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EXPLORING THE SOCIETAL IMPACTS OF LOW CARBON VEHICLE POLICIES

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ABSTRACT

Recently there has been considerable interest in low carbon vehicles (LCVs) driven by the significant greenhouse gas (GHG) emissions from conventional vehicles that contribute to climate change. A number of technologies are now commercially available, and policies are being implemented in order to encourage a successful market penetration. It is the concern of this paper that these policies may bring about some disproportionate impacts in society due to the changes in mobility that they will incur. An ethical framework was established that recognises two conflicting arguments. Firstly, the moral obligations of climate change that requires us to reduce our carbon emissions and secondly the right to preserve some degree of the mobility from car ownership that we currently rely upon. It was found that some policies would result in significant emission reductions. However, other indicators suggested a negative impact on the opportunity of owning a vehicle. Recommendations for policy and model improvements are proposed so that a methodology can be developed that takes into account limitations and moral considerations. In this way, policies that are both robust to ethical criticism and successful in achieving a sustainable LCV market may be identified.

Keywords: Low Carbon Vehicles, Modelling, Ethics, Policy

INTRODUCTION

For over a century, car use has continued to grow in developed countries such as the UK and US. It has developed to a point where car ownership is no longer viewed as a luxury, but as a necessary part of maintaining current lifestyles. Car ownership is a means to mobility that gives many advantages over other modes, including flexibility and independence. Moreover, with many political decisions regarding transport and infrastructure since the mid-20th century being biased towards car ownership, some journeys are almost impossible without a car. However, over the last few decades there has been growing recognition and concern over the potential impacts of climate change caused by anthropogenic greenhouse gas (GHG) emissions, and one of the major sources of these are our cars. As such, governments are introducing policies to facilitate a transition to lower carbon vehicles (LCVs).

Although the automobile industry has been very much a free market up until now, these policies are being implemented to stimulate the market for LCVs that is currently stifled by their comparatively high purchase prices and often inferior attributes to conventional vehicles, namely the fossil fuel powered Internal Combustion Engine Vehicle (cICEV). The concern that has driven this work is that although these policies and technology shifts are necessary, they may have a disproportionate negative impact on those in society who are already worst of, by reducing their opportunity to own a car and thus affect their mobility needs. This concern has been explored over a short time period using a unique interdisciplinary approach combining system dynamic modelling techniques, policy appraisal and ethical analysis. When models have been used in the past, the success of a policy is considered by market penetration or GHG reduction only. This paper claims that it matters how this is achieved and who is affected, so considers the impact the policies have on purchase cost of cars and changes in market shares. However, what is not considered in this paper is the effect of the policies on, or interaction with, modal and behavioural shift. Despite the important role of these aspects in transport decarbonisation, their inclusion is outside the manageable scope of work.

Following a brief background to climate change and uptake policies, the remainder of this paper is separated into three sections. Firstly, an ethical framework is established that argues governments have obligations to the mitigation of climate change, but also that these must be balanced against individuals' claims to car ownership, with a focus on those already worst off in society. The middle section is a case study example of Californian uptake policies. It comprises of a description of the model and policy scenarios used in this work followed by an explanation of the model outputs and subsequent findings. Finally, are the conclusions from this work, which link together the ethical framework and modelling findings, in order to make recommendations for policy amendments and model improvements.

BACKGROUND

The IPPC fourth assessment report on climate change (Solomon et al. 2007) confirmed that it is 'highly likely' that anthropogenic emissions are contributing to an observed increase in temperatures since the industrial revolution. If these temperatures continue to rise and we experience an increase of over 5^{o}C, we may well experience devastating and life-threatening change. The extent of this threat has lead to global agreement on the reduction of emissions through the Kyoto protocol and more recently the Copenhagen agreement that we should work to limit any reduction in temperature to 2^{o}C, even though the detail as of how are yet to be decided. Globally, the transport sector is one of the largest sources of GHGs, and accounts for approximately 15% of overall emissions (ITF 2010). Road transport makes the most significant contribution to this, and in most OECD countries, emissions are dominated by passenger cars. When considering a projected three to four-fold increase in global passenger mobility by 2050 (ITF 2011) this is an area of huge potential for meeting emission reduction targets, or indeed, preventing emission increases.

In the UK, 12% of emissions are from passenger cars (DfT 2011a) and in California (where the case study in this research is based), passenger cars account for 28% of emissions (CARB 2011). California has a population about half the size of the UK, but with almost two thirds the amount of automobiles, although they are of a similar land area. Additionally, private car is the transport mode used most frequently by over half of the UK population (DfT 2011b) and 70% of Californians (Caltrans 2002). Culturally, both regions value civil liberties, recognise anthropogenic climate change and have comparable relationships with the automobile. Although some practises and attitudes regarding car ownership and use do differ, it is assumed in this work that this comparison generally holds true so findings may be transferable. One major difference is the price of fuel, which will affect any payback period for an alternative fuel vehicle.

The current powertrain used widely in personal cars is the internal combustion engine (ICE), which is most commonly fuelled by petrol or diesel. With some small alterations to the engine, lower carbon fuels can be used, most notably natural gas and biofuels. However, the focus of this paper, and of many governments, is the alternative powertrain of the electric motor, powered by either mains electricity or hydrogen fuel cell. There are only four vehicle options considered directly in this paper, the conventionally fuelled ICE vehicle (cICEV) and three pro-electric models, hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PiHEV) and battery electric vehicles (BEV).

Low Carbon Vehicle Uptake Policies

International LCV policies are driven by GHG reduction goals and managed by the UN Environment Programme and the World Forum Harmonisation of Vehicle Regulations. Individual countries then translate these into their own laws. This work has identified five generic policies related to LCV uptake that are being adopted. The policies cover barriers to LCV uptake on both the supply (manufacturers confidence to invest in innovative LCV technologies) and demand sides (public acceptance of the transition, including changes in costs and utility). Some may cover both or interact between them. For example, demonstrations are required to prove the technologies to the consumer and build confidence, that in turn assures manufacturers of a viable business case, or building infrastructure assures both consumers and manufacturers of the government commitment to a low carbon fleet.

