Global Environmental Change 47 (2017) 76–87

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Perspective

# Modelling social influence and cultural variation in global low-carbon vehicle transitions

H. Pettifor[a,*], C. Wilson[a], D. McCollum[b], O.Y. Edelenbosch[c]

[a] Tyndall Centre for Climate Change Research, University of East Anglia, Norwich NR4 7TJ, UK
[b] Energy Program, International Institute for Applied Systems Analysis (IIASA), Laxenberg, Austria
[c] PBL Netherlands Environment Assessment Agency, Bilthoven, Netherlands

ARTICLE INFO

*Keywords:*
Social influence
Behavioural realism
Vehicle choice
AFV

ABSTRACT

We present a unique and transparent approach for incorporating social influence effects into global integrated assessment models used to analyse climate change mitigation. We draw conceptually on Rogers (2003) diffusion of innovations, introducing heterogeneous and interconnected consumers who vary in their aversion to new technologies. Focussing on vehicle choice, we conduct novel empirical research to parameterise consumer risk aversion and how this is shaped by social and cultural influences. We find robust evidence for social influence effects, and variation between countries as a function of cultural differences. We then formulate an approach to modelling social influence which is implementable in both simulation and optimisation-type models. We use two global integrated assessment models (IMAGE and MESSAGE) to analyse four scenarios that introduce social influence and cultural differences between regions. These scenarios allow us to explore the interactions between consumer preferences and social influence. We find that incorporating social influence effects into global models accelerates the early deployment of electric vehicles and stimulates more widespread deployment across adopter groups. Incorporating cultural variation leads to significant differences in deployment between culturally divergent regions such as the USA and China. Our analysis significantly extends the ability of global integrated assessment models to provide policy-relevant analysis grounded in real world processes.

## 1. Introduction

Global integrated assessment models (IAMs) are widely used to evaluate the costs, potentials and consequences of different greenhouse gas emission trajectories. Representing the global energy and land use systems linked to the broader economy, they provide valuable insights into the medium and long term effects of socio-economic development, technological change and climate policy (Krey, 2014). Although modelling on this scale is inevitably stylised, global IAMs provide insights into the consequences of policy choices (Clarke et al., 2014). These insights are generated by exploring robust features of uncertain futures based on scenario assumptions.

Vehicle purchase is a technology adoption decision that will strongly influence future energy and emission outcomes (Girod et al., 2013). The transportation sector is responsible for around 23% of energy-related $CO_2$ emissions. Despite innovations in low-carbon fuel technologies and policies to stimulate alternative fuel vehicle (AFV) adoption, transport emissions worldwide continue to grow faster than any other end-use sector. Around 80% of this increase is attributable to road vehicles (Sims et al., 2014). Vehicles are relatively short-lived capital assets and therefore vehicle fleet turnover opens up opportunity to adopt new types of technologies. However IAM projections suggest there are immense decarbonisation challenges within road transport with slow transition from conventional vehicles (CVs) to electric, biofuel, or hydrogen-powered AFVs. Strong climate policy as well as sectoral transport policies are needed to drive the transition from conventional to alternative fuel vehicles (Creutzig et al., 2015).

IAMs represent vehicle choice and transitions between fuels and vehicle technologies. With their necessary levels of aggregation, due to their global scope and long time frames, IAMs have a simplified representation of consumer choice. Consumers behave as individual rational agents making discrete choices between alternative vehicle technologies based on their preferences for cost and efficiency attributes within income constraints (McCollum et al., 2016; Mercure et al., 2016). As vehicles are expensive capital goods, income availability is a major source of heterogeneity between consumers and rises in income are strongly correlated with consumer's willingness to pay for more powerful vehicles (Mercure and Lam, 2015). In reality, consumer choices are based on a range of other non-financial and non-energy related criteria. There are many types of non-financial consumer

* Corresponding author.
*E-mail addresses:* H.h.pettifor@uea.ac.uk (H. Pettifor), charlie.wilson@uea.ac.uk (C. Wilson), D.mccollum@iiasa.ac.at (D. McCollum), Oreane.edelenbosch@pbl.n (O.Y. Edelenbosch).

http://dx.doi.org/10.1016/j.gloenvcha.2017.09.008
Received 27 January 2017; Received in revised form 17 August 2017; Accepted 25 September 2017

preferences, including current use patterns (people buy what they know), aesthetics (e.g., style, comfort, convenience) and performance (e.g., speed, reliability, safety) (Avineri, 2012; Mattauch et al., 2015). Modelled consumer choices reflect a response to changing technology and resource costs rather than other more complex and non-financial decision processes (Arneth et al., 2014; Mattauch et al., 2015). This limits the models' usefulness to policy makers if they cannot realistically simulate the effect on behaviour of different policy instruments (Rivers and Jaccard, 2005).

We focus on a particularly important aspect of consumer choice: social influence. Social influence is the process by which consumer attitudes and behaviours towards an innovation are shaped by interactions with others. Consumers demonstrate new technology and are particularly influential if they are perceived by others to have expert knowledge or experience (Friedkin and Johnsen, 1990; Lavine and Latané, 1996).

