus companies (Ardila 2005). City governments also oversee the implementation of the general guidelines issued by the national government.

Transit services are provided by private bus companies. It is quite common that private bus companies do not own enough vehicles to meet demand. Therefore, most transit company business is to affiliate buses from owners, who must pay a fee for the right to operate the bus on the companies' assigned routes. The owners of the buses are responsible for their own equipment and bear the whole cost of acquisition and maintenance during the useful life of the buses. Almost 96% of public transportation companies own less than 10% of fleets (Ardila 2005).

Unlike other countries, urban public transportation in Colombia is not subsidized by the national government. To subsidize transportation with national funds is against the law. However, local authorities can subsidize public transportation with their own resources but, in practice, budget constraints do not allow it. Bus transit services are run by private companies that must finance their operations via the collection of fares.

In the last 15 years, Colombia has been working on its policies to update its public transportation systems. Six cities in Colombia (Bogotá, Medellín, Cali, Barranquilla, Bucaramanga, and Pereira) have bus rapid transit (BRT) systems, and a seventh city (Cartagena) is now implementing this service. However, the BRT systems have had many difficulties and challenges from their start (Kash and Hidalgo 2014). One of the main causes of those difficulties is related to the competition from informal services as well as the traditional and outdated transit systems that still operate in those cities.

City governments are now developing integrated transportation systems and promoting intermodality for passengers, including other services such as tram, metro, and cable cars. Currently, Medellín is the only Colombian city with integrated fares for multimodal services (i.e., cable cars, metro services and Metroplus, the BRT system in that city). Recently, Bogotá and Cali have begun implementing integrated fares for the different bus services in the whole city.

Methodological Approach

Discrete choice models are based on random utility theory, which states that consumers seek to maximize their utility (McFadden 2001). Therefore, it is considered that individuals or companies make rational choices. Discrete choice modeling could be used to model a bus transit owner's decision to adopt alternative fuel technologies. It is assumed that bus transit companies make the decision to adopt an alternative fuel technology based on its impact on their operations and, in particular, on their expected profit. This assumption is supported by the fact that in Colombia there are no clear policies encouraging the adoption of clean technologies for buses. Although Law 223/95 provides financial support for environmental conversion projects and Law 1715-2014 regulates the integration of non-conventional renewable energy, it is still expensive to implement clean technologies projects in public transportation, and policies are not focused on prioritizing their use. Indeed, companies have to totally assume the cost of transforming their current equipment or buying new alternatively-fueled vehicles.

In the long term, using cleaner alternatively-fueled vehicles impact costs associated with fuel consumption and vehicle maintenance. They also impact the social cost of operating transit vehicles by reducing negative environmental externalities. However, the social impact is frequently not considered by private companies.

In the proposed approach, each individual (bus owner or bus company) in the choice process faces a set of eligible alternatives (type of propulsion technology), which are described by a number of measurable and comparable attributes (e.g., acquisition costs, operation costs, range, engine power, and maintenance costs). Alternative A_j has an associated utility (U_{jq}) for individual $q \in Q$, described by the following:

$$U_{jq} = V_{jq} + \varepsilon_{jq} \quad (1)$$

The term V_{jq} is a systematic component of the utility that can be measured. This component is based on a number of measurable attributes, X_{jq} , specific to each alternative. Frequently, when the systematic utility is expressed as linear in the parameters, then $V_{jq} = \theta X_{jq}$, where θ is a set of parameters to be estimated.

The observed choice of the individual q is the one that maximizes utility (profit). On the other hand, ε_{jq} is a random component that reflects the uncertainty about attributes considered by consumers that cannot be observed by the modeler (McFadden 2001). This uncertainty can explain two situations that can be considered irrational, such as 1) two individuals with identical attributes and equal alternatives making a different choice, or 2) one individual who does not select the best apparent alternative (Ortuzar and Willumsen 2011).