Supply Side Policies

Supply (technology push) policies, are aimed at manufacturers and suppliers in order to ensure the development of the technologies and fuels to market readiness, alongside the creation of a sustainable supply chain. This is important because for mass adoption consumers need to be confident that any new technologies will not only be safe, reliable, economically viable and fit for purpose, but also that they will continue to be so for the foreseeable future. Thus, in order to ensure that manufacturers are incentivised to research LCVs with a common agenda and are committed to build an LCV market, the government must introduce policies that support:

- *Competition and Collaboration* to ensure aligned but commercially fair R&D programmes;
- *Regulation* that sets legally binding targets, penalties and incentives for manufacturers related to emissions and technology.

Demand Side Policies

In the context of encouraging the uptake of LCVs, demand side policies are necessary to overcome the barriers of economics, behaviours and perceptions currently prevent the development of a successful LCV market. From the consumer perspective, the attributes of LCVs differ from (and are less adequate than) those of cICEVs in the areas of cost (running and purchase), infrastructure provision (recharging/fuel availability and convenience) and utility (technical attributes including range, power and comfort). Thus, the policies to overcome these can be grouped into three categories:

- *Fiscal Measures* to overcome issues of cost;
- *Facilitating Adoption* to overcome inadequate infrastructure; and,
- *Raising Awareness* to ensure consumers have correct information regarding vehicle technologies, in order to assess their needs and alter attitudes and behaviours.

Policies Considered in this Work

Research being carried out parallel to this work (Harrison forthcoming a) has suggested that *Regulation* and *Fiscal Measures* may have the most disproportionate impacts on society, and are arguably the two that are being given the most prominent implementation. As examples of these, this paper focuses on policies of the California Environmental Protection Agency Air Resource Board.

The Low and Zero Emission Vehicle (LEV and ZEV) Regulations (ARB 2012a, 2012b) focus on the manufacturer to reduce the average fleet emissions of GHGs and sell increasing shares of ZEVs, which include both BEV and PiHEV, by incurring civil penalties for non-compliance. This requires manufacturers to achieve a certain number of GHG and ZEV credits. GHG credits are calculated annually by the difference between the standard government target and actual sales-weighted fleet emission average. The ZEV credit target for a company is a percentage quota of non-ZEV sales from the previous six years and credits are awarded to the company for ZEVS produced and sold. A $5000 fine per negative credit (over 5 years for GHG and 3 years for ZEV) is incurred. These are very similar to the European Average Fleet Emission Regulations, which enforce fiscal penalties on manufacturers for every extra g/km CO_2 over average fleet targets.

Secondly, we consider the California Clean Vehicle Rebate Project (CCSE 2013), which is in place to represent Fiscal Measures. This is funded by the California Air Resources Board and provides $42m for the period 2009-2013 (with a likelihood of extension to 2015) to give rebates of up to $2500 to customers who purchase or lease eligible zero emission or plug-in hybrid vehicles. This is similar to the UK Plug-in Car Grant that currently gives government subsidies of up to £5000 at the point of purchase of eligible plug-in vehicles.

THE ETHICAL FRAMEWORK: A BALANCING ACT

This research addresses a concern that transport GHG emission reduction policies and the opportunity for car ownership (as a means to mobility) may be in conflict. In this section an ethical framework for such policies is proposed, and these issues are discussed in more depth in other work by this author (Harrison forthcoming b). In this section, high level arguments regarding obligations to climate change mitigation and claims for car ownership are summarised, before offering a balanced solution to the conflict.

Obligations to Climate Change Mitigation

It is not controversial to say that humans are responsible for contributing towards climate change, and that it will harm a significant number of people across the world, both those alive now and future generations. The extent that humans can be held accountable and how to respond is the more disputed ethical debate. Climate change poses a number of philosophical challenges as it addresses responsibility, justice, rights and harms. Climate Ethics is an emerging field, which has gathered momentum alongside public and political interest in climate science, but is still in its infancy, leading on from more established theories of environmental ethics that became popular in the 1960s, for example 'Tragedy of the Commons' (Hardin 1968). However, a number of ethicists believe that it is the interdisciplinary complexities of climate change that proves to be the greatest obstacle. For example, Stephen Gardiner terms climate change as a *perfect moral storm* due to 'the convergence of a number of factors that threaten our ability to behave ethically' (Gardiner 2006), and Dale Jamieson suggests that we need to develop new values and conceptions of responsibility to motivate people to respond to climate change (Jamieson 1992). Moreover, general accountability for our choices and actions are all still in much debate in the wider applied ethics community.

Further issues within climate change ethics include the economic case for and against acting (Lomborg 2001, Stern 2006), uncertainties within climate modelling (McKinnon 2009) inter-spatial and inter-generational impacts (Caney 2009, Moellendorf 2009), subsistance and luxury emissions (Odenbaugh 2010, Shue 1993) and our requirement to not 'do nothing' (Garvey 2008). The case for individual responsibility is explored by many authors (Butler 2010, Cripps 2011, Hillar 2011, Hourdequin 2010, Nolt 2011, Sinnot-Armstrong 2005) and covers a number of arguments such as over-demandingness and unreasonable sacrifices, ineffectiveness or importance of individual actions, intentional or consequential virtues and lock-in of carbon intense lifestyles and infrastructures. This paper is not designed to be an in depth discussion of climate ethics, but accepts that the gathering catalogue of work on this subject generally agrees that Western governments are morally obliged to take action to prevent or restrict carbon emissions and work towards both climate change mitigation and adaptation. Alongside this there is a weak claim that individuals are obliged to reduce personal emissions but obligations lie more strongly towards ensuring that governments are successful in fulfilling their obligations to implementing climate change mitigation and, once in law, to follow legal policies.

