Powering or De-Powering future vehicles to reach low carbon outcomes: the long term view 1930 – 2020.

S.H.Cousins, J Garcia Bueno & O Palomares Coronado

School of Industrial and Manufacturing Science
Cranfield University, Cranfield, MK43 0AL, UK.

Abstract

Government in UK has long sought to influence both new vehicle fuel efficiency and to encourage domestic car production. Sixty years of data on the change in car characteristics and fuel economy are analysed. Vehicle specific power has doubled in that time and sales of vehicles have grown preferentially in larger engine classes. New cars sold over the period 1970-2000 have a sale price of £150 per bhp at year 2000 prices. A new theory is proposed that the primary driver for increased power of vehicles, and hence CO2 production, is the increase in sale price necessitated by uneconomic production of steel vehicles in mature markets. The standard fuel test cycle shows inverse fuel efficiency relationship with weight and with vehicle power. Primary CO2 reduction targets such as the Kyoto agreement are dimensioned as outputs of energy use per unit time (power); secondary targets such as the ACEA voluntary agreement of 140g/km in 2008 based on energy per unit distance (efficiency). Failure to focus policy on the key variable of vehicle power has allowed power to continue to increase and inhibit fuel efficiency from meeting the voluntary agreement targets. This power 'loophole' in Europe is likened to the emergence of light trucks in response to CAFE standards in USA. New body materials offer the prospect of profitable car production, consumer satisfaction and large reductions in CO2. New policy directions are proposed as a result of the failure of the ACEA voluntary agreement and the real importance of achieving annual CO2 reduction.

Author Keywords

Vehicle power, fuel efficiency, trade offs, long term, ACEA voluntary agreement, Taxation, EC15 test cycle.

Article Outline

Introduction

The success of the car industry and of industrial society itself has led to the present dilemma where CO2 emissions from energy use threaten the stability of the Earth's climate. Dimensionally this is characterised by a global increase in power use. Since Kyoto political processes have set policies in place to reduce CO2 emissions in all sectors including transport and within that, the automotive industry is of prime importance. Early last century car production was briefly dominated by electrically powered vehicles the many start-up and new entrants have been internal combustion engine car makers. These came from many other industries such as bicycle making or agricultural machinery [1]. Since these pioneering days, technical change to the vehicle and its production systems have defined the cars, car manufacturing processes and created the car making companies of this century.

In this paper we take a long-term and a wide ranging view of how the present intractability of automotive CO2 growth has occurred and how it might by mitigated. Specifically we distinguish between the three elements identified above, the technology of the car, the manufacturing system and the company group. We adopt the triple bottom line approach [2] that defines effective solutions only if they are viable in economic, social and environmental dimensions. Within this context we follow the perspective of Nieuwenhuis and Wells [1] that it is the steel manufacturing system which is defining of vehicle economics, defining of company structure and as we will show here, defining of CO2 production. Thus unlike other 'solutions' [3] which have focussed on changing the motive power unit of the vehicle as the primary way of reducing CO2, we suggest that this deflects public policy from the core issue of the profitable production of lower powered vehicles. Such an approach is dependent on innovating new body manufacturing technologies. The current dynamic of the car industry is unlikely to meet the automotive emission targets compatible with the Kyoto agreement and may miss them by a very wide margin. the European Automobile Manufacturers Association (ACEA) has established a voluntary agreement (VA) to systematically reduce CO2 emissions initially to year 2008. As will be shown the ACEA voluntary agreement is problematic in a number of ways, not just about whether the industry will meet it's own targets [4] but whether this subsidiary target of ACEA is sufficient to meet the primary Kyoto objective. The clarity of how subsidiary and primary CO2 targets interact is vital for successful policy outcomes and it has been proposed [4] that subsidiary targets be regularly reviewed by regulatory bodies and raised if the primary targets are not likely to be reached.

1.1 Policy context

It is worth recalling that for a variety of reasons governments over the last 50 years have sought to improve vehicle fuel efficiency but with modest effect. Most often this has been due to a shortage of supply of fuel e.g. in UK during the WWII and the 1956 Suez crisis. These events stimulated the use of alternative fuels such as methane from animal manures or technical development, such as the BMC mini which was developed to increase the number of fuel efficient cars in UK as a defence against future Suez-style crises. Supply restrictions and resulting prices rises in 1973 and 1979 stimulated concerted public policy responses to improve vehicle efficiency with the aim of reducing fuel consumption. The Chernobyl accident in 1986 constrained future nuclear options as an alternative to carbon fuels, while the new awareness of global limits to CO2 production significantly impacted on the automotive sector in 1990 and continues to the present day.

If the above conditions stimulated fuel efficiency improvement policies, another group of *industrial policies* were having a different or even opposite effect. Immediately after WWII the highly graduated horsepower tax (annual vehicle license) was replaced by a single annual tax amount irrespective of the size of the vehicle. Specifically this was intended to encourage the design and production of larger engined, more powerful vehicles, that would generate additional exports to countries such as USA and Australia. A second intent was to increase the production volumes of individual models by reducing the number of model types offered. Models had been offered for each tax band and removing these bands would therefore increase model volumes and with it improve the profitability of the industry [5]. This early form of industrial consolidation policy was just one of many rounds of consolidation in the car industry both in UK and then globally.

The 1973 oil crisis plunged the UK car industry into recession due to a collapse in car buying; consumers had raised their expenditure on fuel but had little left over to buy new cars [6]. In 1975 tax rules for company car purchase were introduced to assist the car industry but in so doing stimulated the design and purchase of larger more powerful cars which are still the bedrock of the UK car buying. Recent changes in company tax rules have sought to stimulate more efficient company car purchase but without abolishing the practice *per se.*

1.2 Triple bottom line approach to automotive CO2 reduction

At heart the triple bottom line is a problem of ensuring that the car industry is profitable but that the cars produced are sufficiently fuel efficient to meet the environmental CO2 goals and that customers buy them contentedly within the prevailing culture. So the big question is, can this set of three objectives be met within the present production systems, environmental targets and social culture? As has been noted above, the UK and many other countries have been facing these issues for 50 years and yet CO2 continues to rise and the car European industry continues to decline or be subject to concern about it's long term economic viability [7]. Thus neither, environmental or, industrial policy has had a successful outcome. The third dimension concerns the consumer. In fact the 'first purchasers' of vehicles i.e. the consumers to whom car production is sold, remain an unusual and narrowly defined group. These consumers either buy against tax incentives (60-70% of all UK new car sales), or, for the remaining 40-30% of sales, i.e. some 800,000 private car sales, are consumers who represent just over 1% of UK population in any one year. Thus there are potentially many other kinds of customers too within the larger population..

