Energy, Emissions and Electrics: New Zealand's Car Fleet in the 21st Century

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I ABSTRACT

In this thesis, I concentrate on light passenger vehicles (or “cars”) in New Zealand. The oil price forecasting and vehicle choice literatures are reviewed, along with a number of other relevant strands of research. I explore and critique the implications of the rational model of vehicle choice. I investigate the impacts of purchase price and operating costs on the types of cars registered in New Zealand over the 2002-2010 period, using data from the Ministry of Transport and Statistics New Zealand and a multinomial logit model. These results are used in the initial calibration of the “Transport Scenarios Model”, which enables a range of different future scenarios to be tested, focusing on the opportunity for plug-in hybrid and battery electric vehicles. Given various user-specified inputs, the model predicts the aggregate travel, energy use and greenhouse gas emissions of New Zealand’s car fleet in the future.

II ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

III ABBREVIATIONS AND ACRONYMS

BEV	Battery Electric Vehicle
CPI	Consumer Price Index
EPA	U.S. Environmental Protection Agency
ETS	Emissions Trading Scheme
GBM	Geometric Brownian Motion
GDP	Gross Domestic Product
GOU	Geometric Ornstein–Uhlenbeck
GST	Goods and Services Tax
GUI	Graphical User Interface
IEA	International Energy Agency
kWh	Kilowatt-Hours
MED	Ministry of Economic Development
MOT	Ministry of Transport
$NZD	New Zealand Dollars
OPEC	Organization of Petroleum Exporting Countries
PHEV	Plug-in Hybrid Electric Vehicle
SNZ	Statistics New Zealand
$USD	U.S. Dollars
VKT	Vehicle Kilometres Travelled

1 INTRODUCTION

The last two years have been momentous ones for the automotive industry, with the launch of the world's first production plug-in hybrid electric vehicle (PHEV), the Chevrolet Volt. The Nissan Leaf, a battery electric vehicle (BEV), also represented a step forward for the industry, recognised by the Leaf being named the 2011 "Car of the Year" (Car of the Year, 2011).

Meanwhile, in New Zealand, we continued to import vehicles from overseas, many of which had had a previous life with other owners. We imported oil, petrol and diesel to fuel our vehicle fleet. As calculated in section 2.2, car imports totalled almost $3 billion in 2010, while net oil imports were nearly $3.5 billion. These items represent around 15% of our total imports and contribute to our significant and sustained balance of payments deficit.

Transportation continues to be almost entirely dependent on fossil fuels in most parts of the globe, and the transport sector is a major contributor to greenhouse gas emissions. In 2009, New Zealand's car fleet accounted for 17.7% of the country's net CO_2-equivalent emissions, as shown in section 2.10. The Ministry of Economic Development (MED, 2010, p. 3) refers to the transport sector as "the key challenge to lowering emissions" in New Zealand.

The way in which we travel also has ramifications beyond global warming. Private vehicle travel can generate negative externalities such as congestion, noise and local reductions in air quality. On the other hand, cars have enabled greatly increased mobility and are a major part of most New Zealanders' lifestyles. Issues around private vehicle travel are especially pertinent in New Zealand, since, as noted by the MED (2010), we have more cars per head of population than nearly every other country in the world. Perhaps unsurprisingly, we make relatively little use of public transport (Ministry for the Environment, 2009).

This thesis has a New Zealand-centric focus, and it is my hope that it will be a useful contribution to the debate over how our passenger transport sector should evolve in the future. The issues faced by the transport sector are too broad to cover in a single thesis, and my work has focussed on travel in private vehicles, and the potential for changes in New

Zealand's vehicle fleet – especially the introduction of electric vehicles – to influence energy demand and greenhouse gas emissions.

New Zealand policymakers should concern themselves with these advanced vehicles for several reasons. Firstly, electric vehicles attract government subsidies in many countries – presumably either because they generate positive externalities, or because governments are trying to help fledgling electric vehicle industries achieve economies of scale and thus future savings. A number of countries are also investing in infrastructure that will make these vehicles more effective. Secondly, electric vehicles can have an impact on greenhouse gas emissions, and the government is responsible for designing emissions policy. Thirdly, electric vehicles can reduce our need to import oil, a commodity which is prone to drastic price changes and supply shocks.

The New Zealand Government (2007, p. 44) made "an in-principle decision... for New Zealand to be one of the first countries to widely deploy electric vehicles". However, little progress has been made on this front. Aside from a short-term exemption on Road User Charges for BEVs – which could be renewed, combined with a more generous package or scrapped entirely when it expires in 2013 – there is no program for encouraging uptake of advanced or other fuel-efficient vehicles.

Indeed, it is not immediately clear why New Zealand *should* be an early adopter of electric vehicles. We have little skin in the game, with no domestic vehicle manufacturing industry, and no particular competitive advantages in the rapidly growing high-tech battery manufacturing industry. Furthermore, our small market size means that we will have little influence on worldwide demand for these advanced vehicles: the battle for cost-effective electric vehicles will be fought on foreign shores.

Chapter 2 of this thesis reviews the literature around oil prices, their effects and how best to model them. It also explores the past and possible future trends in vehicle fuel efficiency, giving particular attention to the potential role of advanced vehicles such as PHEVs and

BEVs. I review the energy efficiency and “well-to-wheels” emissions of these vehicles, examine taxation issues and consider the situations in which they could benefit New Zealand.

In Chapter 3, I undertake a simple analysis of a hypothetical, rational consumer who considers expected lifetime fuel costs when deciding which car to buy. This analysis suggests that rational consumers would be prepared to pay substantially more up front for an advanced vehicle in order to reap the long-term savings from using less fuel, with PHEVs likely to prove more attractive than BEVs. I then critique the “rational” model, concluding that while it may not adequately represent consumer behaviour, it is a useful and appropriate way to evaluate vehicle purchase decisions. From the black-and-white decisions made by consumers in the simple rational model, I move on to consider the logit models that are more commonly used to predict consumer choices.