Depending on the assumption about the random term in Eq. (1), different choice models will result. In particular, when an independent and identical Gumbel distribution is assumed for random terms, the classical multinomial logit model (MNL) is obtained (Ortuzar and Willumsen 2011). For this model, the probability that the individual q chooses the alternative A_i is given by Eq. (2), where $\lambda=1$ is normalized by the inability to be estimated independently from the set of parameters θ .

$$P_{iq} = \frac{\exp(\lambda V_{iq})}{\sum_{A_j \in A_{(q)}} \exp(\lambda V_{jq})} \quad (2)$$

Data

For this study, stated preference data were collected from bus owners and urban bus company CEOs. Trained interviewers scheduled appointments with the respondents to conduct the survey face-to-face using an online form to store the data. (Readers interested in the survey may contact the authors.)

Surveys were applied in the six largest Colombian cities. Due to the difficulty in obtaining responses from bus owners in Colombia and an expected high non-response rate, 12 scenarios were presented to each respondent to get a significant number of observations for modeling and to evaluate respondent perceptions on diverse situations. In each hypothetical choice scenario, respondents had to choose the best alternative among three or four alternatives presented. A fractional factorial design of 48 rows was obtained using the software NGENE® (Choicemetrics 2012). Four blocks were generated to get the 12 choice situations faced by each respondent.

The survey was structured in two sections. The first collected general characteristics and fleet information about bus owners and urban transportation companies; in the second, a stated preference experiment was presented.

The attributes considered to describe each alternative in the stated choice experiment were cost of purchasing a new vehicle chassis (*cost*), range reached with a full fuel load (*range*), the cost of a full fuel load (*refueling cost*), engine power offered as a percentage of the diesel bus engine power (*power ratio*), and the cost associated with fuel consumption for running 1 kilometer (*cost per kilometer*). Attributes are shown in Table 1 with the units and levels considered.

TABLE 1. Attributes and Levels Involved in Stated Preference Design

Vehicle	Midibus (~30 passengers)				Standard Bus (~40 passengers)				Large (~80 passengers)		
Fuel Type	Diesel	Hybrid	CNG	Electric	Diesel	Hybrid	CNG	Electric	Diesel	Hybrid	CNG
Cost (USD)*	\$58,997	\$88,496	\$78,663	\$108,161	\$78,663	\$117,994	\$103,245	\$142,576	\$117,994	\$167,158	\$152,409
	\$68,830	\$98,328	\$88,496	\$117,994	\$88,496	\$127,827	\$113,078	\$152,409	\$127,827	\$176,991	\$162,242
	\$78,663	\$108,161	\$98,328	\$127,827	\$98,328	\$137,660	\$122,911	\$162,242	\$137,660	\$186,824	\$172,075
Range (km)	580	760	420	260	680	910	510	300	760	940	560
	600	780	440	280	710	930	530	320	780	960	580
	620	800	460	300	740	950	550	340	800	980	600
Refueling cost (USD)	\$187	\$187	\$93	\$25	\$280	\$280	\$143	\$44	\$383	\$383	\$197
	\$202	\$202	\$108	\$34	\$295	\$295	\$157	\$54	\$398	\$398	\$211
	\$216	\$216	\$123	\$44	\$310	\$310	\$172	\$64	\$413	\$413	\$226
AFB/diesel power ratio (%)	100	100	80	70	100	100	80	70	100	100	80
	100	110	90	80	100	110	90	80	100	110	90
Fuel Consumption (USD/km)	\$0.32	\$0.25	\$0.22	\$0.09	\$0.41	\$0.31	\$0.28	\$0.15	\$0.50	\$0.41	\$0.35
	\$0.34	\$0.26	\$0.25	\$0.12	\$0.42	\$0.32	\$0.30	\$0.17	\$0.51	\$0.41	\$0.36
	\$0.35	\$0.27	\$0.27	\$0.15	\$0.42	\$0.33	\$0.31	\$0.19	\$0.52	\$0.42	\$0.38

* Cost includes only vehicle chassis, not body.

AFB = alternative-fueled bus

Source: Manufacturers and UPME 2012

Choice alternatives and attribute levels, which refer to values of the variables of each alternative and choice scenario, were customized for different bus classes. Customization was performed to guarantee that every respondent would face attribute levels according to the class of bus they owned. Three different bus categories were considered based on the bus fleets in Colombian cities—midibus with an average capacity of 30 passengers, standard bus with an average capacity of 40 passengers, and large bus with an average of 80 passengers. For the first two categories, four types of alternative-fuel buses were presented: diesel, hybrid, CNG, and electric bus. For the third category (large), the electric bus alternative was excluded because there was no information about the use of this fuel technology in this kind of bus. The attribute level values presented in the survey were collected from literature related to bus technologies, manufacturers, and fuel markets.