Claims for Car Ownership

Although there is a gathering body of work regarding automobility (see Featherstone, Thrift and Urry 2004) and the ethics of mobility (Martens 2008, Mullen 2012, van Wee 2011), there has been little written (in philosophical terms) regarding rights of car ownership directly. Work on the ethics of driving has been tackled by Rajan (2007), who suggests that the normative view of driving is a positive one as it provides freedom and well-being, supports key beliefs regarding autonomy and can be used as a 'social equalizer'. However, because of this a blind-spot exists, which leads to the automobile being so ordinary and accepted that it's 'conceptualization as a unique theoretical subject' is often overlooked, which 'condition(s) us to accept it's importance without question'.

The accessibility a car provides not only adds value to our lives through enabling involvement in social and pleasure activities, but also may be a vital instrument in pursuing our deeply held projects, assuring our employment and security, and allows us a freedom of movement in many other areas important to us as individuals. The private automobile is seen as an essential part of everyday life for many citizens in the western world. To an extent, this is true regardless of socio-demographics. The widespread availability of the automobile is seen by philosopher Karl Popper as a massive benefit to society and an example of "great revolutions… (which) cannot be foreseen by anybody" (Popper and Bosetti 1997). Popper was contrasting this with the social revolutions that Karl Marx believed he could predict, referring to the "Henry Ford revolution, which made motor cars available not only to millionaires but to workers". In fact, it is most difficult for one to imagine what the world could be like if the car had not been invented.

Since the first cars and roads were introduced around a hundred years ago, and the internal combustion engine dominated, our infrastructure and our culture have co-evolved. Numerous political decisions have indirectly cemented the car's place in our society (e.g. cuts to rail networks and out-of-town shopping centres), to the point of creating a 'lock-in' to car ownership for many. It may be argued that some members of society rely so heavily on their access to a private car, that their standard of living may be unfairly reduced if that access is prevented or diminished in some way. For the majority of people, it is not controversial to say that owning a car is advantageous, and a number of constraints may force one into requiring owning a car, such as distance from amenities and car-focused infrastructure. Further weight may even be given by preference, though this is a weak claim. There are certain segments of society that may have special or stronger claims than others for the preservation of car ownership[1]. The strongest depend upon personal mobility (related to any physical disabilities they may have), though could also be through levels of current use (for maintaining social relationships, work commitments, availability or cost of other modes). However, even if some people do have a stronger claim for car ownership, it does not necessarily follow that others, with weaker claims, do not have any right, nor that it is an absolute right that must not be violated. It is not the intention of this work to suggest that car ownership is the only option for travel. Indeed, many people are not able to or do not wish to own a car. For now though, the

[1] One may argue that many people feel that they have a special claim, and allowing for them could be a slippery slope. However, just because we allow for one claim, it does not follow that we would be committing to allow all claims, and that we should therefore slide all the way down the slope. See, for example Williams (1995) and Govier (1982).

question of whether cars *should* be allowed at all is put aside, though it is acknowledged that there are many reasons why we may wish to move towards a less car-oriented society, from environmental and safety concerns to social inequality (Sloman 2006).

Balancing the Conflict

This work does not want to compromise carbon reduction targets as irreversible climate change must be avoided. On the other hand, there is currently such heavy reliance on the automobile that climate change mitigation policies may place unfair burdens on some people, despite the major contribution to harmful carbon emissions. This leads to a conflict that must be addressed within climate change policy. If low carbon vehicles are introduced and their market penetration is supported through the policies of Regulation, Competition and Collaboration, Fiscal Measures, Facilitating Adoption and Raising Awareness, the impacts these may have on specific cohorts of society need to be identified and address. Some will find it easier to retain utility with an LCV, some may be greatly disadvantaged by LCV ownership or the uptake policies designed to encourage it (such as increased costs of cICEV).

A reduction in our ability to run a vehicle, or choice regarding that, may be acceptable for climate change mitigation but what is concerning is that the impacts may be disproportionate across society, creating new inequalities and widening existing ones, as well as unfairly impacting on the worst off. Such considerations may in some cases outweigh concerns of climate change or at the very least demand some amendment to the policy in special circumstances. There are already numerous examples of this in public policy, such as council tax discounts and exemptions, disability access regulations and the semi-controlled free market. Therefore, to reconcile climate change obligations and mobility rights, this paper assumes an ethical framework with a long term aim to decarbonise transport, and a short term aim to minimise the impact on car ownership and use. This is particularly important for those who are already the most vulnerable in society and have strong claims for ownership.

MODEL METHODOLOGY AND DESCRIPTION OF FINDINGS

Background to Modelling LCV Uptake

There have been a number of academic studies modelling the likely uptake of LCVs and identifying the barriers, dating back to the 1980s. More recent uptake models study the impact of policy options designed to overcome these barriers on successful market penetration. Some studies consider generic AFVs through assigned attributes (such as drive range, performance, fuel availability) whereas others may concentrate on specific technologies. Not all models explicitly look at market share or uptake (Dagsvik et al 2002, Greene, Duleep and McManus 2004), but also the impact on economics and environment (Ahn, Jeong and Kim 2008, Contrerasa, Guervi and Possob 2009), or consumer preferences (Batley, Toner and Knight 2004, Beggs, Cardell and Hausman 1981, Brownstone, Bunch and Train, 2000). Many studies agree that even though cICEV will continue to dominate in the immediate future due to its current strong and widespread existence and infrastructure, coupled with higher costs and deficient AFV attributes, a slow but successful introduction of AFVs is possible (Supple 2007) and will effectively lower fuel consumption and decrease emissions (EST 2007, Kazimi 1997, Karplus, Palsev and Reilly 2010). Most studies agree that the market penetration is dependent on technology improvement but is also unlikely without co-ordinated policy intervention.