Empirical research shows that vehicle purchases are strongly socially and culturally determined. Vehicle purchases do not only satisfy financial criteria but also contribute towards self-identity, convey status to others, and enable group membership (Axsen et al., 2013; Schuitema et al., 2013). People rely on the opinion and behaviour of others around them to communicate not only the acceptability of owning particular vehicles but also to signal reliability and quality which is particularly relevant for vehicles with new fuel or body types (Adjemian et al., 2010; Gaker et al., 2010; Heutel and Muehlegger, 2010; Wiedmann et al., 2011). People especially rely on the opinion and behaviour of those within close social networks including friends, family, neighbours, and work colleagues (Adjemian et al., 2010; Aini et al., 2013; Axsen et al., 2013; Grinblatt et al., 2008; McShane et al., 2012). These social influences apply equally to purchases of conventional vehicles (CVs) and alternative fuel vehicles (AFVs) (Pettifor et al., 2017)

Consumer choice is also shaped by broader social beliefs and value systems that prevail within a given culture. This creates distinctions between countries and regions in terms of consumer behaviour and preferences for products (Bauernschuster and Falck, 2015; Caragliu and Nijkamp, 2016; de Mooij and Hofstede, 2002; Dwyer et al., 2005). Dwyer et al. (2005) show countries vary in terms of people's receptiveness to influences from social trends in consumption ("keeping up with the Jones"). Differences in social influence between countries are confirmed in a meta-analysis of studies examining social influence on vehicle purchases (Pettifor et al., 2017)

Global IAMs used to analyse policy effectiveness need to capture the social and cultural influences that shape behaviour (Mercure et al., 2016). The effectiveness of policies to reduce emissions from private vehicles depends on incentivising consumer choices towards alternative fuel vehicles (AFVs). These consumer choices are not only discrete cost-optimising decisions but also socially and culturally determined.

The aim of this paper is to use a clear conceptualisation of social influence backed by strong empirical evidence to improve the behavioural realism of global IAMs used in climate policy analysis. Our aim is not to improve policy simulation but to fill a major gap in the literature between contextualised empirical studies and stylised global modelling tools. We focus on introducing social influences on consumer preferences for new vehicles: both CVs and AFVs. We develop and implement a novel model formulation for social influence which uses empirical data from primary studies and introduces cultural variation between model regions. We implement this formulation in two global IAMs with different designs. We then run scenarios to test the effect of adding social influences. Our approach works within the constraints of cost-optimisation modelling in which consumers have perfect information about available alternatives (Trutnevyte, 2016). However we introduce 'intangible' costs to reflect consumers' non-financial preferences including towards risk and uncertainty. The result is a closer approximation between consumer choice and the models' necessarily stylised representations of decision making. Our efforts build on other research whose aim is to improve cost-optimising models' ability to represent real-world processes (Ekholm et al., 2010; Keppo and Strubegger, 2010; McCollum et al., 2016) .

**Table 1**
Summary of abbreviations used in this paper.

| | Abbreviations | | | Definitions |
|---|---|---|---|---|
| models | IAM | | | integrated assessment model |
| | .. | MESSAGE | | a global inter-temporal optimisation model |
| | .. | IMAGE | | a global dynamic recursive simulation model |
| vehicle types | CV | | | conventional vehicle |
| | AFV | | | alternative fuel vehicles |
| | .. | EV | | electric vehicles |
| | | .. | BEV | battery electric vehicles |
| | | .. | PHEV | plug-in hybrid electric vehicles |
| | .. | Other AFV | | other hybrid vehicles, biofuels, hydrogen fuel cells |
| heterogeneous adopters (based on Rogers, 2003) | IN | | | innovators |
| | EA | | | early adopters |
| | EM | | | early majority |
| | LM | | | late majority |
| | LG | | | laggards |

## 2. Literature review

### *2.1. Diffusion as social influence among heterogeneous adopters*

Consumer choices of most relevance to IAMs relate to technology adoption and subsequent use. The dominant theoretical framework used in the analysis of technology adoption is Rogers' diffusion of innovations (Rogers, 2003). This describes the process by which innovations diffuse as information on their attributes, costs and benefits is communicated among members of a social system and so reduces uncertainty and perceived risks of adoption. Roger's diffusion of innovations theory is built on empirical evidence from many studies of adoption in the USA between 1948 and 1973 all which show the classic bell shaped diffusion curve. A more recent review of diffusion of innovation theory and its modelling approaches confirms its continued relevance and importance (Meade and Islam, 2006). Characteristic within Rogers' frequency distribution is the use of point estimates (the mean and standard deviation) to divide the distribution of adoption propensities into 'ideal types' referred to as adopter groups (Fig. 1). Innovations appeal initially to innovators (IN) who seek novel performance attributes and have a high risk tolerance. Based on a synthesis of empirical research, Rogers (2003) generalises the IN group to consist of the first 2.5% of potential adopters. Assuming adoption propensities are normally distributed, this IN group occupies the area two or more standard deviations (sd) *below* the mean (Fig. 1). Diffusion has two key elements relevant here: (1) social influence; (2) heterogeneous adoption propensities.

There are many types of social influence. Examples include

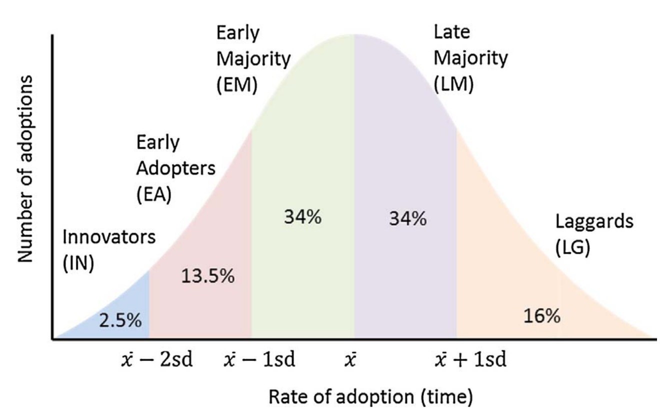


**Fig. 1.** Identification of adopter groups by Rogers (2003).