We cut into this Gordian knot of producers, consumers and regulators by investigating the relationship between car price, which particularly interests consumers and producers, and car CO2 performance which is the concern of the regulator on behalf of the environment. This enables us to untangle the link between emissions and the profitability of car making. Key to this approach is the use of the dimensionally correct form for CO2 emissions when considering global warming.

1.3 Annual CO2 as a Dimensional Analysis problem

Fuel efficiency data for vehicles are conventionally given, in dimensional terms, as emissions output per unit distance i.e. gCO2/km or as inputs relating fuel used to a standard distance travelled as litres of fuel type per 100km or miles per gallon of a fuel type. However, the annual CO2 objective is measured as energy or CO2 per unit time. Energy per unit time is dimensioned as power. Thus technically we are not interested in miles per gallon but in gallons per hour; these two measures are of course linked by miles per hour i.e. the speed at which we travel and how much time we travel each day. As cars become more powerful, speeds and emissions rise. Transport theory has long held that the time we spend travelling each day is highly constrained and has held constant by physical and social conditions [8]. However the time spent driving within the total time budget has started to rise in the last 10 years in the UK [9] which again increases CO2 outputs per annum.

A second issue arises from the use of the standard EC vehicle fuel economy test procedure (Directive 80/1268/EEC) which constrains vehicles to follow a particular urban and motorway speed trajectory. This trajectory is the same for all vehicles. It is not clear that this is now an appropriate reference test if differences in power between vehicles is widening. This implies that vehicles of different power ratings should follow tests with more specific speed trajectories characteristic of how these vehicles are actually used by drivers [10,11]. Also since speed has a role in total amount of travel via the time budget, then a basic multiplier function for each power rating will provide a more reasonable estimate of annual or monthly fuel consumption of different vehicles. At present, in the UK, annual emissions and fuel costs are calculated assuming equal annual mileage irrespective of vehicle type. This information is then displayed on a label at the point of sale for new vehicles. Our data collection and analysis will therefore centre on the history and implications of vehicle power since this is the dimensionally correct form relevant to annual CO2 outcomes and whose role needs to be better understood.

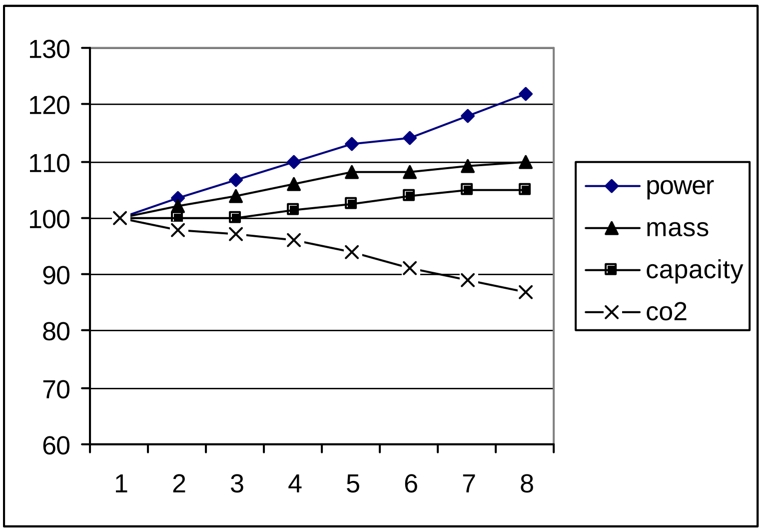

Fig 1 shows annual change in vehicle characteristics in, the 15 European member states, from 1995 (100) to 2002.

Data (Figure 1) from ACEA [12] show that while average fuel consumption using the EC standard test for all vehicles achieved an improvement, the average peak engine power shows a consistent rise. Although the manufacturers may account for this in terms of needing to accelerate the increasing mass of the vehicles, which is also shown in Figure 1, it is nonetheless the power output that is of interest with regard to annual emissions from the installed base of petrol and diesel engines and this shows a relentless increase.

2. Methods

As current policy requirements deal with targets for CO2 performance in the period between now and 2050 it is appropriate to consider at least equally long term data sets from the past to assess the capacity for change. This is particularly relevant given the long history of trying to reduce fuel consumption in the automotive sector where this policy objective similarly stretches back well over half a century.

2.1 data collection

A database of vehicle characteristics was assembled [13] from UK motoring periodicals between 1900 and 2000 using the libraries of the Royal Automobile Club and the Society of Motor Manufacturers and Traders in London. For early years, data were taken mainly from advertisements and model reviews in the periodicals, later data were published in standard formats making collation and comparison more straightforward. Where possible long journal publication runs were used. Data were collected by engine size class and by year of production with the objective of recording data for 10 different vehicles in each engine size class for a reference year in each decade. The data sought for each vehicle was make, model, fuel type, mpg, weight, engine displacement, price, bhp, 0-60 accel, max speed, model descriptive detail. Horsepower in the earlier part of the century was a taxation class which was determined by displacement volume not direct power measurement. Thus 9 hp was the tax class for engines of 1000cc and 16 hp tax class for 2000cc and so on. Simple data averages were made using the vehicles in each engine size category for each decade for each vehicle variable and then these are plotted over time. Only measured bhp was used (not hp tax category) for engine power data. Data were not very complete prior to 1930 but some data for some categories go back to 1900 [13]. Fuel economy data was taken from average test drive values in early years or from standard test cycle data more recently. While standard test data may allow more precise comparison between models it may also overestimate economy by 15 – 30% [10,11] compared to the actual in- use fuel economy achieved. Thus some of the improvement in fuel use over the long timescale will be due to the change in recording methods which may overestimate actual fuel savings relative to the past.

2.2 Modelling approaches

First we took the decadal price data for vehicles of different power ratings and adjusted the prices to year 2000 values. The goodness of fit to a simple regression equation was examined and the best relationship chosen for the relationship between vehicle price and power for petrol and separately diesel cars [[14].

Second, a causal model was developed to estimate annual UK total automotive CO2 emissions based on daily emissions from the national car stock as a function of driving speed within an available time budget. Driving speed was influenced by vehicle power and hence scenarios of different vehicle power distributions could be examined. To simplify the model two average speeds were considered, an urban speed where congestion was assumed present and a free flow condition on inter-urban roads. The urban road speeds were assumed not to be influenced by vehicle power. The sensitivity to speed with power we took from the IEEP [4] travel distance data between the three engine size categories of the scenarios. We applied a similar sensitivity test to time spent driving and the combination of time driving and driving speed as a function of power.