In Chapter 4, I use a logit model to explain observed car registration patterns between 2002 and 2010. This analysis is carried out at the New Zealand-wide level, distinguishing between small, medium and large cars and between “new” and “used import” cars – the latter being a very particular feature of the New Zealand market. My findings suggest that, while substitutions between these car types did occur in the last decade, these shifts had little to do with fuel price changes.

Chapter 5 contains an overview of the Transport Scenarios Model, a MATLAB program which was developed for this thesis. Using results from the earlier chapters, I construct a model which, using oil prices and a number of other parameters which can be specified by the user, predicts changes in New Zealand’s car fleet over time. The model forecasts the number of cars in the fleet, the distance they travel, their energy demand in terms of petrol, diesel and electricity, and their greenhouse gas emissions.

Chapter 6 shows the results of several “runs” of the model, giving a range of different outcomes. Chapter 7 elaborates on some the assumptions of the model and suggests avenues for further work, and Chapter 8 concludes this thesis.

2 LITERATURE REVIEW

2.1 Historical Trends in Oil Prices

To understand the issues around transport energy, it is necessary to look at the history of oil. Despite the recent growth in biofuel production, oil remains by far and away the most important transport energy source worldwide. In New Zealand, oil products accounted for 99.8% of transport energy demand in 2010 (MED, 2011a).

The electric motor predates the internal combustion engine, and many early motor vehicles ran on electricity rather than gasoline. However, oil-based fuels had a number of advantages over electricity. The International Energy Agency (IEA, 2009) points out that these fuels gave much more energy per unit of volume or mass than batteries, and were easy to handle, transport and store. These advantages, combined with the fragmented nature of electricity networks at the time (Beard & Chakravorty, 2010), led to oil-based fuels becoming the dominant source of transport energy.

Over the twentieth century, increasing wealth and better technology made motor vehicles increasingly affordable. Globally, the number of cars per capita has increased rapidly since the 1970s (IEA, 2004, p. 130). New Zealand has followed a similar trend, with increasing access to cars being accompanied by a decline in public transport use (Dravitzki & Lester, 2007). The increasing demand for vehicles has led to higher demand for oil.

Today, oil-based fuels still have several advantages over alternative fuels. These include what amount to first-mover advantages: “strong demand from the current stock of vehicles and a widely established infrastructure for delivery to users”, and “extensive experience and knowledge of fuel systems, coupled with considerable progress having been made in optimising them” (IEA, 2009, p. 83). Even today, oil-based fuels are relatively cheap compared to many other sources of energy, and “there are generally no economic substitutes available for liquid fuels in [transport] applications” (R. D. Samuelson & Taylor, 2005).

Oil-based fuels are not without their disadvantages: they can lead to air pollution, although this can be mitigated through better refining processes and car modifications, e.g. catalytic converters (IEA, 2009). The "oil shocks" of the 1970s illustrated another disadvantage of oil as a fuel: the potential for supply shocks and price spikes. More recently, another negative factor for oil has come to the fore: the high greenhouse gas emissions associated with its combustion.

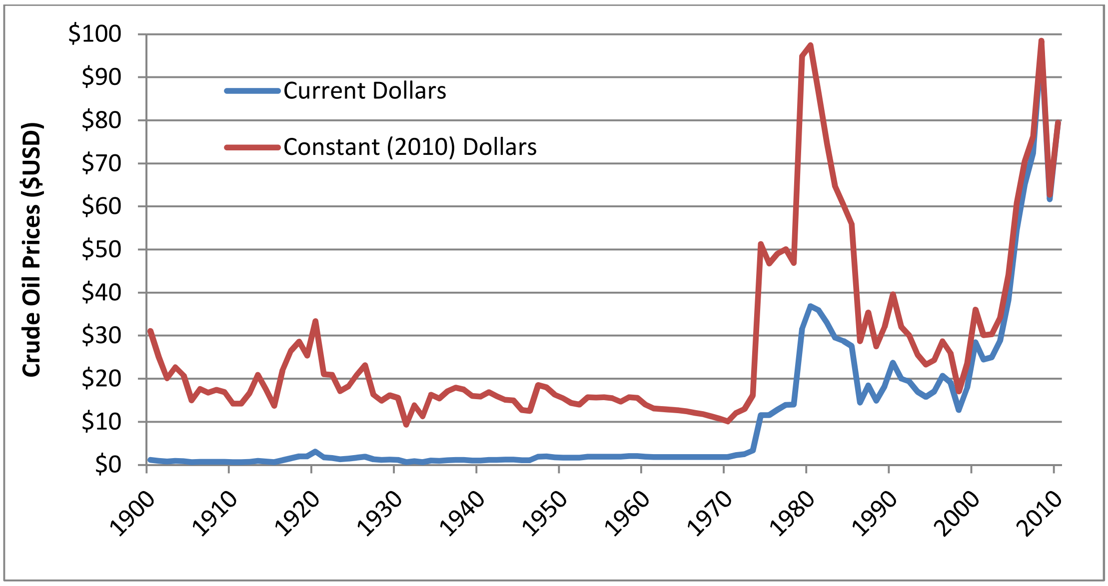
In real terms, world oil prices remained fairly low for the first 70 years of the twentieth century. In the 1970s, oil prices soared as a result of events in the Middle East. The Yom Kippur War and subsequent oil embargo by the Organization of Petroleum Exporting Countries (OPEC) led to a dramatic increase in prices in 1974. This was followed by a further doubling of prices in 1979, as a result of the Iranian revolution.

Internationally, governments took various actions to mitigate the impact of these massive increases in oil prices. In New Zealand, these initiatives included lower speed limits on open roads; graduated registration and licensing costs to encourage people to buy small cars; the "carless days" scheme, notorious even though it was in effect for less than a year; and attempting to identify alternative fuels such as compressed natural gas and liquefied petroleum gas (Dravitzki & Lester, 2007).

The price of oil fell during the 1980s as OPEC nations expanded their production, and other non-OPEC countries became more significant oil producers. Prices continued to decline in real terms until the early 2000s. From around 2004 onwards, oil prices have increased sharply again. This has occurred in the context of rapidly growing demand from developing countries such as China, and continued instability in the Middle East – including the US-led occupation of Iraq (Twomey & West, 2008).