Tipping points of policies are important to understand, though they are dependent on the parameters used in the model (Shepherd, Bonsall and Harrison 2012, Struben and Sterman 2008, Supple 2007). On the demand side, fiscal policies such as subsidies (Kazimi 1997, Leiby and Rubin 1997, Janssen et al 2009) cheaper fuels (Collantes 2010) and tax reductions (Mabit and Fosgerau 2011, Potoglou and Kanaroglou 2007), can be effective in stimulating a market, however, subsidies may only work in the short term or under conditional marketing conditions (Shepherd, Bonsall and Harrison, 2012). Building infrastructure may be more important than subsidies (Kohler et al. 2010). Softer policies, such as parking incentives, are not as significant (Potoglou and Kanaroglou 2007), though influencing consumer behaviour and attitude change through word of mouth is (Walther et al. 2010, Shepherd, Bonsall and Harrison 2012, Struben and Sterman 2008, Janssen et al. 2006). Policies aimed at manufacturers are required for success, (Walther et al. 2010, Zhang, Gensler and Garcia 2011), such as policies to increase R&D, expand vehicle production and infrastructure (Leiby and Rubin 1997) and a large and early range of AFV across segments and body types is required (Greene, Duleep and McManus 2010).

However, it is of note that none of the mentioned papers have been explicit of any concerns of how the policies may impact across society – which segments of society are affected and to what extent. The concern that is addressed in this research is that because of this, many have recommended policies focused on achieving the driver for the model (i.e. emission reduction, market penetration), without assessing the risks they may impose on an individual level. As such, using models are subject to similar criticisms as cost benefit analysis, which while used widely in policy making, it is suggested should be accompanied by an ethical appraisal of both process and impacts (Gardiner 2011, Harris 1997, Thomopoulos, Grant-Muller and Tight 2009, van Wee 2011). The driver of this concern is that for some, there is an intuition that it does matter where the impacts are felt, and this is not readily identifiable in a purely quantitative process. Furthermore, these may be a heavy reliance on the point of view and knowledge-base of the actor responsible and is dependent on the parameters, design and focus of the assessment. Although this may be acceptable if overall welfare is increased, should one segment of society be found to become disproportionately worse off in a new situation created by the introduction of a policy, does it remain acceptable? Such arguments form debate for and against utilitarian approaches to public policy decision making. This concern may be even more prevalent when this segment is already worse off in some way.

Thus, in this research, this theory is tested with a case study example (Walther et al., 2010). This model was chosen, not just because it examined a particular policy that was of interest to this research but also because it contained a number of desirable features, such as word-of-mouth effects (Struben and Sterman 2008), a discrete customer choice model (Brownstone and Train 1999). and a level of detail in the vehicle market that enables deduction of impacts on different segments of society.

Background to Case Study

The case study selected for this research (and used with permission of the lead author) is a recent example that considers *Regulation* through a detailed and complex system dynamic model (Walther et al, 2010). This study is concerned with assessing the Californian LEV and ZEV Regulations as described previously. Although the regulations target manufacturers with the responsibility to meet regulations, rather than leaving it direct to consumer choice, it must not be overlooked that the strategy that the manufacturer chooses may still give choice to the customer and thus fail in meeting regulations. Walther et al use the model to assess different strategies in meeting these regulations in regard to customer demand and minimising civil penalties in the period to 2021, identifying three GHG strategies (vehicle or fleet adjustment, or both) and four ZEV strategies (conservative or aggressive, with or without BEV) across the powertrains (ICE, HEV, PiHEV and BEV) and segments (extra small (XS), small (S), medium (M) and large (L)). These can be applied in any combination, to assess which were most successful in meeting the regulation requirements at lowest cost to the manufacturer.

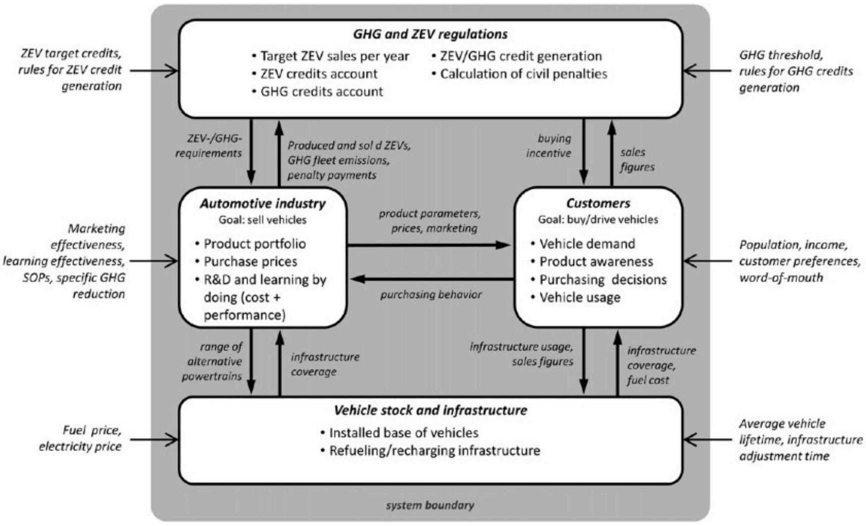

Figure 1: Structure of the Model (Walther et al, 2010)

What follows is a brief overview of the original model, but for further information, the reader should refer to the original paper. The model illustrated in