The simple model outputs from equation 1 for 1996 and 2003 for which national emissions data were available were found to be overestimates which were then fitted by an emissions reduction factor. In projecting the scenarios to 2010 and 2020 we have assumed that growth in mean annual driving time will continue T(2010)=160hours, T(2020)=183hours, and that the national fleet will increase in line with the DfT forecast [15] N(2010)=27786000, N(2020)=32199000. Speed limits are assumed not to change over the period. In equation 1 the proportion x of the total is either diesel or petrol, N is the number of vehicles in three vehicle size classes i below 1400cc, 1400 – 2000cc and above 2000cc; T is the daily time budget which is split into two parts j for urban speed U and EU extra urban driving speeds, s; and E is the CO2 emissions characteristic of the variables xij [16].

$$Annualcars CO2 = 365 * \sum_{x=petrol}^{diesel} \sum_{i=cc_1}^{cc_n} N_{xi} * \sum_{j=U}^{EU} T_{ij} * s_{ij} * E_{xij} \qquad \text{…eqn 1}$$

3 Results

The available systematic horsepower information for UK vehicles began in our dataset in 1938. We tracked this for different engine sizes for petrol engines Figure 2. An increase in specific power output is clearly illustrated. Thus technical improvements have enabled much more power to be obtained from the same size of engine with small engines more than doubling in power; mid sized engines 1600-2000cc going from 55 bhp to 130 bhp in 60 years; with similar gains for larger engine categories too.

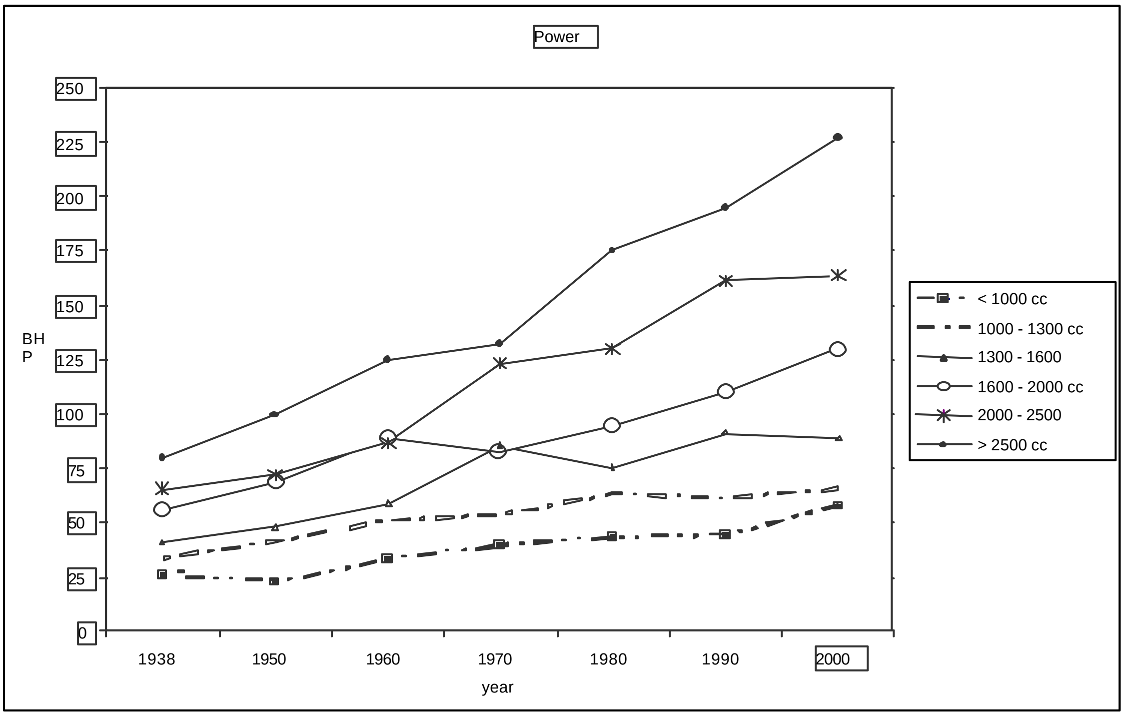

Figure 2 Evolution of power output by engine size

The increase in specific power was also accompanied by a shift in purchasing pattern, or sales pattern, in which the modal engine size also increased dramatically. This moved from 1000 cc and below in 1940, to the 1300cc category in 1980 and the 1600-2000cc in year 2000, see Figure 3. Also to note is the increase in number of cars purchased in these categories. Thus more cars, each with on average bigger engines which each on average generate more power for any given engine size is ample evidence of the increase in installed capacity in the automotive sector. Analogous to the national sum of electricity power station capacity, the installed capacity here is the sum of the total potential power output of all vehicles at the date concerned.

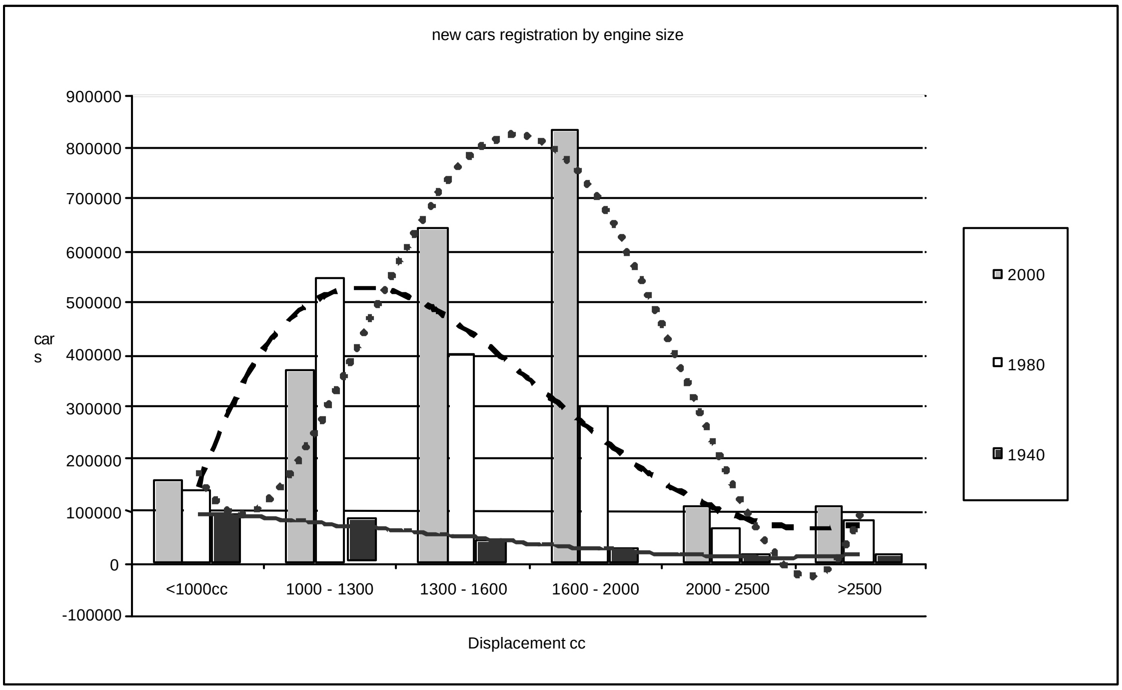

Figure 3 Percentages of new car registrations by engine size

In terms of annual CO2 emissions we note here that for the typical one hour a day that the time budget constrains that these engines are running, and given typical duty cycles for the engines, then the annual CO2 emissions are a function of this installed capacity. Future reductions in annual CO2 which are the objective of policy will to the first approximation require a reduction in the installed capacity i.e. a reduction in total potential vehicle power.