Figure 1, overleaf, shows the way in which world oil prices have fluctuated over the last 110 years.

Figure 1: World Oil Prices for 1900-2010, in U.S. Dollars per Barrel



Source: BP (2011b).

Samuelson and Taylor (2005) state that "oil prices have been highly volatile [since 1970], and seem likely to stay that way... the oil market as it is structured today seems inherently prone to further disruption". They also argue that "over the longer term, the oil industry appears to be a highly cyclical one, with periods of tight supply, high prices, and high investment followed by periods of glut, low prices, and low investment" (R. D. Samuelson & Taylor, 2005).

Whatever the causes of specific oil price shocks, the size and scale of their effects is due to another characteristic of the oil market: both the demand and supply curves for oil are inelastic, meaning "that unforeseen changes in supply and/or demand result in substantial changes in price" (Donovan et al., 2009, pp. 6-7).

Events in the last few years seem to have proven Samuelson and Taylor right, with oil prices spiking dramatically to almost $140 U.S. dollars (USD) per barrel in July 2008 – even as the world economy began to waver – before plummeting to finish the year at less than USD $40/ barrel (MED, 2012b). Meade (2010, p. 1486) mentions that this bubble has been variously attributed to "an economic boom in the world's largest developing countries, particularly China and India; restrictions in supply; [diminishing] known reserves [or]... an excess of speculative activity".

2.2 Oil Prices, Macroeconomic Factors and Energy Security

It is generally accepted that high oil prices can have negative macroeconomic consequences for oil-importing countries, including lower growth and higher inflation (Milani, 2009), although their effects are now less pronounced than they were in the 1970s (Blanchard & Gali, 2007; Milani, 2009). Blanchard and Gali (2007, p. 1) attribute this to the "smaller share of oil in production... more flexible [labour] markets, and... improvements in monetary policy".

However, advanced economies continue to rely on oil, much of which has to be imported. This leads to the concept of energy security, which the IEA (n.d.) defines as "the uninterrupted physical availability [of energy] at a price which is affordable, while respecting environment concerns". Oil is a rather insecure source of energy, given its volatile prices, and the small number of – sometimes quite unstable – countries which export it. To give some measure of security, countries which belong to the IEA, such as New Zealand, are "obliged to hold oil stocks equivalent to 90 days of [their] net imports" (IEA, 2011, p. 2).

Along with most developed countries, New Zealand is a net importer of oil; in 2010, a net 49% of the oil and oil products we consumed were imported (MED, 2011a). When oil prices rise, New Zealand is forced to pay more for these products, adding to our current account deficit and transmitting a shock through the economy. Given the low short-term elasticity of demand for oil, the economy is highly sensitive to such price rises.

New Zealand's net imports of oil and oil products amounted to 195.65 petajoules in 2010, or 31,992,156 barrels of oil equivalent (MED, 2011a). The average world oil price in 2010 was $108.21 in New Zealand dollars or $NZD (MED, 2012b), suggesting that our net oil imports for the year came to $3.462 billion. Additionally, figures from Statistics New Zealand (SNZ, 2011d) show that $2.836 billion of "passenger motor cars" were imported into New Zealand in 2010.

By comparison, New Zealand's current account deficit for 2010 came to $4.381 billion (SNZ, 2011a), part of a nearly four-decade run of annual deficits (Reserve Bank of New Zealand, 2012). Given the current state of the global economy, our high levels of international debt are a particularly pressing concern. The scale of transport and oil-related imports is such that if New Zealand is able to use oil products more efficiently, we could greatly improve our current account deficit.

As discussed later in this thesis, electric vehicles have the potential to greatly reduce New Zealand's transport emissions, and deliver a range of other benefits. However, King (2007, p. 9) asserts that "arguably [their] largest benefit for New Zealand will be gains in energy security... using transport fuels other than oil will increase our energy diversity, improve our ability to cope with fluctuations in international oil prices and significantly improve our balance of payments".

If they are to improve New Zealand's current account deficit in the long run, electric vehicles will have to deliver fuel savings over their lifetime to the extent that they recoup their higher up-front prices, a subject tackled in chapter 3. If electric vehicles can do this, then they have the potential to help solve a long-standing problem for New Zealand, and their introduction could have very positive implications in the long run.

Whether or not electric vehicles are able to do this, there is surely some additional benefit from their use, since they improve our energy security and help to decouple the economy from oil. If these vehicles become widely established, New Zealand would be likely to enjoy more stable economic growth, and lower and more predictable inflation rates.

2.3 Modelling Oil Prices

Predicting the future is always fraught with uncertainty, especially in the transport sector. Oil prices are very hard to predict, and there is uncertainty over how much oil can be produced from unconventional sources, and the extent to which alternative fuels can supplant oil.

Samuelson & Taylor (2005) reviewed the empirical literature on futures markets, noting that the literature has found futures markets to be unbiased and the most efficient predictor of future oil prices. Even so, these markets are relatively *weak* predictors of what the oil price will be in the future. Furthermore, futures markets only cover the short to mid-term, meaning that other means of prediction must be used for the long term.

As at November 2005, the NYMEX futures markets were predicting oil prices to slowly decline over the period to December 2011, from $57.68 to $53.13 in nominal $USD, with most analysts agreeing that prices were expected to fall (Samuelson, 2005). Spot prices reached this level briefly in 2008-2009, but have since recovered. By December 2011, spot prices for West Texas Intermediate oil were fluctuating around $100 a barrel.

Given that oil experts struggle to predict future oil prices, it is little wonder that consumers are in the dark. According to an online survey carried out by ShapeNZ in May 2008, 91% of respondents expected petrol and diesel prices to rise over the next two years (ShapeNZ, 2008). With the benefit of hindsight, it is apparent that fuel prices were almost at their peak at the time of this survey, at around $1.90 for a litre of 91-octane petrol. Although prices continued to rise over the next two months – reaching $2.17 briefly in July 2008 – they fell soon after, and remained below $1.90 until late 2010.