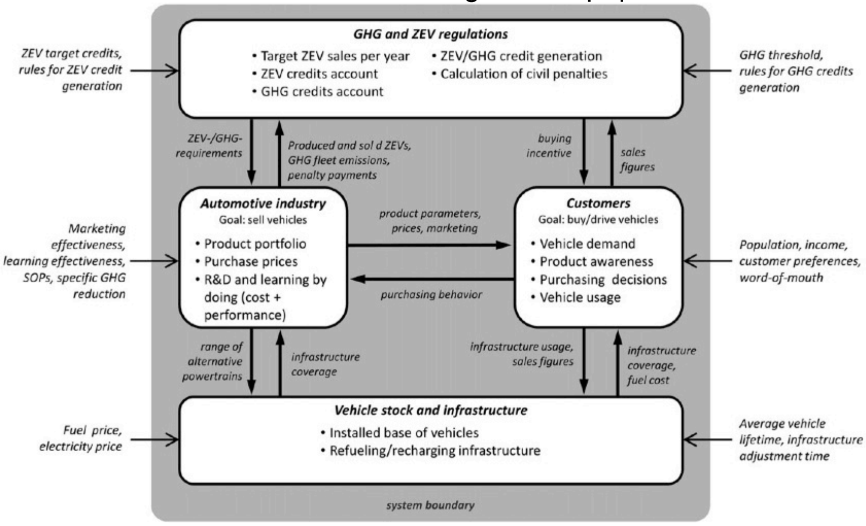

Figure 1 comprises of four modules, which are; *Regulations*, *Industry*, *Customers* and *Infrastructure*. The *Regulations* module has a complicated structure designed to calculate credits and civil penalties through sales (from the *Customer* module) emissions and ranges of ZEVs (from the *Industry* module). These outputs feed in to the *Industry* module and combine with purchaser behaviour (from the *Customer* module) to predict adjustments in vehicle purchase prices and fuel consumptions and emissions from the GHG regulations, taking into account learning through experience. ZEV adjustment impacts are also calculated in this module, taking into account targets, actual sales, vehicle range, and costs of new technologies. Vehicle demand is calculated in the *Customer* module, as a function of population and income, with a purchase probability based on customer awareness (through marketing and word of mouth, and vehicle range availability and utility feeding into a choice model (from outputs of the other modules). Both the *Customer* and *Industry* modules feed into the *Infrastructure* module, which models the interdependence of market share and network effects.

Case Study Adjustments and Limitations

A number of small additions to the original model were required in order to be able to retrieve the information required for this investigation. Firstly a switch was implemented that prevented the incurring of penalties, to create a "no penalty" baseline representative of a Business as Usual (BAU) scenario without any LCV policies in place. Secondly, a reduction of BEV and PiHEV purchase cost to imitate a *Fiscal Measures* type policy of a subsidy or rebate was included. Thirdly, it was made possible that the BEV models could become available at fixed dates rather than being conditional on infrastructure and range requirements. This was done to allow a fair comparison between certain policy interventions.

It is relevant to note at this point that some aspects of this research are limited by parameters of the case study itself. Firstly, it must be remembered that this model only represents purchases of new cars – not the second hand car market. This in itself is important as those who buy new cars are usually the more well off segments of society. Of particular concern, there are a fixed number of customers, which restricts the ability of customers to 'drop out' of the market by either not being able to afford a vehicle or change their general behaviours. There is also no underlying growth in the market, which could also impact on uptake of AFVs. Finally, the model is set up to mimic the actions of just one manufacturer rather than be representative of the automobile industry as a whole. In future research it may be relevant to explore the impacts of these limitations.

Scenario Development

Two baselines are considered based on scenarios used by Walther et al. One represents the 'conservative' introduction of ZEVs where their availability is dependent upon minimum infrastructural and technical (range) requirements (*Conditional Baseline)*, and the other is the 'aggressive' introduction where ZEV models are available on the market at fixed dates (*Fixed Baseline)*. Although the Fixed Baseline would be preferable for direct comparisons as the same vehicles would be available, the uptake trajectory was not realistic when compared against existing predictions (Table 1) for California (particularly for BEVs), whereas the Conditional Baseline had a much better fit, so this was used to compare impacts on market shares and emission reductions. Further to this, it is not wholly realistic that manufacturers would have been motivated to develop and release models at these fixed times, and are much more likely to carry out a conditional production strategy.

However, on investigation of the effect of policies on purchase prices, it became clear that this baseline was not appropriate, because as models are not available at the same points in time, prices were not comparable. Therefore to make this comparison we take the prices from the Fixed Baseline. Although this is not ideal, it is felt that it is acceptable in the circumstance as it will be representative of a BAU situation pricing and cash flow strategy of a manufacturer. In effect, the Conditional Baseline shows what would happen if no real effort were made to introduce new models, while the Fixed Baseline allows the filtering out of policy impacts rather than the effect of introducing new models at fixed times. It was found during these tests that the marketing effectiveness parameters had a much stronger effect than any other variable. As this was not the current focus of the work, the marketing effect used by Walther et al was retained in all scenarios. In future work it will be prudent to explore these effects in more detail as they could be representative of *Raising Awareness* policies.

SCENARIO	2020 SALES MARKET SHARE (%)		
	PiHEV	BEV	PiHEV + BEV
Californian Plug-In Electric Vehicle Collaborative (McCarthy et al, 2010)	N/A	N/A	2 – 6
US Department of Energy (Balducci, 2008)	N/A	N/A	~ 10
Boston Consulting Group (BCG, 2009)	29	2	31
Conditional Baseline	9.34	1.91	11.25
Fixed Baseline	22.1	16	38.1

Table 1:ZEV Market Share Predictions in 2020

To understand what influence subsidies may exert on ZEV market penetration, and help decide what parameters should be used in the research, sensitivity tests were carried out:

- *Standard_$45m* - $1500 for PiHEV and $2500 for BEV with a $45m budget that is equal to the current funds set aside in California.

- *Standard_6 years* - Subsidies as above, but with a 6 year unlimited budget.
- *Standard_Unlimited* - Subsidies as above but with an unlimited budget to 2030.
- *High_6 years* - A higher subsidy of $8000 (equal to the UK subsidy) for 6 years.

It was found that there is very little difference between any of these scenarios at either 2020 or 2030. The largest variation between scenarios was realized with the high subsidy, which yielded an increase in both BEV and PiHEV market shares, mainly at the expense of HEV, but as soon as the subsidy period ended the market share returned to almost the same trajectory as the other scenarios, as shown in **Error! Reference source not found.**. For this research, the fixed 6 year was used to compare to the baseline and regulation scenarios as is it possible that the California state will extend the scheme, and reflect this.