However the economically interesting factor is to understand the relationship between vehicle power and vehicle sale price. Here we took the vehicle prices and adjusted them to year 2000 prices using an inflation corrector and then examined the price for each decade taking 6 to 8 vehicles in each power class. Figure 4 shows that in the early part of the century additional power was extremely expensive and delivered not very great increases in power. By contrast in the later part of the century power has become much cheaper and available in much greater absolute amounts but the deflated prices of cars have not changed greatly. Adding the decades together and choosing the decades with least variance about the linear relationship of power to price, the period 1970-2005 provided the best fit. The equation for this model Eqn 2 shows £150 per bhp provides an estimate of the vehicle sale price.

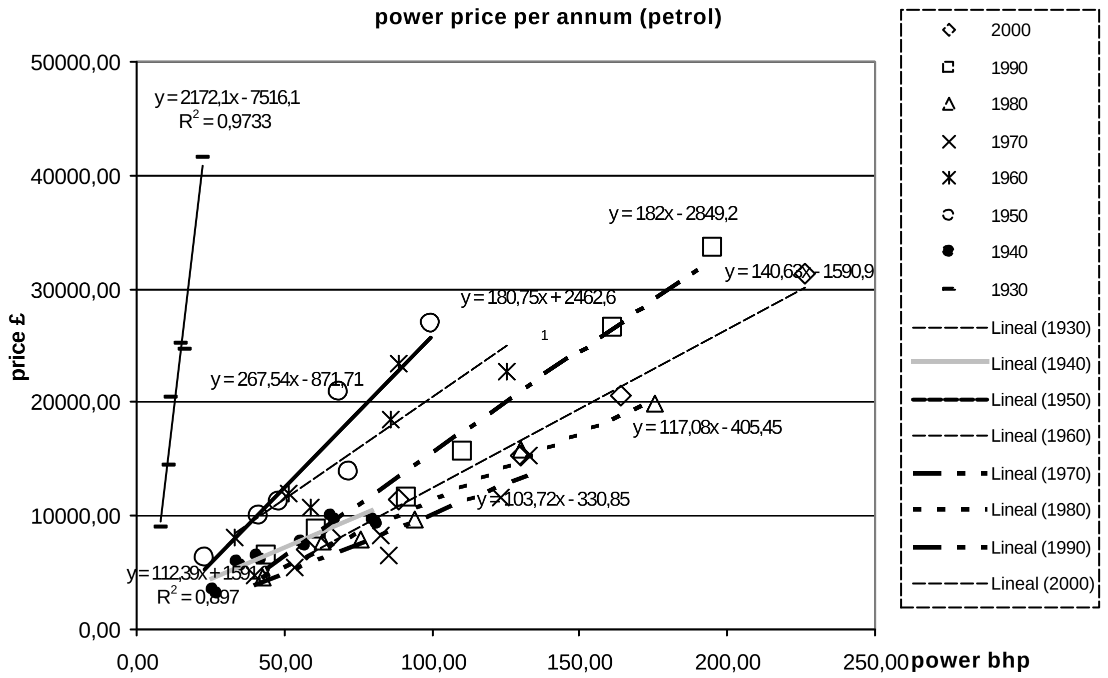

Figure 4 Vehicle power-price trends by decade.

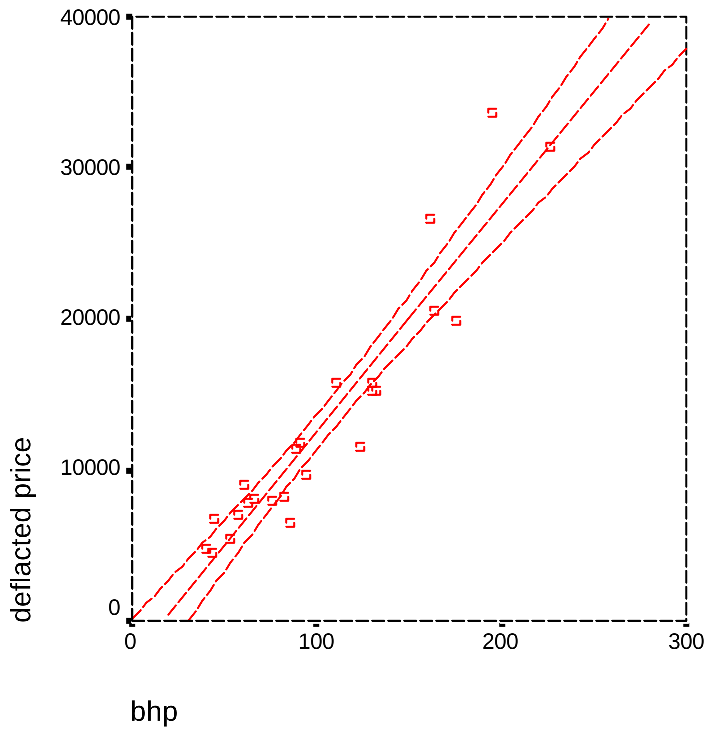

Figure 5. Power-price correlation for petrol engines, 1970-2005.

The equation for the model is:

$$£ = -2464 + 149.7 * Power(bhp) \qquad ....eqn\ 2$$

This selected model is the power-price for petrol engines since 1970 until 2005 with a determination coefficient of 89.4% which is the total variability percentage explained by the linear model. The model has a Pearson's correlation (correlation coefficient) of 94.6% with the original series, it moves very close to the original points as we can see in the Figure 4. Both statistic parameters i.e. Pearson's correlation and Determination coefficient, demonstrate that there is a strong linear relation among the considered variables in the linear model. When the confidence intervals are calculated and as it can be seen in Figure 4 the intervals of the estimates are represented with 95% reliability, it can be seen that around six points are outside this 95% isocline. Some of these outliers correspond to the 1970 series, when the price had to diminish due to the oil crisis, and others correspond to a higher dispersion when the power increases. The model loses accuracy when we are talking of high levels of power since we have fewer points in this region.

3.1 Data exploration

The data on weight versus standard fuel efficiency testing shows the 1930s to 1980s as lying on the same line while the year 2000 points clearly indicate a large fuel efficiency improvement for any given weight which would imply large engine efficiency improvement and/or changed measurement methods between 1980 and 2000.