There is little agreement in the literature about the best way to model long-term oil prices. One of the simplest methods is to assume a Geometric Brownian Motion (GBM) process. As noted in Pindyck (1999), a GBM process for the price of oil is one which can be represented by the following equation:

$$dP_{oil,t} = \delta\, P_{oil,t}.dt + \sigma P_{oil,t}.dZ \tag{1}$$

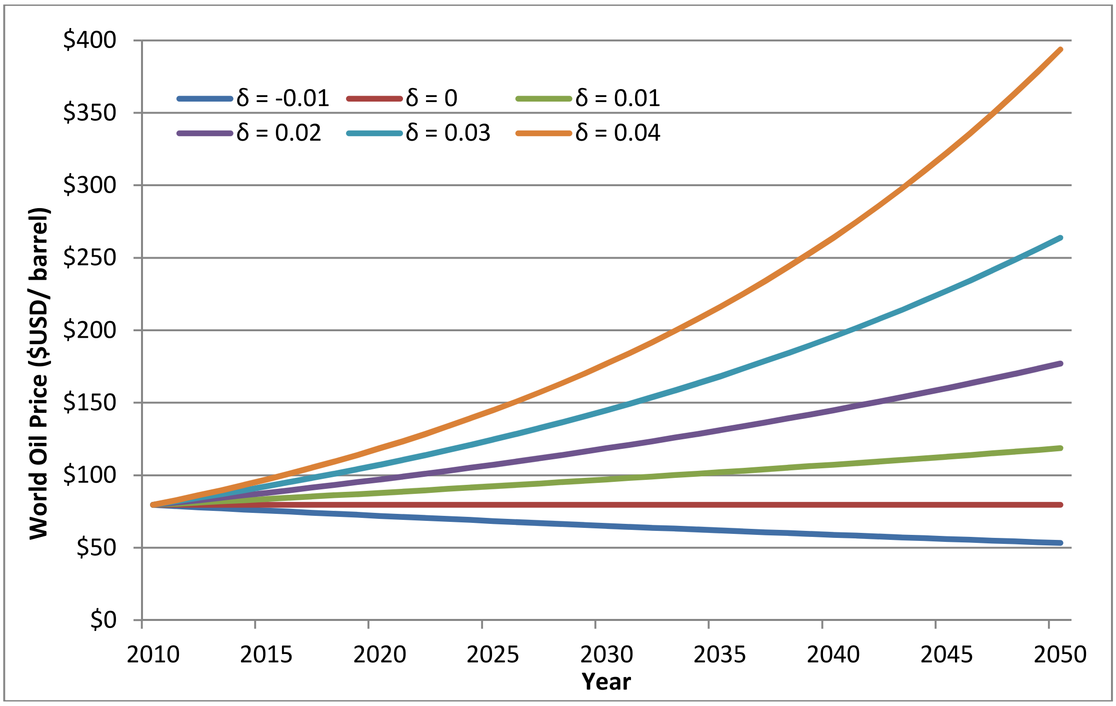
In equation 1 above, δ is the “drift term” – or the expected growth rate of the price – and σ is the “volatility term”, with both δ and σ being constant. Z is a Wiener process and is stochastic. Following Kaffel and Abid (2009), the Wiener process I use is simply a standard normally distributed random variable which is recalculated each period, N_t~(0,1).

The differential equation above gives rise to the following equation for the price of oil:

$$P_{oil,t} = P_{oil,t-1} \exp\left[(\delta - \sigma^2/_2)\Delta t + \sigma Z\sqrt{\Delta t}\right] \tag{2}$$

If the stochastic parameter σ is set to zero, the GBM equation becomes a simple non-stochastic, exponential growth formula. Figure 2 below shows future oil price paths for the case in which σ=0, for a range of δ values.

Figure 2: Exponential Oil Price Growth, for a Range of Delta Values



The exponential form used for the GBM equation ensures that oil prices will always be strictly positive, although there is a small chance that they can reach unrealistically low or high prices – e.g. lower than the marginal cost of production at the most efficient fields, or significantly higher than the point at which biofuels or other substitutes for oil become competitive. Furthermore, the basic Hotelling model predicts that the prices of an exhaustible resource will increase exponentially (Beard & Chakravorty, 2010), although there are of course a large number of factors which can intrude to prevent this.

There are various advantages to modelling oil prices with GBM: such processes are simple, parsimonious and allow closed form solutions for many problems (Postali & Picchetti, 2006). However, the GBM model gives little insight into the underlying characteristics of the oil market.

Other researchers have postulated that, while oil prices fluctuate randomly, they have a tendency to revert to a "mean" or equilibrium price in the longer term. This mean price may be allowed to change over time; we might expect the mean price to increase as oil resources become depleted (Hotelling, 1931). One type of mean-reverting process is the Geometric Ornstein–Uhlenbeck process, which is formulated so as to remove the possibility of having prices less than zero. As given in Postali and Picchetti (2006), this is a process defined by the equation:

$$dP_{oil,t} = \eta(\bar{P}_{oil,t} - P_{oil,t})P_{oil,t}.dt + \sigma P_{oil,t}.dZ \quad (3)$$

Postali and Picchetti (2006) summarise the rationale behind the GOU process as follows. The model is predicated on the argument that when prices are above their long-term average, high marginal cost producers will enter the market, and vice versa. Prices take some time to return to trend; on the supply side, entry and exit is not instantaneous – given, for example, the time required to develop a new oil field. On the demand side, the fact that long-term elasticity tends to exceed short-term elasticity means that consumers will tend to slowly reduce their demand over time.

While mean reverting processes may be closer to the true picture, Postali and Picchetti (2006, p. 511) suggest that the "speed of reversion is low enough to allow the use of Geometric Brownian Motion as a good proxy for the evolution of oil prices". Part of the reason for this is that both the level and the slope of the mean price appear to vary stochastically. Indeed, the mean price trend is "unclear and unstable, subject to a complex information set rarely available to every agent, which causes great variability in the forecasted price" (Postali & Picchetti, 2006, p. 522).

