APPRAISAL OF POLICY APPROACHES FOR EFFECTIVELY INFLUENCING PRIVATE PASSENGER VEHICLE FUEL CONSUMPTION AND ASSOCIATED EMISSIONS.

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Abstract
When a stock model approach is used to model private passenger vehicle fuel consumption there is little room to incorporate consumer or behavioural related influences. Conversely, econometric modelling does not account for technical private passenger vehicle characteristics accurately, rather usually examining other influential factors such as fuel price, disposable income and employment levels to determine their influence on energy consumption and associated emissions.

In this paper the private passenger transport sector is modelled using two different methods, namely an ordinary least squares regression (OLS) and a LMDI-I decomposition analysis, comparing the historical 20 year period from 1995 to 2015. A number of overlapping factors are used to compare and rank the influencing factors examined in terms of their impact on fuel consumption and CO₂ emissions.

Further analysis of the OLS regression facilitated calculation of a hedonic or consumer influence over the 20 year period which attempts to quantify the impact of behavioural effects or consumer choice on energy consumption. The hedonic effect measures the influence of matching and unmatched vehicle purchases over time.

The aim of soft-linking the decomposition and regressions analysis methodologies is to understand the policy levers that can be most effective at influencing private vehicle energy consumption and emissions. The result is a greater understanding of the most effective policy levers that can be used to influence private passenger transport fuel consumption and associated CO₂ emissions.

The result of the regression analysis confirms the result of the decomposition analysis; that the growth in stock numbers is the most significant influence on consumption over the period. Further with a change of 4% over the period quantified as the impact of consumer choices from a time-dummy hedonic regression, those choices do not have a particularly strong impact on driving fuel consumption and associated emission.

Introduction
Transport is responsible for around a third of all energy use in Ireland and the associated CO₂ emissions account for a fifth of all CO₂ emissions including those from agriculture and other sources [1], [2]. Transport is also the fastest growing sector in terms of energy demand and is dominated by imported petroleum products. In order to meet international emissions targets and improve local air quality, effective policies are needed for transport. Within the transport sector private passenger transport accounts for close to half of all transport energy demand [3].

In order to understand the available policy levers it is necessary to understand the underlying factors influencing private car fuel consumption and related CO₂ emissions. One method of modelling private car energy consumption is a vehicle stock model. A decomposition analysis can be applied to a detailed stock model to understand the underlying trends influencing trends in overall energy consumption and emissions. This was the approach used in a companion paper and the results of that analysis are included in this paper [4].
In this paper an alternative model of private car fuel consumption is undertaken using a linear regression model. While the decomposition stock model analysis is limited by factor that are directly included in the energy modelling equation or identity, a regression can look at non-stock related factors such as fuel prices, employment and disposable income for example.

A common problem when analysing the trends of private car stocks is that the vehicle stock is constantly evolving and there is rarely matching of vehicles when they are replaced [5]. To work around this problem it is proposed to construct a hedonic index in this paper that accounts for the impact of the changes or evolution based on consumer preference for larger or newer cars.

A hedonic method allows information on non-matching observations to be used [6]. The name is derived from the Latin word hedonism which relates to pleasure. Hedonic regression is normally used to identify and valuate changes in the quality of goods and services from price changes [7]. The hedonic price method is used to measure the relative importance – through use of regression analyses – of independent or non-market variables on the price of goods and services.

A classic example of the application of hedonic regression is for house prices where the cost of environmental attributes such as air quality, or proximity of amenities such as schools are separated from house characteristics such a property size and number of floors or rooms [7]. For the purpose of the analysis in this paper the aim is to quantify the impact of consumer choices related to private cars on the overall energy consumption and energy-related emissions of that transport sub-sector.

This paper addresses the research question of the influence of consumer decisions on private vehicle energy use. It had been suspected that purchasing patterns out-weighted efficiency improvement [8]. By calculating a hedonic regression – based on the change in average engine size and the share of new vehicles in the stock a quantification of the consumer choice can be calculated.

It is possible to link a stock and a regression model by using common input factors. The rational for soft-linking of the two different models is based on the heuristic that any one specific energy modelling tool cannot address all aspects of the energy system being modelled [9]. In this paper the soft-linking facilitates gauging the ranking of influence of different direct and indirect factors on private car fuel consumption. In turn this can be used for development of evidence based policies.

The result of a model linear regression is a best fit line. The coefficients of the independent variables represent the slope of that best fit line. When a logarithmic transformation of the regression inputs (independent variables), and output (dependent variable) if undertaken prior to a regression analysis, termed a log-log regression, the coefficients of the independent variables represent the percentage change. In order to rank or compare the impact of the independent variables included in a regression the absolute value of the coefficients can be analysed. The results of a regression analysis are closer to that of a fixed base year decomposition analysis.