A total of 114 SP surveys were completed, which resulted in 1,368 choices. The diesel alternative was chosen in 45.1% of the choice situations, followed by the hybrid alternative, which was chosen in 21.5% of the choice situations (Table 2). These results suggest the presence of the “inertia phenomenon” (Cantillo, Ortúzar, and Williams 2007), the tendency to choose the known and mature technology while avoiding the new one. It could be inferred that respondents may consider the hybrid-electric bus as a second-best option because of the similarities with the diesel-fueled bus.

TABLE 2.
Number of Choices per
Alternative

Alternative	Number of Choices	Percentage
Diesel	617	45.1%
CNG	211	15.4%
Electric	246	18.0%
Hybrid	294	21.5%

The fact that the CNG alternative had the lowest number of stated choices in Table 2 could be explained by the fact that in the late 1980s in Colombia, there were many conversions from diesel and gasoline technology to CNG in urban buses. During that time, there were technological problems causing unexpected bus performance and economic losses for bus owners, generating aversion to the use of the CNG technology in buses, and respondents mentioned that in several occasions in the survey.

From a total of 114 respondents, 71 were owners or managers of buses linked to urban transit, representing more than 62% of respondents. The other 43 offered other transit services, as shown in Table 3. The midibus was the most common type of vehicle. The 114 surveyed entrepreneurs owned a total of 1,671 buses, most of which were powered by diesel fuel, evidencing its market strength and the popularity of this technology. Gasoline buses are still in operation, but they run in the oldest models. The average age of the fleet was close to seven years, an age at which vehicles require constant maintenance. For a summary of the main characteristics of the respondents that participated in the survey, see Table 3.

TABLE 3.
Respondent Characteristics

Total Respondents	114
Operating Mode	
Urban transit	71
Shuttle service	7
Regional transit	23
Mixed services	13
Buses per Fuel Technology	
Diesel	1,621 (97.9%)
CNG	40 (1.2%)
Gasoline	10 (0.9%)
Total	1,671
Average age of buses (yrs)	7.3

The research had two main limitations: 1) limitations associated with the use of stated preference data (Ortúzar and Willumsen 2011), and 2) lack of data for additional variables that could have an important role in explaining the reported preferences of respondents (e.g., maintenance-related and reliability variables).

Results

Different models were explored. A nested logit model was structured grouping alternative fuel buses in one nest and leaving the conventional diesel alternative in another. A mixed logit model also was structured. Also, due to multiple responses per respondent, a panel effect term was considered in the modeling. None of these approaches showed an improvement when compared to the traditional MNL, which was the most robust and simple model (see Table 4).

TABLE 4.
Results of MNL Model

Variable	Value	t-test	Robust t-test
Diesel ASC	Fixed	-	-
CNG ASC	-3.63	-2.77	-2.77
Electric ASC	-1.76	-1.52	-1.52
Hybrid ASC	-0.210	-1.25	-1.25
Cost (10 ³ US\$)	-0.02451	-6.60	-6.62
Fuel consumption (US\$/km)	-3.287	-2.45	-2.58
Power ratio electric	0.0187	1.30	1.29
Power ratio CNG	0.0322	2.11	2.11
Range – regional transit	0.000279	0.88	0.87
Observations	1368		
Final log-likelihood	-1728.647		
Final log-likelihood for EL model	-1754.997		
LR test	52.70		
χ^2 (8, 95%)	15.51		

Results are in line with microeconomic *a priori* expectations. Parameters related to monetary cost variables (*cost* and *cost per kilometer*) show a negative sign, evidencing the expected marginal effect. Moreover, it is expected that the sign of the *power ratio* parameter be positive, as it increases the expected utility.