Postali and Picchetti (2006) note that under GBM, a price change causes all future prices to be re-evaluated, whereas under GOU, the mean reversion property "imposes an upper bound to the expected changes... For this reason, mean reverting movements produce a lower level of [price] uncertainty than the GBM". The higher level of uncertainty associated with GBM is perhaps an advantage, given that neither GBM nor GOU can account for unexpected future price spikes.

Meade (2010, p. 1485) argues that "in addition to reflecting the [day-to-day] volatility of the market, the density function of future prices should also incorporate the uncertainty due to price jumps, a common occurrence in the oil market". Models such as GBM and GOU have been extended to include such jumps, with Kaffel and Abid (2009, p. 996) concluding that a GBM process with jumps "is the best stochastic process for [modelling] the crude oil price".

However, as Meade (2010, p. 1485) points out, "modelling these [price jump] events tends only to improve in sample fit rather than improve forecasting accuracy". Samuelson (2005, p. 3) argues that since 1970, "most of the events that impacted oil prices were unpredicted and inherently unpredictable. There is nothing to suggest that the [future is] going to be any different". There is no easy way around this problem, and indeed, if stochastic modelling processes are modified to incorporate specific historical shocks then they will presumably *understate* average volatility.

Meade (2010, p. 1497) argues that GBM "is not supportable as a long term model", since volatility actually appears to vary over time, and since oil prices "exhibit many jumps of a magnitude completely inconsistent with a Gaussian density function". To tackle the first problem, Meade (2010) proposes that a generalised autoregressive conditional heteroskedasticity process be used instead. Meade (2010, p. 1497) does not have a solution for the second, indeed, he "regard[s] the structural breaks that occur in the oil market [as] too frequent to model" and argues that "evidence from the literature suggests that modelling breaks does not improve out of sample forecasting accuracy."

Despite Meade's reservations around GBM, the simplicity and ease of use of this process means that I have chosen to incorporate it in my modelling work. The final word is given to Pindyck (1999), cited in Postali and Picchetti (2006): "for irreversible investment decisions for which energy prices are the key stochastic state variables, the GBM assumption is unlikely to lead to large errors in the optimal investment rule."

2.4 Future Oil Price Scenarios

The International Energy Agency (IEA) and the U.S. Energy Information Administration are two organisations which have created publicly available scenarios of how oil prices could change in the future.

2.4.1 Scenarios from the International Energy Agency (IEA)

The World Energy Outlook is an annual IEA publication, with the most recent version considering oil prices from 2010 to 2035 under three different scenarios: the "Current Policies Scenario", "New Policies Scenario" and "450 Scenario" (IEA, 2011). The oil price is just one of the outputs of the modelling process, which also looks at a wide range of other energy-based supply and demand issues, and initiatives.

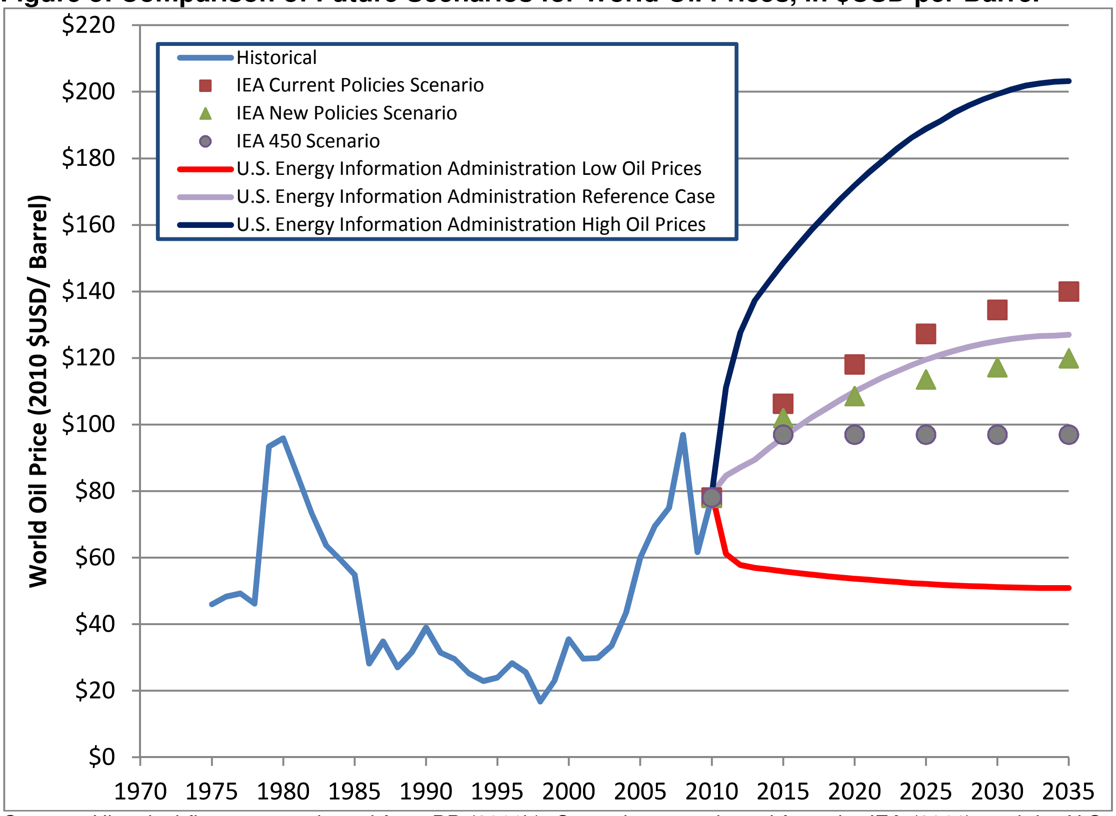
The IEA's "central" scenario is the New Policies Scenario. This assumes that governments implement the policies they have announced, although with a degree of conservatism. The "Current Policies Scenario" assumes a continuation of government policies in place as at mid-2011, but does not take into account probable future changes in policy. The "450 Scenario" is aimed at restricting atmospheric CO_2-equivalent increases so that the global average concentration stabilises at 450 parts per million.