A regression model result is a predicted consumption (fuel consumption in litres was examined in this paper). In a hedonic regression the difference between the predicted best fit line and the actual energy consumption is explained by the hedonic effect. It is then possible to create an index of the hedonic effect. This hedonic index can then be compared to the results of a decomposition analysis to help gauge the impact of the hedonic effect relative to other factors.

Section 2 briefly discusses the methodology used in this paper when undertaking an OLS regression to quantify a hedonic influence. Section 3 presents the results of the different analysis. Section 4 discusses the policy implications of the results of the analysis. Section 5 concludes.
Methodology

In this paper an ordinary least squares (OLS) linear regressions is undertaken to provide a
quantitative basis for understanding the impact of private car stock characteristics that are
de not directly included in a consumption equation derived from a vehicle stock mode, as well
as other additional indirect factors. A linear regression methodology assumes that there is a
linear relationship between the variable being examined, the dependent variable, in this case
fuel use and the explanatory or independent variables. A scatter plot can be examined to
check the relationship between the dependent and independent variables in a regressions
analysis.

Where the relationship between the dependent and independent or explanatory variables is
not linear, it is possible to transform the regression input data, using logarithms, for the
purpose of simplifying the relationship between the variables and facilitating use of a linear
regression model. A logarithmic transformation changes skewed data into a normal
distribution. Using the logarithm of one or more variables instead of the un-logged form
makes the effective relationship non-linear, while still preserving the linear model [10].

Another advantage of using logarithmic transformations is that they produce multiplicative
relationships (or ratios) between the independent variables and the dependent variables of a
regression. Multiplicative relationships are considered more robust with longer life spans
when compared to additive relationships [10].

The interpretation of a log-log regression, based on the natural logarithms of all variables in
the regression equation, is the percentage change in the dependent variable when an
independent increases by some percentage. Where both the dependent and independent
variables are log-transformed, they are referred to as elastic in econometrics, and the
coefficient of natural log of the independent variable is referred to as an elasticity.

As well as the assumption of a linear relationship, another assumption underpinning a linear
regression analysis is that there should not be any strong positive correlation between the
independent variables of a regression analysis, also termed multi-colinearity. The question of
multi-colinearity is often resolved qualitatively and at the discretion of the analyst.

The results of an ordinary least squares regression are checked to see if the null hypothesis;
that the coefficient of a particular independent coefficient is zero, can be rejected. If the
probability value (p-value) is less than the level of significance (confidence level) then the
null hypothesis can be rejected.

An iterative approach is used to derive the hedonic regressions index. The first step is an
OLS linear regression, which relates the energy consumption to certain vehicle stock
characteristics. The regression results are then used to predict effects and adjustments are
made based on the predicted effects. A quality-adjusted index can be calculated from the
results. There are two methods of calculating a hedonic estimation of consumer preference.
An indirect hedonic method or predicted price approach, although in this paper it is the fuel
consumption that is predicted rather than price.

The imputation method involves estimating a hedonic function and using this function to
impute estimated consumption for the non-matched models. The predicted consumption
values are then used in an index formula in a conventional manner. This procedure is firmly
nested within conventional index methods, which means that the imputation method very
closely linked with index number analysis which in turn is the basis for Index Decomposition
Analysis (IDA). A drawback of this method is that a lot of data is required to construct the
hedonic function.

An alternative approach to construct a quality-controlled price index is the hedonic
regression time-dummy approach, sometimes called the direct hedonic approach. An
important and desirable feature of this index method is that it does not depend upon the
particular value of the quality-characteristics vector chosen. For the purposes of this paper,
where the hedonic effect should quantify changes to the vehicle stock as a result of
consumer choices where vehicles are not replaced as matched pairs a time-dummy approach was adopted. The justification for the time-dummy approach is that data are not readily available on differences between vehicles that are replaced in the stock.

Results
In this paper separate regressions are undertaken for the petrol private vehicle stock, the diesel private vehicle stock and also the combined petrol and diesel stock. Also, as the petrol consumption is non-linear over the twenty-year period examined, from 1995 to 2015, two time periods are examined separately. The first period spans 1995 to 2007 and the second 2008 to 2015.

Variables with data available for inclusion in a regression analysis are included in table 1. Individual regressions were run for each variable and the significance was tested using a 95% confidence level.