Attribute range was included in a preliminary version of the model but its parameter was not significant ($p\text{-value} = 0.35$), suggesting that it was not relevant to respondents. The attribute was included in the model interacting with a dummy variable that was 1 if the bus operated in regional transit services, considering that urban buses in Colombia travel relatively short distances per cycle. For instance, in Bogotá (the capital and most sprawled city of the country), an average bus travels less than 180 km per day in about 5 cycles (Ardila 2005). Due to the fact that the shortest value for the *range* attribute in each choice situation and every alternative was enough to accomplish a regular urban route in a typical cycle with no need of refueling on the way, this is possibly not an issue for the respondents. However, the parameter estimated for the attribute *range* was not significant at 0.05 level.

The level of significance of the parameters in the model suggests that respondents are quite sensitive to cost variables. One interesting result is related to the *power ratio* parameter, which is expected to be important for bus owners in Colombia at the moment of buying a new vehicle because of the diverse topography in several Colombian cities that urban public buses must face daily.

There is a solid disincentive for bus owners to shift to CNG buses. The CNG alternative specific constant (ASC) is significant and has a negative sign, confirming the aversion to the CNG alternative discussed previously. On the other hand, ASC for electric and hybrid alternatives was not significant at the 0.05 level. Those results suggest that, *ceteris paribus*, there is not a clear preference for these kinds of fuel technologies when compared with the diesel alternative.

The marginal substitution rate between *fuel consumption* and *capital cost* states that entrepreneurs are willing to pay about \$1,401 US extra for a bus that allows saving 1¢ in terms of fuel consumption per kilometer. Considering, again, an average covered distance of 180 kilometers per day per vehicle, the additional capital cost could be recovered in about two and a half years of operation. On the other hand, they are willing to pay about \$700 US extra for increasing the engine power of the bus by 1% in relation to the diesel engine power.

It is important to take into account that the former relationship between fuel consumption and capital cost will depend on the average revenue-km of each bus agency. Agencies that use buses more intensively, with higher vehicle-km traveled, are expected to be more sensitive to fuel consumption. Other agencies maybe could be more sensitive to capital costs.

Utilities and market shares were simulated considering different scenarios for the cost of a typical diesel bus and keeping constant the remaining attributes with the average values shown in Table 5.

TABLE 5.

Parameters Used to Simulate
Market Share Varying Diesel
Bus Cost

	Diesel	Gas	Electric	Hybrid
Cost (10 ³ US\$)	-	105	133	114
Fuel consumption (US\$/km)	0.382	0.279	0.138	0.299
Power ratio	100	85	75	104

Figure 1 shows that the price of a new diesel bus has to be more than \$110,000 US to let the other alternatives take a significant market share.

FIGURE 1.

Variation of demand to cost
of diesel bus

Figures 2, 3, and 4 show the simulated market shares considering the different ratios of an alternatively-fueled bus cost to a diesel bus cost, using the parameters shown in Tables 6, 7, and 8. From Figure 2, it can be concluded that the cost of a CNG bus must be less than 70% of the cost of a diesel bus to have the highest market share among the reviewed technologies. Even if the cost of diesel and CNG are the same, the latter would have the lowest market share.

FIGURE 2.

Variation of demand to cost
of CNG bus

FIGURE 3.

Variation of demand to cost of electric bus

FIGURE 4.

Variation of demand to cost of hybrid bus

TABLE 6.

Parameters Used to Simulate Market Share Varying CNG Bus Cost

	Diesel	Gas	Electric	Hybrid
Cost (10 ³ US\$)	80	-	133	114
Fuel consumption (US\$/km)	0.382	0.279	0.138	0.299
Power ratio	100	85	75	104

TABLE 7.

Parameters Used to Simulate Market Share Varying Electric Bus Cost

	Diesel	Gas	Electric	Hybrid
Cost (10 ³ US\$)	80	105	-	114
Fuel consumption (US\$/km)	0.382	0.279	0.138	0.299
Power ratio	100	85	75	104

TABLE 8.

Parameters Used to Simulate
Market Share Varying Hybrid
Bus Cost

	Diesel	Gas	Electric	Hybrid
Cost (10 ³ US\$)	80	105	133	-
Fuel consumption (US\$/km)	0.382	0.279	0.138	0.299
Power ratio	100	85	75	104

In the case of the electric bus (Figure 3), it was found that if the cost of this technology is less than 120% of the cost of the diesel bus, it would be the alternative with the highest market share. Figure 4 infers that the highest choice probability for hybrid buses could be achieved if the hybrid bus cost is competitive when compared with the cost of the diesel alternative. For this purpose, the price of a hybrid vehicle could be similar or less than the cost of the diesel alternative.