Under the drastic policy changes envisaged in the 450 Scenario, oil is likely to become a much less desirable energy source, leading to a decline in world oil prices. However, the IEA assumes that retail prices for petrol and diesel in the 450 scenario will be similar to those in the Current Policies Scenario, through increased government taxation on oil-based fuels. This "ensures that the lower international prices [for oil, petrol and diesel]... do not lead to a rebound in transport demand through lower end-user prices" (IEA, 2011, p. 62).

2.4.2 Scenarios from the U.S. Energy Information Administration

The U.S. Energy Information Administration is a US government department and, like the IEA, it produces an annual publication – the *Annual Energy Outlook* – with oil price scenarios out to 2035. The central "Reference" scenario "is a business-as-usual trend estimate, given known technology and technological and demographic trends" (U.S. Energy Information Administration, 2011, p. ii). The "Low Oil Price" and "High Oil Price" scenarios adopt rather different assumptions about demand growth from the developing world and oil supply, with prices reaching $50/ barrel and $200/ barrel respectively in 2035. Figure 3 below shows oil prices from 2010 to 2035 under the six scenarios put forward by the IEA and the U.S. Energy Information Administration.

Figure 3: Comparison of Future Scenarios for World Oil Prices, in $USD per Barrel



Sources: Historical figures are adapted from BP (2011b). Scenarios are adapted from the IEA (2011), and the U.S. Energy Information Administration (2011).

Significantly, none of the scenarios above – with the exception of the U.S. Energy Information Administration's "Low Oil Prices" scenario – resemble an exponential function, which makes it difficult to compare them with the GBM model. However, the two central scenarios show oil prices reaching around $120/ barrel by 2035. A similar result can be obtained in the GBM model by setting $\delta=0.02$ and $\sigma=0$, although of course the price path before and after 2035 looks rather different.

The U.S. Energy Information Administration (2011) also summarises several other long-term oil price projections. These all fall within a similar range to the IEA and U.S. Energy Information Administration projections described above, and as such, I have not considered them further.

2.5 Historical Trends in Car Fuel Efficiency

Light passenger vehicles, or "cars", are significant users of transport energy. Their energy consumption depends on two factors: their fuel economy or efficiency, and the distance they travel. In the future, New Zealand's energy demand will be heavily influenced by the extent to which we can make fuel economy improvements to our car fleet.

This issue is complicated by the slow rate of fleet turnover: vehicles bought today have a good chance of still being around in twenty years' time. Furthermore, history is not on our side: fuel economy seems to have improved little in recent decades.

Over the last 35 years, automotive technology has improved markedly, and car engines have become much more efficient. The U.S. Environmental Protection Agency (EPA) notes (2010b, p. 39) that "at constant weight, [2009 model] cars consume about 40% less fuel per mile than their [1975 model] counterparts".

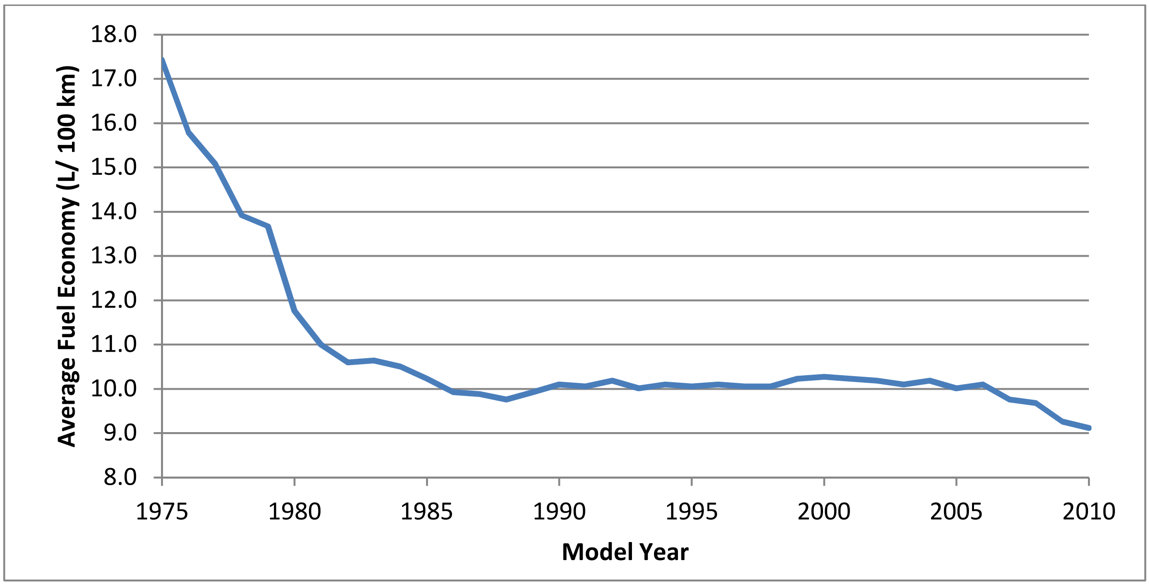
The "constant weight" proviso is an important one, because cars have become significantly heavier in many countries. Heavier cars require more energy to move, and as such, fuel economy improvements have tended to be less drastic than improvements in engine efficiency.

Furthermore, on-road fuel economy – that is, what vehicles actually achieve on the road, in real conditions – has improved less than lab-measured fuel economy. The reasons for the lack of improvement include increased congestion, and much wider use of energy-intensive extras such as air conditioning (IEA, 2004). Kwon (2006) estimates that there is a 10% gap between lab-measured and on-road fuel efficiency for new cars in Britain, and cites other studies which have found a gap of 10% to 25% in other countries. New Zealand is likely to have a relatively small gap between lab-measured and on-road performance, as our roads are less congested and our temperate climate means we do not use air conditioning as intensively as other countries.

Figures from the IEA (2004) show that lab-measured fuel economy improved in many European countries from 1980 to 2000, while improvements in the US, Australia and Japan were modest or non-existent. New Zealand is likely to have followed a similar path to these last three countries, although there is no long-term data series on the fuel economy of New Zealand vehicles.