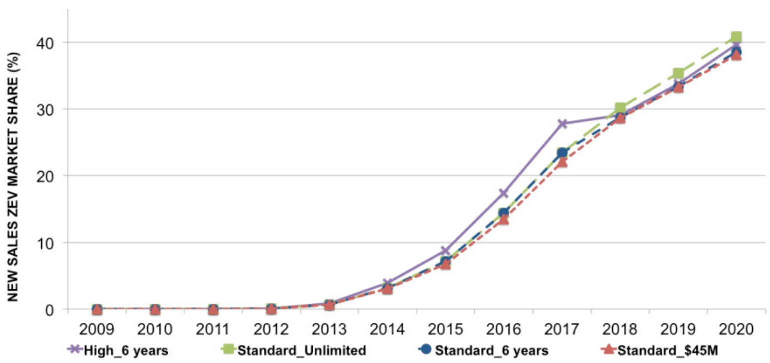

Figure 2: ZEV (PiHEV + BEV) market shares under subsidy scenarios considered

Three policy scenarios are tested. The first is the *Regulation* policy, which the model was designed around, and there are detailed and complicated dynamics associated with it. Second, the Fiscal Measures policy type is tested in the *Subsidy* scenario, replicating the current Californian Rebate scheme of $1500 for PiHEV and $2500 for BEV for a 6-year period. Finally, the two policy scenarios were combined into a *Both Policies* scenario. All input parameters are shown in Table 2.

INPUT PARAMETER		SCENARIO				
		Conditional Baseline	Fixed Baseline	Subsidy	Regulation	Both Policies
Model Availability (year)	ICE (XS, S, M, L)	2010, 2000, 2000, 2000	2010, 2000, 2000, 2000			
	HEV (XS, S, M, L)	2014, 2012, 2009, 2010	2014, 2012, 2009, 2010			
	PiHEV (XS, S, M, L)	N/A, N/A, R(60), R(75)	2016, 2015, 2012, 2013			
	BEV (XS, S, M, L)	I(0.5), I(0.6), R(200), R(400)	2011, 2012, 2013, 2015			
Penalties on		NO			YES	
Subsidy ($)	PiHEV	NO		1500	NO	1500
	BEV	NO		2500	NO	2500
Subsidy Duration		N/A		2011-2017	N/A	2011-2017

Table 2: Scenario Input Parameters (I=Minimum Infrastructure (%); R=Minimum Range (m))

Model Findings and Outputs

There are two key outputs of this model that need to be indentified and understood in order to satisfy the established ethical framework. Firstly, if GHG emission reduction targets met and secondly, if there any indicators of impact on inequality of opportunity for owning a car.

GHG Reductions

As a result of the increased uptake of LCVs realised by the policies, significant reductions in fleet average GHG emissions are witnessed by 2020. Figure 3 shows the average fleet GHG emissions (including ZEV propulsion energy emissions and non-ZEV tailpipe). Under the Subsidy scenario and Fixed Baseline this is a reduction of around 35gmile^{-1} of GHG saved and under the Regulation and Both Policy scenarios, the reduction is around 80 gmile^{-1}. Assuming an average annual mileage of 15,000 miles per year and a 10 year average life, this would equate to savings of 34 to 186 Mt GHG (respectively) from all new vehicles produced in the time period. The biggest emission reductions are made when *Regulation* is in place, as manufacturers are set a specific level to aim for within the model, and thus most emission reductions come from efficiencies made with ICE rather than introduction of ZEVs. However, the Subsidy scenario does not meet GHG targets by 2020, as there is no motivation for manufacturers to make efficiencies in ICE, HEV or PiHEV.

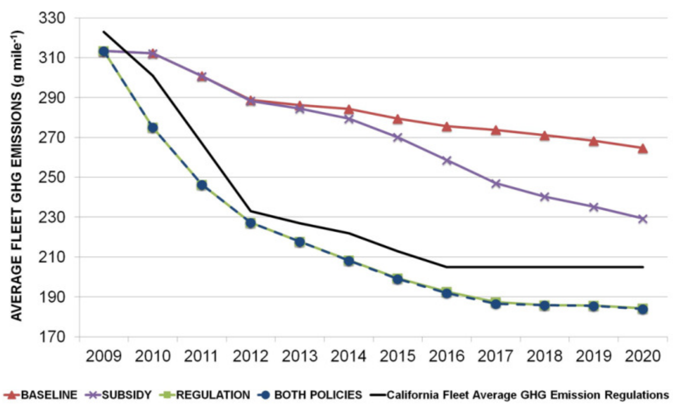

Figure 3: Reduction in GHG emissions (gmile^{-1}) under policy scenarios

Opportunity to Own a Car

In this paper, the model outputs that will be used as indicators of the opportunity to own a car are market share and purchase cost. Table 3 shows, not surprisingly, that compared to the Conditional Baseline, the policy scenarios result in much more successful BEV and PiHEV new market shares, and it is reassuring that this is the case as these policies are indeed being implemented. The Regulation policy was marginally more successful than the Subsidy policy, yielding 9.5% more PiHEVs and 17.8% more BEVs by 2020. When both were combined, this gave only a 1% increase in success, which reduced further in the period up until 2030. However, it is of note that there is very little difference between the Fixed Baseline and the Subsidy scenario, which was on average over the period to 2030 less than 2% for PiHEV and less than 4% for PiHEV. Although the Fixed Baseline is not realistic (as explained earlier), this could suggest that the introduction of models at specific times (and as early as possible) is more important than the Subsidy policy being in place. However, when looking at the difference in share in the last year of subsidy (2017), PiHEV is almost 5% more under the subsidy scenario and BEV over 10%. In fact this is the peak of the impact, as the difference reduces to under 1% by 2020 and is negligible by 2030.

Although this finding may initially suggest that subsidies are not effective, what this finding may indicate is that subsidies need to be stronger than those tested here to ensure that the learning curve is maintained after removal. Without LCV policies in place, manufacturers are assumed not to be motivated to bring in the LCVs at fixed dates, and so they are conditional on infrastructure and range attributes. As a result, by 2020 in the BAU conditional scenario, ICE retains an almost 50% market share, and EVs are little over 10% of the market. However, with policies in place, ICE market share reduces to around 25% by 2020 and EVs have captured almost half of the market, improving to over two thirds by 2030. There is very little difference between the Subsidy and Regulation cases, other than at both times the Regulation case has a smaller portion of ICE models. The subsidy shares are even closer to the fixed baseline, with all shares remaining within 1%.