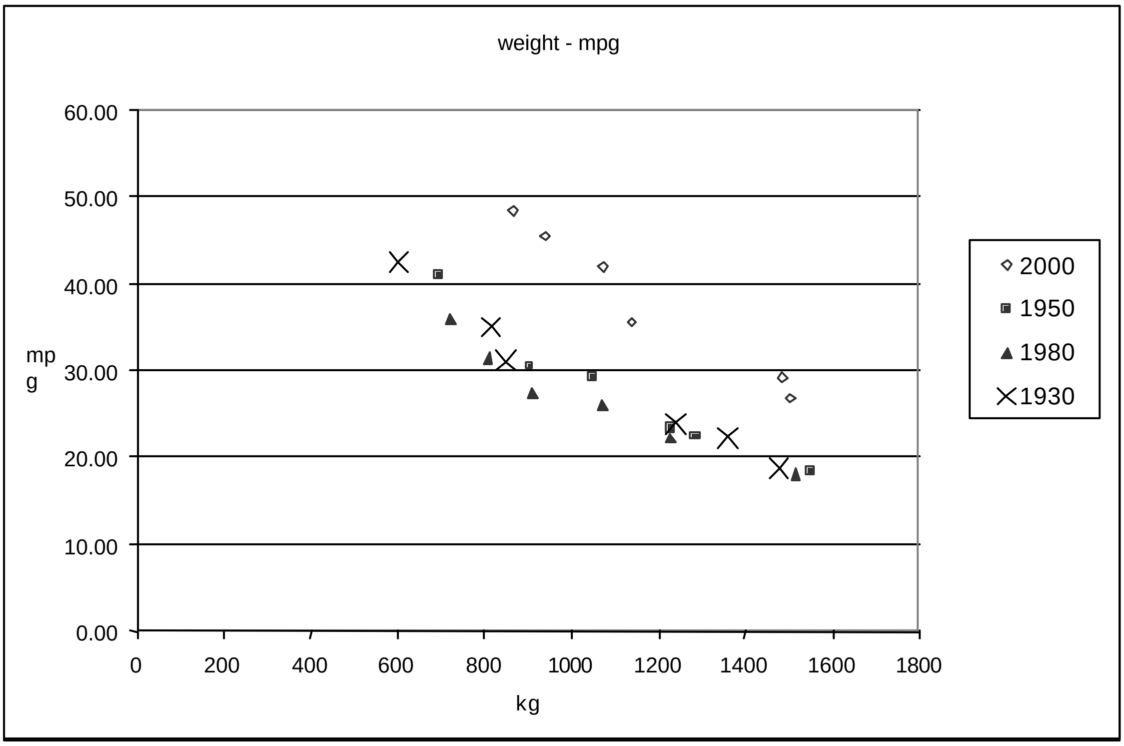

Figure 6 Vehicle weight against mpg

The other piece of data exploration undertaken using these long term data is to observe that vehicle top speeds have been increasing as we proceed from 1930 to the present day which may unsurprising but informative. The other factor is that fuel consumption as measured on the standard test is a negative relationship with vehicle top speed. Top speeds from 1980 are well in excess of the UK national speed limit of 70 mph. The top speed of a vehicle is reached when the vehicle power output equals losses from aerodynamic and tyre drag.

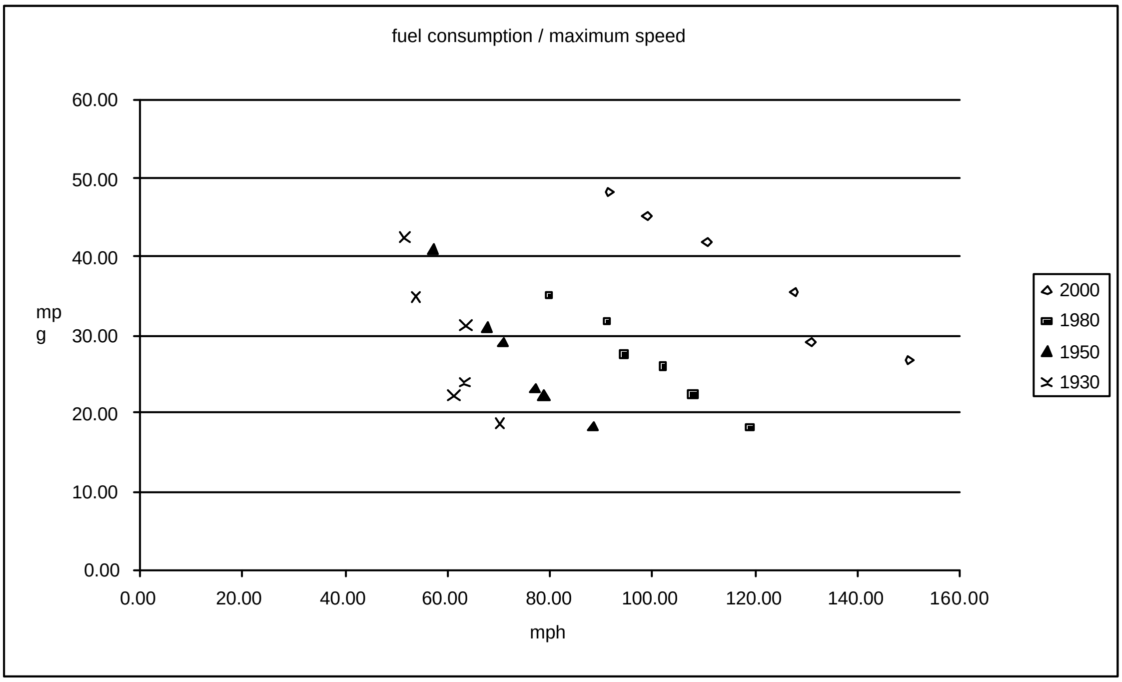

Figure 7 Fuel consumption against vehicle maximum speed (peak power)

3.2 Modelling outputs and driver behaviour

The final results arise from modelling the outcome of driver behaviour as a function of the vehicle power rating of the vehicle using equation 1. This treats the driver as responding to the vehicle rather than assume that the driver would behave similarly in all vehicles. The following scenarios vary the distribution of vehicle power in the national stock. While the changes are implemented gradually between 1995 and 2020 the power distributions from Table 1 are implemented in 2010 and 2020 as steady state averages without vehicle age structure. Thus as the power rating of the average car increases with time to 2020, the average vehicle speed and acceleration also increases.

%	<1.4	1.4-2.0	>2.0	Comments
1996	45	47	8	Real situation in 1996
2004	37	51	12	Real situation in 2004
A	33	50	17	Current Trend
B	17	50	33	Long term trend of increasing power
C	17	33	50	Radical increase of power

D	55	40	5	Low powered situation
E	80	15	5	Radical decrease of power

Table 1 Scenarios : percentage of the car stock by engine size

Figure 8 shows that assuming the current trends in vehicle driving time and in the growth of the number of vehicles, then with the existing emissions levels assumed to level off at 2005 levels and no distinction in driving behaviour between vehicles of different power levels, then the model shows a 50% increase in emissions by 2020 for the base case. Low power and high power scenarios show a range around this figure of +/- 20%.