<table>
<thead>
<tr>
<th>Significant variable from multiple single variable OLS regressions</th>
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<tbody>
<tr>
<td>Petrol `95-'15</td>
</tr>
<tr>
<td>Price per litre (real)</td>
</tr>
<tr>
<td>Avg. mileage</td>
</tr>
<tr>
<td>Avg. age</td>
</tr>
<tr>
<td>Avg. engine size</td>
</tr>
<tr>
<td>Stock numbers</td>
</tr>
<tr>
<td>Fuel economy</td>
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<tr>
<td>Disposable income</td>
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<tr>
<td>Employment</td>
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<tr>
<td>Share of new cars</td>
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Once the significance of the variables for which reliable data are available was determined a multi-variable regression analysis was run, to facilitate comparison of the impact of those variables on overall fuel consumption. The total stock was used to calculate a multi-variable OLS regression equation as that has a linear trend throughout the period examined, unlike petrol consumption which increase year-on-year until 2007, when it reached peak consumption for the period examined and started to decline year-on-year since then.

Only two three-variable combinations resulted in regression equations where all variables were within the level of significance of 95%. One combination included employment share, average engine size and mileages, and resulted in an R-squared of 0.995. All coefficients were positive with engine size (2.27) significantly greater that employment (0.75), which had a coefficient that was almost twice the mileage coefficient (0.44). The second combination of stock numbers, employment and mileages had an R-squared of 0.993, with the stock numbers coefficient being the largest (0.61), followed by the mileage coefficient (0.49) and the employment coefficient (0.41).

In order to calculate a hedonic index a time dummy was added to the OLS regression analysis. The best regression equation which resulted in an R-squared of 0.998 and included a time dummy variable was a combination of the fuel economy of the stock – calculated from the total litres and the overall mileage to give a derived litres per hundred kilometres – and employment. The results are presented in Table 2 and were used to construct a predicted fuel consumption (in litres).

<table>
<thead>
<tr>
<th>All vehicle OLS regression results including time dummy</th>
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<tbody>
<tr>
<td><strong>Coefficients</strong></td>
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<tr>
<td>Intercept</td>
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</table>
The predicted consumption in litres calculated from the regression equation in table 2 was compared to the actual consumption over the twenty year period. The difference between index of change of the predicted and actual consumption was used to calculate the hedonic effect which relates to the change in the make-up of the vehicle stock due to consumer preferences. The overall change in the actual fuel consumption was an increase of 85% (when calculated as a chained index to a base year of 1995). The change in the predicted fuel consumption was 81%, (similarly calculated as a chained index to the base year of 1995), suggesting that the impact of consumer preferences which resulted in unmatched pairs when vehicles were replaced in the stock led to a 4% increase in fuel consumption.

It is interesting to compare the hedonic impact over the period to the results of a Log Mean Divisia Index (LMDI) regression over the period based on a bottom up stock model, presented in Table 3. The impact of consumer choice as measured by the hedonic time dummy OLS regression is less significant that all of the other stock model characteristics examined.

Table 3 LMDI-I 5-Factor decomposition analysis for overall vehicle stock fuel consumption

<table>
<thead>
<tr>
<th>% change</th>
<th>Stock</th>
<th>Mileages</th>
<th>Efficiency</th>
<th>Aging</th>
<th>Technology Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>98.27</td>
<td>-13.40</td>
<td>-19.57</td>
<td>4.76</td>
<td>14.49</td>
</tr>
</tbody>
</table>

Policy
The most commonly implemented private passenger vehicle policy measure globally relates to the fuel economy or emissions performance of vehicles. This is in spite of the most commonly advised policy strategy for controlling transport energy demand is to use the Avoid, Shift and improve (A-S-I) approach [11].

The Avoid term relates to urban planning and design, public transport planning. The Shift term relates to both shifting transport mode – to less energy and emissions intensive modes, as well as shifting technology or fuels. The Improve term relates to improving the fuel economy or emissions intensities of the different transport modes.

A significant problem in Ireland is that there is a large dispersed rural population that relies heavily on private vehicle transportation in order to reach their employment. Therefore neither vehicle ownership or total usage are desired policy levers. Instead soft measures which could reduce the annual average mileage of a large number of vehicles may be an effective policy lever, in light of the recent vehicle emissions scandals which highlight that the improvements from fuel efficiency may not actually be achieved in real world vehicle usage.

Conclusion
The results of a OLS regression analysis established that a vehicle stock model captures the most significant factors influencing private car consumption and emissions. The impact of consumer purchasing decision, which results in the vehicle stock constantly changing as there is rarely matching of vehicles when they are replaced, was quantified as increasing overall consumption of the stock by 4% over the 20 year period examined. Thus it can be concluded that those consumer choices do not have a particularly strong impact on driving fuel consumption and associated emissions relative to other vehicle stock characteristics such as the overall size of the vehicle stock and the average annual mileage.
References