SCENARIO		NEW SALES OF POWERTRAINS			
		ICE	HEV	PiHEV	BEV
2009		1,365,259	0	0	0
2017	Conditional baseline	860,734	527,186	10,688	0
	Fixed baseline	635,356	457,883	177,024	132,638
	Subsidy	623,002	450,591	184,032	145,460
	Regulation	586,969	466,845	191,605	158,021
	Both	574,955	458,887	198,688	169,614
2020	Conditional baseline	656,835	585,729	130,751	26,695
	Fixed baseline	424,666	442,801	309,484	224,455
	Subsidy	421,399	439,644	312,983	226,254
	Regulation	366,041	426,080	342,609	266,583
	Both	361,707	422,417	347,082	269,713
2030	Conditional baseline	37,8532	478,299	271,971	271,198
	Fixed baseline	89,915	121,983	703,458	484,644
	Subsidy	87,956	119,393.9	706,235	486,415
	Regulation	57,657	82,693.66	714,246	545,404
	Both	56,175	80,582.2	716,249	5469,94

Table 3: Powertrain new sales in 2017, 2020 and 2030

Changes in segment market shares are shown in Figure 4 and it would appear that having the LCVs policy in place will push the market into the XS/S segments rather than the M/L segments favoured in the baseline scenario. This may be a cause of concern as an indication that customers with legitimate claims for larger cars may be forced to downsize to a car that does not suit their needs, and are thus disadvantaged by the introduction. The effect of fixed introduction of vehicle models is even more obvious, as there is no difference between the Fixed Baseline and subsidy scenarios, and Subsidy has negligible effects on shares when applied in conjunction with Regulation.

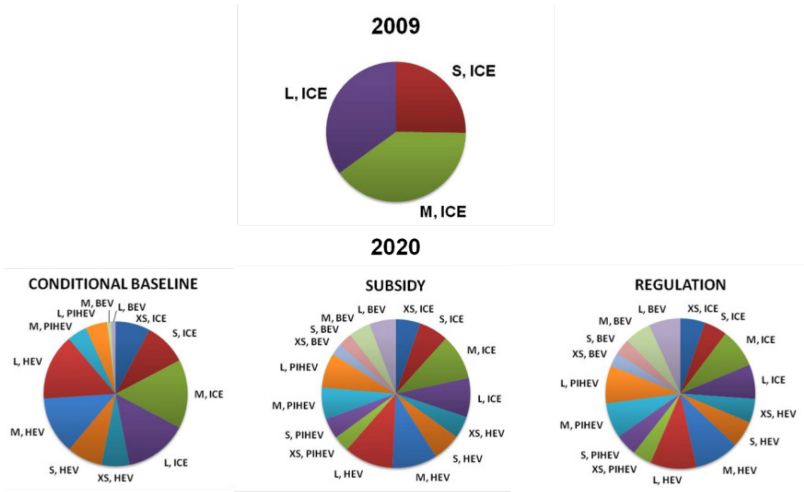

Figure 4: Market shares of all models

To further understand how certain sections of society may be affected by the LCV policies, attention now turns towards the changes in purchase prices over the time scales, shown in Table 4, where for simplicity, only the Fixed Baseline and Both Policies scenarios are given.

PURCHASE PRICE ($)	2009	2020			2030		
		Fixed Baseline	Both Policies	Variance (%)	Fixed Baseline	Both Policies	Variance (%)
Average	19,964	22,079	25,580	15.8	22,010	24,419	10.9
ICE	19,964	21,014	26,958	28.3	21,732	26,634	22.6
HEV	23,626[2]	19,880	23,481	18.1	17,762	21,474	20.9
PIHEV	24,840[2]	21,769	23,809	9.37	18,892	21,581	14.2
BEV	15,214[2]	28,861	29,302	1.53	27,658	28,345	2.49
XS	10,032[2]	13,432	15,048	11.9	13,341	13,937	4.44
S	12,799	16,172	20,698	28.0	15,500	18,923	21.8
M	17,749	21,683	25,340	16.8	20,725	22,879	10.2
L	27,649	30,365	34,413	13.2	29,721	33,562	10.5

Table 4: Weighted Average Purchase Prices for powertrains and segments

First of note is that in all scenarios although prices increase by 2020, they have reduced by 2030. The majority of the price changes witnessed come from the introduction of ZEVs that are at a higher cost to begin with (due to being an immature technology with high battery costs). However, under policies, they also come from rising purchase costs of ICE vehicles, as manufacturer penalties are passed on to the customer. These increased costs to the customer will be partly offset by cheaper running costs from more efficient vehicles, which should be explored in future work. Secondly, concerning costs of powertrains, the price differential between the scenarios of ICE and HEV are much greater than those of the two ZEV models, particularly the BEV, as it's purchase price increases by only 2.5% by 2030.

However, what is of concern is that of the price differential in segment sizes. Within the model, in order to meet GHG requirements, each segment is subjected to the same relative reduction in emissions by the manufacturer ensuring the necessary corresponding fuel consumption efficiency is made. As the reductions are relative, rather than absolute, it would suggest that there should be proportional changes in purchase prices corresponding to this.

[2] HEV, PiHEV, BEV and XS models are not available in the model in 2009, these prices are the market entry prices under fixed baseline. See Table 2 for entry years, paying note to the segments available at that time as this influences the price.

Prices are also affected by desired profits (increasing all powertrain prices, but mainly ICE), desired market share (adjusting BEV costs) and production costs. In both 2020 and 2030, the small segment weighted average purchase price has increased disproportionately compared to other segments. This would suggest that those who considered a small car would then be more likely to choose an extra small (that may not fully meet their needs), and those who chose a large would not be as penalized by the introduction of the policies. It could also imply a dis-incentivisation to downsizing. Of course, these figures do refer to new vehicles bought by the more affluent members of society, and assuming that these are private customers rather than business fleets. However, as these will then pass onto the second hand car market it may lead to a fewer S-segment cars in the market than there would otherwise be, hence less choice for those customers. Additionally though, as the average overall price is 16% greater by 2020 under the policies, some people may not be able to buy a new car at all. This could mean they may keep their older (and more polluting car) for longer.

