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Simulating early adoption of alternative fuel vehicles for sustainability

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ABSTRACT

We quantify the conditions that might trigger wide spread adoption of alternative fuel vehicles (AFVs) to support energy policy. Empirical review shows that early adopters are heterogeneous motivated by financial benefits, environmental appeal, new technology, and vehicle reliability. A probabilistic Monte Carlo simulation model is used to assess consumer heterogeneity for early and mass market adopters. For early adopters full battery electric vehicles (BEVs) are competitive but unable to surpass diesels or hybrids due to purchase price premium and lack of charging availability. For mass adoption, simulations indicate that if the purchase price premium of a BEV closes to within 20% of an in-class internal combustion engine (ICE) vehicle, combined with a 60% increase in refuelling availability relative to the incumbent system, BEVs become competitive. But this depends on a mass market that values the fuel economy and CO_2 reduction benefits associated with BEVs. We also find that the largest influence on early adoption is financial benefit rather than pro-environmental behaviour suggesting that AFVs should be marketed by appealing to economic benefits combined with pro-environmental behaviour to motivate adoption. Monte Carlo simulations combined with scenarios can give insight into diffusion dynamics for other energy demand-side technologies.

1. Introduction

Achieving sustainable energy policy requires rapid diffusion of new technologies i.e. smart grids, electric vehicles, photovoltaic, heat pumps, smart meters, etc. [1,2]. But it is not well understood whether consumer adoption patterns will support large-scale diffusion. One of the most difficult sectors to decouple from unsustainable fossil fuel use is transport. Globally, the transport sector's total final energy consumption is ~27% with a similar outlook towards 2035 [3]. Consumer acceptance of alternative fuelled vehicles (AFVs) such as hybrid electric (HEVs), plug-in hybrid electric (PHEVs), full battery electric (BEVs) and hydrogen fuel cell (FCs) vehicles is expected to play a major role in decoupling transport's ~93% dependence on liquid fossil fuels [1]. Yet a major area of uncertainty for energy policy is how to overcome consumer risk aversion and accelerate adoption of AFVs across global markets. Our ability to identify potential markets and incentivise early adoption will depend on understanding consumer heterogeneity including different preferences, lifestyles and other motivating factors that may influence adoption behaviour.

For AFVs little is known about the combination of factors that might shift a mass-market adopter into an early adopter category. The aims of this paper are to 1) synthesise and assess recent findings of early adoption behaviour, and 2) develop a

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Monte Carlo simulation model which is able to assess different combinations of technological and behavioural factors that might trigger large-scale adoption. This paper takes a novel approach by combining Monte Carlo simulations with scenario analysis, which could be used to assess a wide range of consumer behaviour for commercializing new energy technologies. The paper proceeds as follows: empirical review of global AFV markets, methods and data, simulation results and discussion and, limitations of analysis and further research.

2. Empirical review

2.1. Alternative fuel market

To gauge the potential EU market for BEVs, a recent industry on-line survey (N = 4760) covering Belgium, France, Germany, Italy, Spain, Turkey and UK was conducted [4]. Country level data was normalized by total adult population for each country to represent a pan-European demographic sample adjusting for differences in sample size at country level (overall margin of error for pan-European results were reported at 1.4%). The survey indicates that 16% of respondents were *potential first movers* most likely to buy or lease a BEV, 53% *might be willing to consider* meaning they are interested but less likely to purchase, and 31% were *not likely adopters* of BEVs. The survey further suggests that 1–2% of the potential first movers will be *early adopters*. When comparing the stated interest in AFVs against actual sales there is geographic variation. In 2009/10, global sales of HEVs, BEVs and PHEVs reached ~934,000 units representing 2.0% of the world's 45 million passenger vehicles [5]. In 2009, US sales of HEVs and PHEVs reached ~270,000 units, or 2.8% of total passenger vehicles sales [6]. The US accounted for nearly 40% of the global HEV market [6]. In the same year, European HEV sales were markedly lower at ~73,500 units, or 0.4% of total passenger vehicle sales [7]. This is primarily because of a more established EU diesel market that offers competitive fuel economy with petrol-HEVs but at a comparatively lower purchase price. Another reason is that consumer choices remain limited with around 8 HEV models available and only 3 in the non-luxury class. In the US, there were 8 HEV, 5 BEV, and 2 PHEV models available that year [5,6].

In 2009, China became the largest automotive market in the world reaching 13.6 million total vehicle sales, surpassing the 10.4 million sold in the US. Although, HEVs have been available in China since 2005, only ~1900 were sold in 2009, less than 0.1% of the passenger vehicle market [5,6]. This is likely due to the highest price differentials where the cost of an imported Japanese HEV is more than twice the cost of a domestic ICE. Conversely, the largest AFV market in the world is in Japan where combined sales of HEVs and PHEVs reached ~350,000 in 2009, or 10% of total passenger vehicle sales [5]. Fig. 1 compares the difference between total passenger vehicle market versus HEV and BEV sales by region showing the US and Japan commanding 89% of sales despite

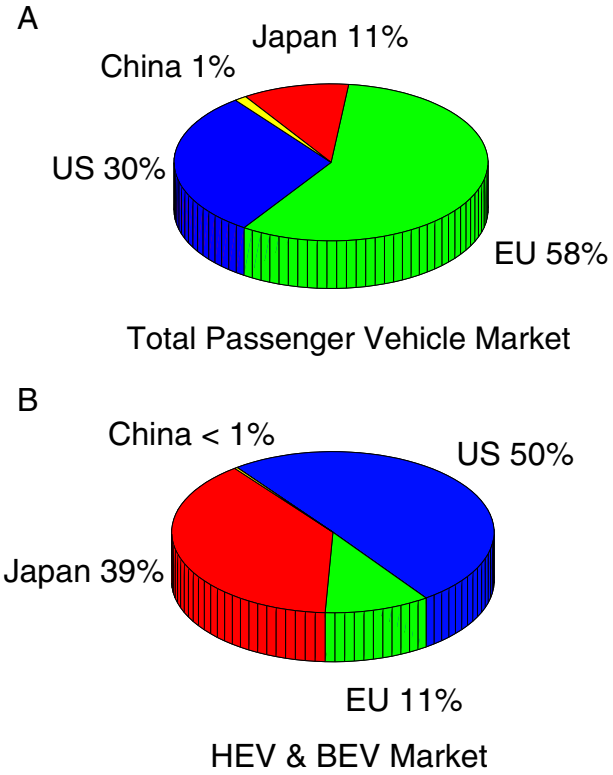

Fig. 1. A) Total passenger vehicle market, B) HEV and BEV sales by region in 2009. Calculated from data in refs [5–7].