Long-term data on fuel economy is available for the US, where the EPA has collected detailed information on fuel economy trends for new vehicles over the last 35 years. The EPA (2010b, p. 5) found that the average fuel economy of new "light-duty vehicles" – including cars, vans and SUVs – has gone through four phases since 1975, as shown in **Figure 4** below. In response to regulatory requirements on car manufacturers, average fuel economy increased rapidly through the late 1970s and more slowly through the 1980s. From the late 1980s until the mid-2000s, fuel economy was essentially flat, in an environment of low fuel prices and benign regulation. Fuel economy has begun to increase again from 2005 onwards – this can presumably be put down to fuel price rises, since there were no changes in the regulatory structure during this period.

Figure 4: Average Fuel Economy for New U.S. Cars, for 1975-2010 Model Years



Source: adapted from appendix C5 of the EPA (2010b).

However, these overall trends give an incomplete picture. Firstly, there has been "explosive" growth in the number of sports utility vehicles produced since 1990, to the point where they now make up 25% to 30% of new light-duty vehicle sales in the US (EPA, 2010b, p. v).

Furthermore, even during the 1987-2004 period when fuel economy was static or declining, automotive technology continued to improve (EPA, 2010b). Cars became larger and heavier – this gave them more interior space and allowed more features to be accommodated. Vehicle performance improved, with cars achieving higher horsepower and better 0-60 mph times. A host of new features were added, including some which contribute to higher fuel use: air conditioning and automatic transmissions. Vehicle safety improved, through better vehicle design and new features such as airbags.

Since 2005, however, technology has been used to improve both fuel economy and other vehicle performance measures. Importantly, the average weight of new vehicles has now stabilised (EPA, 2010b). In the future, we can expect that conventional vehicles will continue to improve their fuel economy, especially if oil prices remain high.

New Zealand is likely to have followed broadly similar trends to the USA – although most of our cars now come from Japanese manufacturers, the trends in technology and vehicle size are likely to be common to New Zealand. As for the US (EPA, 2010b), New Zealand has a predominantly petrol-fuelled fleet, and a large proportion of SUVs in our light fleet.

As an additional comparison, Mees (2008), as cited by Dodson, Li, and Sipe (2009), shows that observed on-road fuel efficiency for Australian passenger vehicles was remarkably constant from 1963 to 2006, fluctuating between 11.4 and 12.6 L/ 100 km.

In summary, therefore, data from other countries suggests that the on-road fuel efficiency of New Zealand cars will have been little improved over the last few decades, despite significant improvements in automotive technology. However, cars are larger, more powerful, more comfortable and safer than they have been in the past. Recent trends suggest that the cars entering our fleet are now becoming more efficient, and this will have a growing influence on our observed aggregate energy demand.

Data from the Ministry of Transport (MOT, 2011) shows that on-road fuel economy for New Zealand petrol vehicles has remained very flat between 2001 and 2010, averaging 10 L/ 100 km. This is in spite of a significant rise in petrol prices over the decade. However, the lab-measured fuel economy of vehicles entering the fleet has improved since recording began in 2005 (MOT, 2011).

2.6 Conventional Vehicles: Petrol, Diesel and Hybrid Cars

As discussed below, the fuel efficiency of New Zealand's car fleet could increase in the future due to "conventional" vehicles becoming more efficient, and through the introduction of new "advanced" vehicles which are inherently more efficient. Conventional vehicles are defined in this thesis as cars which use internal combustion engines and run only on liquid or gaseous fuels. For the most part, such vehicles run on petrol or diesel, although other fuels such as compressed natural gas or biofuels can also be used. These alternative fuels are fairly unimportant for New Zealand – although biofuels could increase in importance in the future – and they have not been covered in detail in this thesis.[1]

According to a range of sources, there is still significant scope to improve the fuel efficiency of conventional vehicles. This is due to various fuel-saving technologies, such as continuously variable transmissions rather than automatic transmissions, diesel rather than petrol engines, hybridisation, regenerative braking, and so on. These technologies are likely to become more widespread over the longer term, and assuming that vehicle weights do not increase in the future, they will lead to reduced fuel consumption.

The IEA (2010, p. 109) estimates that "it [will be] possible to reduce the fuel consumption of a conventional internal combustion engine vehicle of medium size on average worldwide by about 40% [by 2030]... compared with the year 2000", and that this will exhaust the limits of engine technology. Similarly, BP (2011a, p. 30) envisages the average fuel economy of new vehicles improving by around 35% between 2010 and 2030, although it is unclear whether this is partly due to an uptake of advanced vehicles. The Boston Consulting Group (2009) takes a more pessimistic view, and believes a 20% increase in efficiency can be achieved for conventional petrol cars.

Regulation, whether here or overseas, is also likely to encourage changes. The MED (2010, p. 4) notes that "in Europe and Asia, vehicle manufacturers are now being strongly regulated to improve the efficiency of vehicles and New Zealand drivers should benefit as these more efficient vehicles are purchased and gradually replace the existing stock". However, in their Reference Scenario modelling, the MED (2010) assumes that the fuel efficiency of new light vehicles will improve by just 11% by 2030, a more conservative outlook than any mentioned above.

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[1] According to figures from the New Zealand Transport Agency (New Zealand Transport Agency, 2011a), there were just 19 cars running on compressed natural gas at the end of 2010, and 1,155 running on liquefied petroleum gas – compared with a total fleet of more than 2.8 million cars.

In the European Union, high-efficiency cars make up a rapidly increasing share of new car registrations – 29% in 2010 (European Automobile Manufacturers' Association, 2011). These cars have CO_2 emissions of less than 120 g/ km, equivalent to a petrol fuel efficiency of better than 5.2 L/ 100 km. The next most efficient category of cars, with CO_2 emissions of 121-140 g/ km, has also increased its share of registrations in the European Union, reaching 30% in 2010 (European Automobile Manufacturers' Association, 2011).

