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# Modeling of the behavior of alternative fuel vehicle buyers. A model for the location of alternative refueling stations

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ABSTRACT

This paper addresses the problem of estimating the infrastructure to be made available for refueling alternative fuel vehicles as a function of the profitability thresholds required by the investment. A methodology has been devised based on sales forecasts for alternative fuel vehicles. These methods use discrete choice models in which the factor of refueling infrastructure, rather than being considered simply as one more attribute of the model, acts as a constraint on the choice set for vehicle buyers. This methodology is used to estimate the infrastructure of hydrogen refueling stations and electricity charging stations for Spain (8,112 population centers) in 2030. Evolution of fuel cell vehicles over the years 2016 and 2030 is also estimated and compared with forecasts for countries such as France, Germany and the United Kingdom.



## Introduction

The transportation sector is responsible for a large share of the European Union greenhouse gas (GHG) emissions, and consequently it is a central goal of the European Commission in sustainability development strategies. The European Union is attempting to replace 10% of conventional fuels with biofuels, hydrogen and ecologically-sourced electricity before the year 2020 [16] and for 2050 has set the much more ambitious target of 60% reduction in emissions of polluting gases [10].

The use of Alternative Fuel Vehicles (AFV) to replace vehicles powered by internal combustion, is an alternative form of road transport that may provide, in the long term, reduction in GHG emissions and improvement in air quality in cities [19,21].

European Union member countries have decided to implement programs to further accelerate the introduction of

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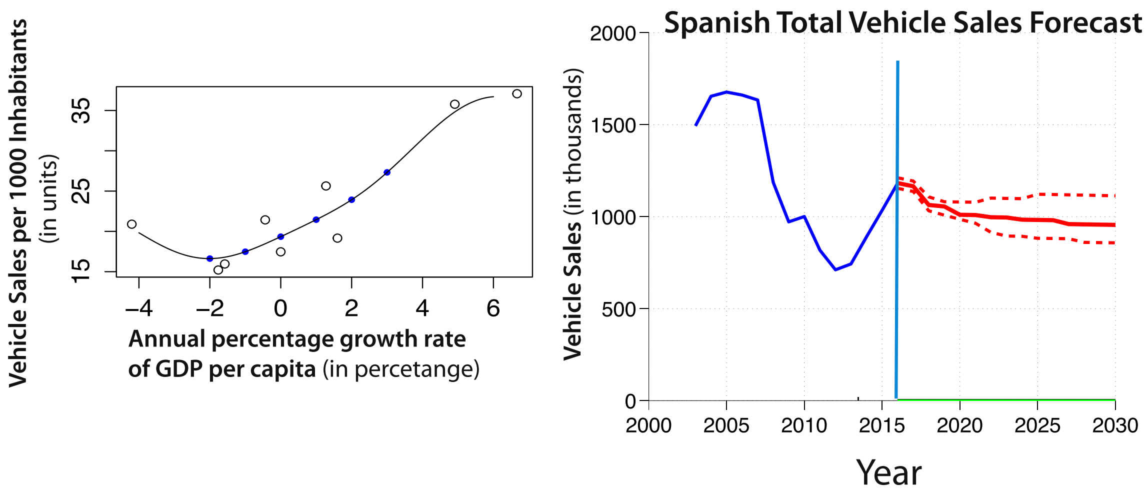


**Fig. 1 – Multiplier $\phi(\Delta GDP)$ for sales (on the left) and the forecast vehicles sales in Spain (on the right).**

AFV vehicles. The European Directive 2014/94/EU [17] establishes a common framework of measures for the deployment of alternative fuels infrastructure in the European Union. One of the main problems which must be addressed in the roll-out of the necessary infrastructure for the use of alternative fuels in transport is the so-called *Chicken -or- Egg dilemma* [13,21]. Consumers are not keen to buy alternative-fuel vehicles while the refueling infrastructure is hard to find, and refueling points will only become common when there are enough vehicles to make it worthwhile.

This study assumes that private enterprise will finance the roll-out of the refueling infrastructure if it considers that the investment required will reach a certain profitability threshold. This assumption removes the dilemma of precedence between supply and demand, and raises the question of whether the supply will generate sufficient demand, that is, whether the chicken will or will not lay an egg. Thus we call the approach the *the chicken or roster problem* as addressed in this paper.

The stated preference methods are the tools most widely used to analyze relevant factors in the market penetration of AFV. These studies use the marginal willingness to pay (WTP) and the analysis of market share in different scenarios to weight each of the factors. Martin Achtnicht and Hermeling [13], Hoen and Koetse [7] review these methods and show that availability of refueling stations is an essential factor. Hackbarth and Madlener [4]; Ito et al. [9] use this methodology to assess potential demand for infrastructure investment for AFV vehicles.

The literature considers the infrastructure as just another attribute of the utility of vehicles buyers. This paper, on the other hand, considers that the infrastructure limits the so-called *universal choice set*. We adopt a two-stage representation of decision making. In the first stage, the choice-set generation is simulated. The car buyers screen alternatives and eliminate those in which it is economically impossible to introduce the required infrastructure where they live. In the second stage, the buyers choose only from the alternatives remaining in the reduced choice set [12]. Finally, a sensitivity analysis of the profitability thresholds for the necessary investment in rolling out the infrastructure will allow the typology of the feasible infrastructure in the study area to be determined.

## Forecasting of alternative fuel vehicles sales by using discrete choice models

### *A basic approach*

This section describes the basic method[1] to predict the evolution of AFV as a function of the roll-out of infrastructure. This method assumes that vehicle sales satisfy the equation:

$$v_i^t = P^t \cdot \phi(\Delta GDP^t) \cdot \mathbb{P}(i/t) \tag{1}$$

where $v_i^t$ is the number of vehicles of type $i$ sold in period $t$ (in thousands of units), $\phi(\Delta GDP^t)$ is a multiplier which transforms the variation of GDP per capita in period $t$ into vehicles sold per thousand inhabitants and $\mathbb{P}(i/t)$ represents the market share of vehicle type $i$ in period $t$.

This method has been applied to Spain. Three scenarios are considered (one baseline case, one optimistic and one pessimistic) consisting of a combination of forecasts of population development $\{P^t\}_{t\geq 2016}$ and of the $\{\Delta GDP^t\}_{t\geq 2016}$. The population estimate was obtained from the INE (Spanish Statistical Office). The baseline case considers a final population of 45.4 million, 44.3 in the pessimistic case and 46.5 in the optimistic case. The left of Fig. 1 shows the estimate of the multiplier $\phi(\Delta GDP)$ using a Gaussian radial basis approximation and on the right of Fig. 1 the forecast for total vehicles sales $v^t = P^t \cdot \phi(\Delta GDP^t)$ for the three scenarios.

This study considers seven types of vehicle $i$ that are already available on the Spanish market, or will be in the near future. We have considered gasoline and diesel (conventional technology, CT), biofuel vehicles (BVs), natural gas vehicles (NGVs), hydrogen (fuel cell electric vehicles, FCEVs). There are

[1] The data used in this paper can be found at the following web address http://cort.as/f5Vw.

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