Direct and cross elasticities were evaluated for every attribute in the model; results are shown in Table 9. The attribute whose variation causes the greatest impact on the choice probability for every alternative is the acquisition cost. In particular, an increase of 1% in the cost of a hybrid bus will cause a decrease of 2.17% in its market share. On the other hand, if the cost of a diesel bus rises by 1%, it will lead to a decrease of 1.10% in its market share. Even though direct elasticities with respect to cost are greater than 1 and could be viewed as very large, it should be noted that market shares for buses powered by alternative fuel technologies are currently very modest. These kinds of technologies are, right now, in the very elastic part of the demand curve. In contrast, the direct elasticity of demand respect to cost for diesel buses, which is the most mature technology, is shorter than the direct elasticity of any other technology.

TABLE 9.

Direct and Cross Elasticities
with Respect to Different
Attributes

Attribute		Diesel	CNG	Electric	Hybrid
Cost	Diesel	-1.097	0.879	0.879	0.879
	CNG	0.384	-2.190	0.384	0.384
	Electric	0.576	0.576	-2.695	0.576
	Hybrid	0.625	0.625	0.625	-2.170
Cost/km	Diesel	-0.694	0.563	0.563	0.563
	CNG	0.137	-0.781	0.137	0.137
	Electric	0.080	0.080	-0.372	0.080
	Hybrid	0.222	0.222	0.222	-0.761
Power ratio	CNG	-0.418	2.318	-0.418	-0.418
	Electric	-0.249	-0.249	1.141	-0.249

The demand for each alternative is less impacted by the variations in the *cost per kilometer*. Policies should be meant to encourage the choice for alternative fuel buses and must be oriented primarily on affecting the *cost* and then the *cost per kilometer*. Bus manufacturers could improve alternative fuel bus technology to offer higher power ratios and higher efficiencies in terms of the energy source consumption.

From the cross elasticities, it can be also inferred that the variations in the diesel bus attributes cause the highest impact on alternative fuel bus demand. An increase in the

diesel cost of 1% will lead to an increase of 0.88% in the demand for the alternatively-fueled buses. On the other hand, an increase in the diesel cost per kilometer will lead to an increase of 0.56% in the demand for the alternatively-fueled buses. The former results suggest that if proper incentives and policies are offered by policymakers and manufacturers, these alternatives could be substitutes for the diesel bus.

To encourage the shift from conventional fuel bus technologies towards cleaner ones, Colombian policymakers should formulate appropriate policies and stimuli. As variables related to cost were the most important, reducing or subsidizing the cost of alternative fuels (CNG, electricity), increasing taxes to conventional diesel fuel, and subsidizing purchasing costs or reducing taxes of alternative-fueled buses could be policy options to consider.

Conclusions

The model for estimating demand for alternatively-fueled buses in Colombia suggested that the most relevant attributes considered by private public transportation companies at the time of buying a new vehicle are those related to money. The most significant are purchase price and the cost per kilometer. According to results, *range* was not considered as an important attribute of the buses.

The results indicate that, *ceteris paribus*, diesel bus was the most attractive alternative. On the other hand, CNG technology was the least preferred by respondents, and it consistently got the lowest choice probability in the scenarios evaluated. CNG buses must be much cheaper than the diesel alternative to get an important market share. The second best competitor was hybrid bus.

To encourage the shift to cleaner technologies, policies aimed at reducing purchasing and operating costs for bus companies should be established. This could be achieved through subsidies or tax benefits.

In addition, to incentivize choosing alternatively-fueled buses, bus manufacturers and sellers could bring new fuel technologies closer to bus owners through information campaigns, advertisements, forums, demonstrations, and field or test drives. These strategies can counteract the effects of the bad experiences that bus owners and drivers previously had with the conversion to CNG.

Future research could focus on the effect of perceptions on the choice for alternatively-fueled buses. Safety and security perceptions, environmental concerns, and attitudes toward government policies related to clean technologies in buses, among others, could be considered. This could be done by using hybrid choice modeling including latent variables. Also, the possibility of combining different data sources such as stated and revealed preferences surveys to enrich the data could be considered.

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