These observations are relevant when considering the permissibility of encouraging downsizing and introducing ZEVs, forcing the car market away from cICEV. Not only would it appear that those in the larger segments are effectively favoured within the regulations as the purchase price has the least increase, but also that those for whom a ZEV is not viable are also dis-advantaged. These people are likely to already be in categories of higher need (for example, availability of home charging is related to housing type, which is in turn related to affluence) and could therefore be disproportionately affected.

Cost Burdens

Finally, in order to understand if the policy was fair to customers, government and industry, it was thought necessary to establish where the cost burdens lay.

SCENARIO	**COSTS ($b)** ***(% change)***			
	Customers	**Government**	**Industry**	**Overall**
Subsidy	-0.95 *(-0.3)*	1.18	0.13 *(1.1)*	0.36 *(0.12)*
Regulation	50.66 *(15.7)*	0.00	1.05 *(-8.6)*	49.61 *(15.96)*
Both Policies	49.38 *(15.3)*	1.35	-0.93 *(-8.4)*	49.79 *(16.02)*

Table 5 shows these in absolute cumulated discounted costs ($b) by 2020 between policies and the fixed baseline. Customers' costs is the extra amount spent on purchasing vehicles, government costs is the amount spent on subsidies (from public taxes) and industry costs are the difference in profit between baseline and scenario. The cost of moving from the Conditional to Fixed Baseline (which isn't shown) is in the order of $20b for customers and $16b for industry. With Subsidies, and compared to the Fixed Baseline, customers witness a benefit from government and industry costs. Customers' costs increase greatly by $50b when Regulation is in place, suggesting that the majority of industry costs are passed on to them. Indeed, industry experiences a profit through passing on these costs and Increasing purchase prices. Under Both Policies, subsidy has a negligible impact overall compared to that of Regulation, but does decrease customer costs and industry profit a little.

It is worth noting here that due to restrictions within the core model, investment is not considered and profits are not passed on quickly enough so overall industry is experiencing negative profits. This omission will be explored in future work and could lead to model amendments, which will allow the investigation of the impact of investment, representing the Competition and Collaboration policy measure.

SCENARIO	COSTS ($b) *(% change)*			
	Customers	Government[3]	Industry	Overall
Subsidy	-0.95 *(-0.3)*	1.18	0.13 *(1.1)*	0.36 *(0.12)*
Regulation	50.66 *(15.7)*	0.00	1.05 *(-8.6)*	49.61 *(15.96)*
Both Policies	49.38 *(15.3)*	1.35	-0.93 *(-8.4)*	49.79 *(16.02)*

Table 5: Cumulated cost burdens of policies by 2020 in $b and change compared to Fixed Baseline

CONCLUSION

The concern of this work is that governments may be obliged to reduce GHG emissions due to climate change but policies to achieve this in new passenger cars could impact on inequality in society, due to the effect on the opportunity of car ownership. The findings here have demonstrated the complicated feedbacks that exist within car ownership and it was found that putting regulatory penalties and purchase subsidies in place would achieve the greatest GHG emission reductions but also increase purchase costs and change market shares. These are issues that may impact on inequality so countermeasures may be required to limit their impact.

Suggested Amendments to Policies to Satisfy the Ethical Framework

Ensure Affordability. An overall fleet average emission target may favour owners of larger vehicles if a manufacturer chooses to respond by proportional emission reductions as in this model. As larger vehicles are generally more expensive this may therefore favour richer segments of society. Thus manufacturers should be made to consider segmental skews resulting from business strategies. This could be analogous to existing affordability regulations in the utility sector for those experiencing fuel and water poverty. Idealistically, manufacturers should also have awareness of the impact on the second-hand car market, as this may include the more vulnerable segments of society.

Protect Vulnerability. Segments of society with special claims for car ownership, as identified in the ethical framework, need protection from disproportionate increases in purchase cost or decrease in utility. In order to achieve the emission targets and introduce LCVs, market shares of cICEV will be reduced to a quarter of what they are today. Even if assumed that such a significant change in purchase habits in just over a decade is realistic, it is unlikely that LCV attributes will have improved sufficiently to equal cICEV. Under this assumption, those segments who have most reliance on car ownership will be most impacted, as they may be priced out from owning a vehicle suiting their needs or bear high costs because of their needs. This is of most concern to those who have a lower income in the first place, though more affluent segments may be justifiably able to bear higher costs.

Distribute Burdens. This research found that customers bore the highest costs of market transformation under Regulation. Although customers should expect to bear some costs as

[3] Fixed Baseline costs are zero for government so change cannot be calculated.

car ownership does not outweigh climate change obligations, they should be more equally shared. Industry in particular pass on additional R&D costs to the customer, which could be supported by government policies. This spreads the cost over taxpayers but also has problems as car manufacturers are not necessarily from the same country. Other cost increases may be due to scarcity of materials and these, it could be argued, should be paid for by the customer, as industry would not be expected to lose money indefinitely. Further work is required within the model to understand this, as well as the dynamic between purchase and operating costs for the customer, and the acceptable use of government funds.

Recommendations for Model Improvements and Extensions

In addition to further exploration of sensitivities and tipping points, it may be possible to make some amendments to the model. These are required to more accurately reflect the dynamic nature of technological development and demand response, as well as making some model extensions in order to make it more fit-for-purpose, and possibly represent other policy situations. Example extensions are:

- Inclusion of LCVs other than EVs;
- Extension of timeline to 2050;
- Combining different manufacturer responses;
- Incorporating life cycle emissions;
- Link with segments of society so the most vulnerable can be identified;
- Development of second-hand car market dynamics.

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