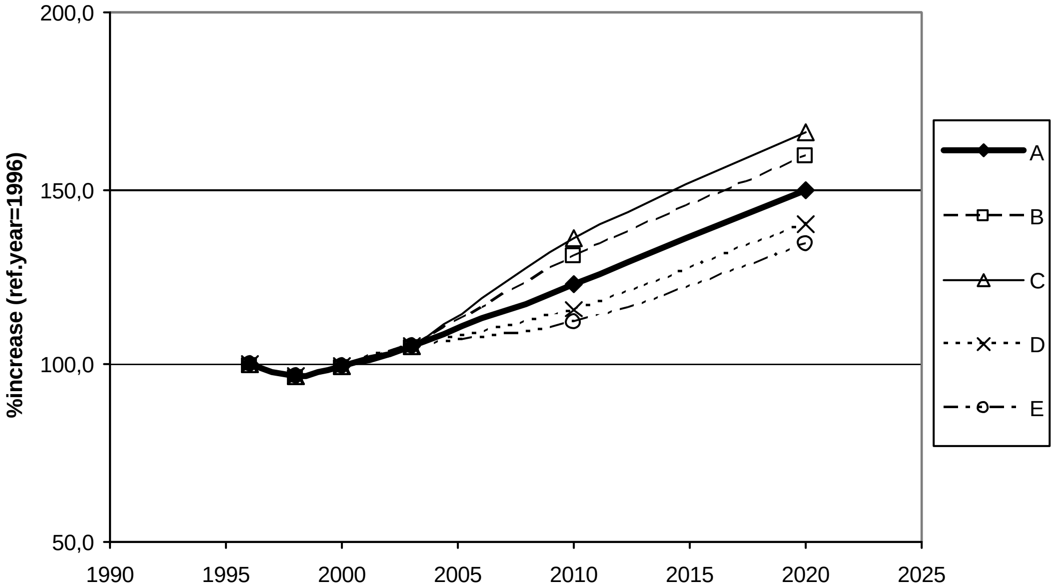

Figure 8 Car emissions forecast from base year 1996

However if driving behaviour is influenced by vehicle power, which is a reasonable assumption because drivers generally buy more powerful cars to drive faster, then emissions are greater at higher speeds, and greater distances are achieved within the same 'extra-urban' portion of the driving time budget. It is assumed that vehicles speeds in urban areas are unaffected by vehicle power.

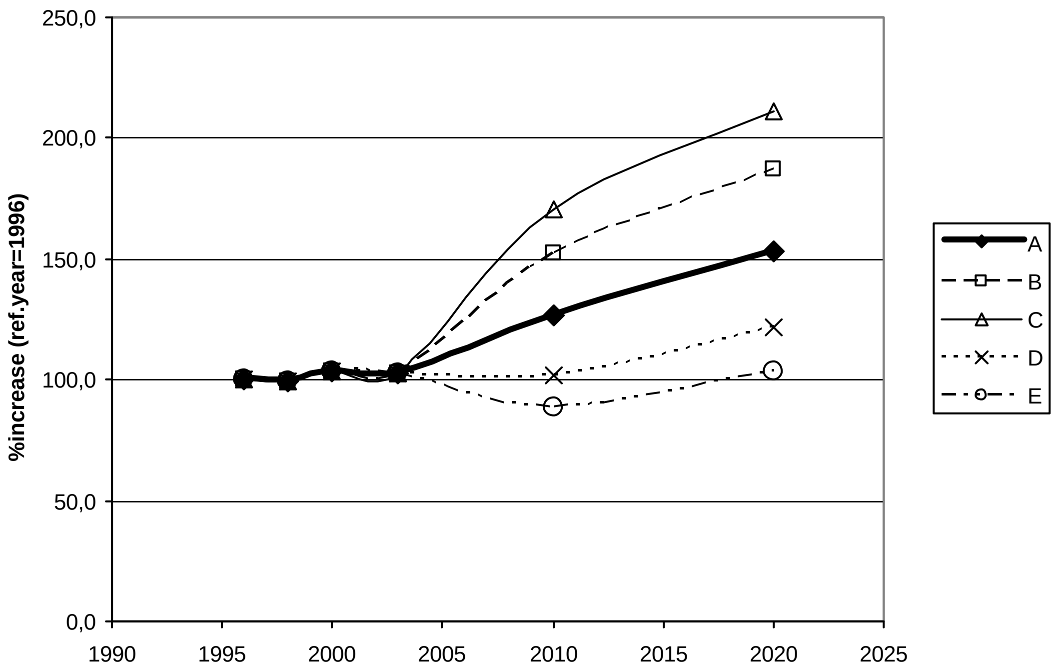

Figure 9 Car emissions forecast with behavioural effects from base year 1996

The outcome of the assumption that driver behaviour is a function of vehicle power, is shown in Figure 9. Here the high and low power scenarios have a range of +/- 50%. The low power scenario for 2020 has the same emissions level as 2000 despite a major increase in car population and driving time. The high power output shows over a doubling of emissions. All of the scenarios in Figures 8 and 9 are independent of any future emission improvements post 2004 either achieved or voluntarily planned in the ACEA agreement. As such the low power scenario could with fuel economy improvements bring the 2020 emissions total well below the 2000 level.

4 Discussion

The policy driver to remove the causes of global warming has generated a number of intermediate monitoring datasets and policy targets. The most significant of these is annual global CO2 emissions reduction target created by the Kyoto agreement.

4.1 Primary and subsidiary policy targets

In order to meet the primary target of reducing annual CO2 emissions consistent with the Kyoto agreement, the major automotive sector policy initiative is the ACEA voluntary agreement to reduce new vehicle emissions. This is a secondary or subsidiary target and is measured using the standard EC vehicle fuel economy test which is itself, a tertiary measure. Under the ACEA agreement emissions of new vehicles sold were to fall by an average of 2% a year going from 180 g/km in 1995 to 140 g/km in 2008 and a future aspiration to get to 120g/km in 2012. Whilst these targets are welcomed, there are at least three steps between the voluntary agreement and having an impact on the annual emissions of CO2 and global warming. Potter

[17] has stressed that each stage including the VA in this sequence has to deliver major change in order to meet the Kyoto target. First the target has to be reached each year, second the measured vehicle fuel test has to be representative of the way in which vehicles, including vehicles of different power ratings, are actually used on the road; third growth in the number of cars driving and the distance driven per year also has to be factored in to the total annual emissions achieved annually. Thus the dimensions of the policy outputs from the test results in miles per gallon or kgCO2/km of the subsidiary targets have to link to energy per unit time, i.e. CO2 per annum. Ultimately this is the sum of individual vehicle power outputs. For CO2 per annum to fall, the average delivered vehicle power output must also fall. Thus a reduction in vehicle power output is the primary target consistent with lowering global warming. This holds true for hydrocarbon fuelled systems which we assume to dominate over at least the period to 2020.

When we modelled scenarios with different distributions of engine size we found that the current trajectory of power growth per vehicle would lead to nearly double the CO2 emissions by 2020 if present ACEA agreement trajectories were maintained; but that by returning to the percentage of larger than 2000cc engines sold a decade ago coupled with 80% of vehicles being below 1400cc then no increase in consumption would occur by 2020 [14] even with the growth in vehicle numbers anticipated. These sensitivity tests are indicators only of the role played by vehicle power in the growth of vehicle use and vehicle fuel consumption. The absolute values are subject to debate but the effect is large.

In the automotive sector public policy in UK and EU has focussed on the ACEA agreement for delivery of CO2 reductions leading to lowering global warming. From Figure 1 we see that this secondary target is failing in two ways; the EC15 test on which the VA is based is itself failing as a representative test for how different vehicles are used on the roads [10,11], and the producers are failing to meet the 2% annual reduction targets even given the existing test. By contrast the primary Kyoto target of power reduction continues to grow in the wrong direction. The increase in power of vehicles produced year on year negates the spirit of the CO2 reduction target whilst officially targeting annual average improvement based on the standard EC vehicle fuel economy test in which power use is constrained. This 'loophole' can be likened to the dilemma of the US CAFÉ controls and the emergence of light trucks outside the spirit of the vehicle fuel consumption agreement. Given this context we would encourage the selection of policies that target the core issues and therefore move from the subsidiary policy of achieving annual improvements in efficiency per unit distance, to capping and then annually reducing vehicle power as the policy instrument to bring about primary policy of reducing CO2 output per annum.

4.2 A production theory of the underlying mechanism of vehicle CO2 growth

We have seen from Figure 1 that on average European new vehicles have continued the long term trend to become substantially more powerful since 1995. The improvements in fuel economy brought about by the ACEA VA have also been significant but insufficient to meet the goals for 2008 or 2012. It is proposed here that these issues are linked and that underlying the growth in vehicle power is tied to the economics of the vehicle production system.

What we have seen from the post 1938 data is that vehicle power has continued to rise in the UK both as specific power which shows power outputs for each engine size doubling over the 60 years to 2000 and as the average size of engine purchased also increases. What Figure 5, establishes is the relationship of power with vehicle price. This is consistent with two aspects of the triple bottom line approach. First, new car purchasers have been and are content to pay a purchase price which is directly proportional to the power of the vehicle. Second from Figure 4, manufacturers can now supply power fairly cheaply and so can create profit or recoup losses by making vehicles more powerful. Indeed since the major car company groups in Europe and North America are struggling to cover the costs of their legacy, tooling and design investment in steel car models [1], increasing the power of vehicles is a way of increasing the sale price of the product in a manner that consumers will pay. From this viewpoint, the basic driver for the increase in CO2 emissions is the need of the car company groups to deliver more power in order to achieve financial sustainability given their high capital cost production methods in steel. We propose this cost recovery constraint as a major mechanism and theory of the processes that are driving CO2 growth in the mature markets of Western Europe. Whilst cost recovery generally refers here to recovering the high capital cost of vehicle production in steel, other legacy issues such as health care responsibilities can be additional to this, as is currently the case in the USA.

The context of a mature market for vehicles is that it is richly supplied with products such that competing vehicle producers find their niches narrowed and the sales volumes mutually constrained, leading to difficulty in reaching profitability on many models [1]. Profitability can be restored either by moving production to developing markets, which are by definition unsaturated, where low prices can be obtained by high volume production and low wages. Or, by putting the price up and increasing the vehicle power to justify the price. Or, by changing the production system such that with new materials, or new forms of organisation, profitability can be restored at much lower volumes per model.

With the globalisation of the car industry, the car design standards in both mature and developing markets ensure that no single country in an island and that the historical data for UK can be considered as representative of a mature European car market. What is proposed here is that to meet the CO2 targets, the power increase model of successful car making in a mature market is not viable. This leaves either pushing production to lower wage economies or, if it is to be retained in Europe, to change the production system away from the steel body in white.

4.3 Alternative fuels

Proponents of alternative fuels derived from renewables, nuclear or from carbon sequestration may feel that they offer the option of higher power use as well as less emissions. Is this an important solution that we've missed or is it a diversion from the real issues? Here we have presented the theory that the driver for CO2 growth in the automotive sector arises from the current state of evolution of a major technology – the all steel vehicle body production in a mature market. To deal with that problem directly is less difficult than creating 30% of the UK's energy supply from investment in new types of energy generation. Other sectors of the economy which have been improving (unlike automotive) arguably have a more legitimate call on renewables and sequestered carbon, while the national security and pollution aspects of nuclear remain difficult issues. Thus as a sector, automotive could usefully put its own house in order, before laying easy claim to high investment cost, low carbon sources of energy for which there are other sector uses and claimants. Nonetheless, lowering average vehicle power ratings in the period 2010 to 2020 will lower the cost of entry of alternatively fuelled vehicles of similarly lower power ratings by, for example, requiring smaller fuel cell stacks to fit into the acceleration behaviour of a future vehicle market.

4.4 Vehicle fundamentals of economy and efficiency

Figures 6 and 7 deal with two of the fundamental relationships between fuel consumption and vehicle design; weight and power respectively. In the latter case the relationship between vehicle top speed and fuel consumption over the standard test cycle clearly shows a negative slope with increasing speed. This is also a graph of test consumption against peak engine power output since a vehicles top speed is achieved when aerodynamic drag (plus a much smaller load for tyre drag) balances the peak output of the engine. This relationship shows how selling engine power compromises fuel economy in the normal vehicle operating range and how the divergence of power and economy in Figure 1 is fundamentally linked to the average fuel economy of the ACEA agreement not being reached. Our hypothesis is that the trade-off between power and economy has sided with power on the basis of the link to vehicle sale price shown in Figure 5.

The other relationship is the negative slope of fuel economy with increasing vehicle weight as shown in Figure 6. The interesting aspect is the separation of the year 2000 data from the 1930-1980 data. This may be due to increase in engine efficiency e.g. increased diesel use since 1980. The range of vehicle weights in 2000, from 900kg to 1500kg, is slightly narrower than the 600kg to 1550kg of the 1930-1980 data. Vehicle weight increases are generally attributed to seeking to increase occupant safety in crash events. At a system level this could be viewed as an arms race in which the race to be heavier in a crash than the other car to ensure your slower deceleration rather than theirs. In practice there are many factors that control deceleration during an accident, e.g. crashworthiness design, and propensity to crash perhaps as a function of power to weight ratio. As with any arms race, something brings it to a halt. Here we suggest that a gradual lightening of vehicles across the vehicle parc coupled with good crashworthiness standards will reduce personal accident risk as a whole. Lightening vehicles has a critical role to play in CO2 reduction and we propose that incentives be introduced to stimulate the production of vehicles that infill the categories between the current 400kg quadricyle automobile and the 800kg baseline of conventional vehicles. Some influential commentators [18] have accepted unchanged, projected trends that vehicles will get heavier, whilst same authors are content to imagine radical change to the motive power unit. Reducing weight and reducing power is fundamental to reducing CO2 with or without change to the type of motive power unit.

4.5 triple bottom line solutions

It is observed here that to reach the government CO_2 targets requires a re-examination of car production methods such that these can achieve profitability at much lower volumes than is possible with steel body manufacture. Since lightweight materials are the basis of new body manufacture techniques then less power is needed to propel the vehicle in use. With a return to fundamentally profitable car making in new materials it will ease the pressure on 'selling customers excessive power'. There is thus a virtuous triple bottom line solution made viable by new body materials that allows a profitable industry, consumer viable power to weight ratios of new lighter vehicles with less energy use per unit time i.e. less power.

It can be argued that the current product offering to consumers is over supplied, by which we mean that the car will outperform what drivers can do with it on the road, is more luxurious and less fuel economic than they might actually require as a result of employer and tax subsidies. This is the classic oversupply situation that is vulnerable to disruptive innovation [19] by simpler products at lower cost. This is the easyjet model compared to national carrier airlines – selling less can be very compelling. We cannot predict what will occur in the car industry but the conditions are right and the technologies of alternative body materials are maturing. These require 100x less capital to create a viable vehicle which also happens to be light weight and inherently fuel efficient [20]. This removes the barriers to entry to the car industry and foretells the existence of many new start-up vehicle companies, or companies that enter from other industries (*sensu* Swatch and Smart) some of which may become major players. From this viewpoint the highly consolidated structure of the car industry is a function of the body production technology and that if and when disruptive alternatives are viable the industry will reconfigure around new companies and new product mixes. New combined weight and power taxation classes would encourage this change in body materials.

Conclusion

Over the past fifty years the UK Government has sought both to improve the fuel consumption efficiency of vehicles and to strengthen UK car production industry. The priority between these two objectives has been largely event driven with a tendency to relax between crises. Both problems are actually long term and persistent. How will car production succeed in the 21st century in Europe [7], what will happen to oil prices and the need for automotive sector to play its part in the Kyoto CO_2 reduction target of 60% by 2050, remain key problems which require effective solutions.

As has been discussed here, it is vital that the policy and voluntary or legally binding frameworks act in a very direct way towards the solutions that are sought and with a minimum of loopholes. In this case the long term objective is annual reduction in total CO_2 emissions from the growing national stock of vehicles. By correctly dimensioning the policies and frameworks the scope for working outside the spirit of the framework is greatly reduced. Without some form of jack-knife to the upward pointing graph of average vehicle power, Figure 2, such that the graph pivots and points downward to lower average power ratings in 2012, 2020 and beyond, there is no reasonable prospect of annual CO_2 emissions reduction in the automotive sector as a whole.

There is widespread acknowledgement that the current ACEA agreement will not deliver the UK and European targets for 140 g/km and 120g/km average vehicle CO_2 emissions for 2008 and 2012. This is a very serious occurrence. Now may be the time for the EU rethink the form of this agreement in order to reflect the fundamentals of energy use and emissions per unit time rather than distance. Therefore we propose consideration that the VA be replaced by a set of vehicle taxation categories for all EU markets which are defined by a combination of vehicle weight and power. Within these categories, innovation in vehicle or engine efficiency would have to result in fuel economy improvement rather than increased power output, since power itself is capped in each band. There are two existing examples of this type of vehicle legislation in EU namely the Light Quadricycle (350kg, 4kw) and Quadricycle (400kg, 15kw) automobiles. Given a mass and power limit then the size of the vehicle is limited by the material used, steel cars smaller than aluminium cars smaller than carbon fibre vehicles and so on. The fuel economy will be limited by the efficiency of the motive power unit and by the drag coefficient of the vehicle body and tyres. Thus the competition between companies will drive engine efficiency, new materials and aerodynamics to achieve vehicle acceleration performance when power itself is capped. Because power is the correct legislative target for CO_2 reduction per annum and not mpg or l/100km, very large reductions in fuel consumption are created when power itself is capped. The power ceilings for each band can also be further reduced, on a planned annual sliding scale akin to the current ACEA agreement. Further categories such as 600kg 30kw, 800kg 40kw with special rights to lower urban congestion charges, would be sufficient to drive competitive innovation of fuel efficient vehicles and find new customers beyond those fixated by power outputs. Evidence that 25% of new car buyers in Germany would trade off power for high fuel economy [21] establishes that buyers of other vehicle types exist in the larger population.

Achieving a major change in the direction of automotive CO_2 outputs will not be easy; if the fifty years of trying to do this are a guide to the fifty years ahead then the outlook is not good. What appeared a serious government-industry attempt (ACEA) at voluntary steps has reinforced the pessimistic view. Instead of annual CO_2 reductions, on average, cars have become very much more powerful. Schipper et al [22] take a similar need for a reduction in aggregate vehicle power. If producers maintain their preference for high volume steel vehicle production it is likely to drive the bulk of car production to lower wage economies and immature growth markets where steel production is still highly competitive. An alternative view is of light vehicles profitably made from new materials, with the prospect of consumer delight, local European production and, via de-powering, meeting long term CO_2 targets. This would be a viable triple bottom line solution. A solution likely achieved through weight and power tax bands rather than targets or voluntary agreements on fuel economy per unit distance. From this perspective the important study [4] which proposes emissions trading as a means of reforming the ACEA VA would in our view be targeting the wrong problem. If trading targeted power reduction rather than emissions per unit distance then the policy is correctly linked to the outcome of reducing annual energy use and therefore power reduction. The US CAFE experience with light trucks is a warning to avoid obvious policy loopholes and therefore should cause a fundamental rethink of the principles of the ACEA VA. We propose that combined power and weight taxation categories will provide the stimulus to light efficient vehicles which drive technology to produce highly fuel efficient vehicles profitably out of new materials.

Further research is justified to investigate the relationship between the standard EC vehicle fuel economy measures and in use fuel economy of cars of different power ratings and to examine if this test remains the correct basis on which to assess the changing fuel economy of vehicles entering the vehicle stock.

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