By comparison, figures from the MOT (2011) show that just 1% of new light vehicles registered in New Zealand in 2010 had CO_2 emissions of less than 120 g/ km, and 11% had emissions of 121-150 g/ km. This suggests that we have some way to go before we approach the efficiencies already being achieved in Europe.

2.6.1 Diesel Cars

In general, diesel engines are more efficient than their petrol counterparts. Diesel cars typically use 20% to 30% less fuel than comparable petrol models, as noted by the EPA (2010b) and New Zealand Government (2007). However, this is mitigated somewhat by the energy density of diesel, which is around 10% higher than that of petrol.

Although they offer improved fuel economy, diesel cars are more expensive than petrol cars. Figures from the Automobile Association (2011a; 2011b) suggest that the price differential for diesel cars ranges from $2,281 to $4,882, depending on the vehicle size.

Nonetheless, diesel cars have become increasingly popular in Western Europe over the last decade, and they accounted for 51.8% of new car registrations in 2010 – up from 32.8% in 2000 (European Automobile Manufacturers' Association, 2011). According to the New Zealand Government (2007) and the MED (2010), we are likely to see a similar trend here.

2.6.2 Hybrid Cars

Many of the most efficient cars on the road today are hybrids. Unlike PHEVs, hybrids run entirely on oil-based fuels, and cannot be plugged in to a source of electricity to recharge the battery; as such, they require no new infrastructure. As such, they can be simply thought of as particularly efficient "conventional" vehicles, rather than advanced ones.

The IEA (2009) and McConnell and Turrentine (2010) estimate that hybrids will be able to improve fuel efficiency by more than 40% compared to similarly sized non-hybridised cars. Like other fuel efficiency-improving technologies, hybridisation is expensive, with the IEA (2009) estimating that, even without considering development costs, hybrids currently cost around USD $2,450 more to build than comparable petrol cars.

2.6.3 Biofuels

Biofuels are fuels that are made through biological processes and which can be produced on relatively short timescales. These fuels are renewable, "so long as the growth of new crops and trees replenishes the supply" of biomass used to produce them (IEA, 2010, p. 284). In theory, the cultivation of biomass is emissions-neutral, as the carbon dioxide absorbed by plants during their lifetime is returned to the atmosphere on combustion.

Conventional cars are able to run on biofuels, with minor modifications. However, biofuels "are generally not competitive with gasoline and diesel at market prices" (IEA, 2010, p. 366), although their production costs are likely to fall in the future. For the time being, biofuels play a fairly small role in global transport, accounting for 3% of global road transport energy use in 2009 (IEA, 2010) and a negligible fraction in New Zealand (MED, 2011a).

Unlike most renewable energy sources, biofuels may not be sustainable – at least those which are produced from "first-generation" sources such as sugar cane, soy or maize (IEA, 2010; New Zealand Government, 2007). The crops or feedstocks used to produce the biofuels could otherwise have been used to produce food, meaning that increased biofuel production could put pressure on the world's food supply. Furthermore, if forests are cleared to provide land for the cultivation of feedstocks, the production of biofuels could actually *increase* greenhouse gas emissions, even compared to the use of oil-based fuels (IEA, 2010).

As such, biofuels could potentially play a role in reducing our dependence on fossil fuels in the future, and improving our energy security, but they may have a negligible or even negative effect on greenhouse gas emissions. Given the additional complications around how their production costs will change in the future, I have not considered biofuels in detail in this thesis, or included them in the Transport Scenarios Model described in chapter 5 onwards.

2.7 Advanced Vehicles: Battery Electric Vehicles and Plug-In Hybrids

In recent years, automakers have begun to focus more attention on PHEVs and BEVs, referred to throughout this thesis as "advanced" vehicles. The distinctive feature of such vehicles is their ability to drive using electricity from the grid. Both PHEVs and BEVs incorporate a larger battery than those in traditional hybrids, and use this to power an electric motor. BEVs are entirely reliant on this motor, whereas PHEVs also include an internal combustion engine and can run on conventional fuels.

PHEVs and BEVs are significantly more efficient than conventional petrol or diesel vehicles, and have lower running costs as a result. Advanced vehicles are able to reduce countries' dependence on oil, improving energy security. Driving these vehicles may assist in reducing greenhouse gas emissions, although – as explored in section 2.10 – this may not always be the case. To maximise the emissions-reduction potential of advanced vehicles, a country must have access to plentiful renewable electricity resources.

PHEVs have smaller batteries than BEVs, and a limited electric-only range which may still be sufficient for the daily travel needs of many drivers. For longer trips, PHEVs will use their engine, giving them a comparable range to other cars.

BEVs have large batteries and a much longer electric-only range than PHEVs, although their range is likely to fall well short of conventional cars. Larger batteries also take longer to recharge, and this, combined with an inability to run on petrol or diesel, could make it difficult to use BEVs "at short notice" (Morton, Schuitema, & Anable, 2011, p. 10).

Furthermore, BEV owners have to contend with issues such as the risk of batteries not lasting the full lifetime of the car, or the risk of the car depreciating faster than other cars. Given that BEV technology is still in its early stages, it is difficult to quantify these risks.

PHEVs eliminate many of these issues, and it seems that the only major barrier to their implementation is the up-front cost of such vehicles. PHEV owners will be able to do much of their driving on electricity, although the proportion will depend on a range of factors, most importantly the distance that they have to travel in between charges. According to the IEA (2009), the proportion of electric-only driving is likely to be below 50% for mainstream PHEV owners.

However, BEVs have several advantages over conventional vehicles, and even over PHEVs. In addition to having lower running costs and greenhouse gas emissions, they are also likely to have lower maintenance requirements (Hyder Consulting (NZ) Limited, 2009). As noted by King (2007), the challenges around BEVs are not insurmountable; for example, rapid recharging or battery switching facilities could assist in overcoming the low ranges and long charge times of these vehicles.

2.7.1 Hydrogen-Fuelled Cars

One potential source of transport energy is hydrogen. Hydrogen reacts with oxygen to produce water, a reaction which can take place through combustion – in which case the hydrogen-powered vehicle would make use of an internal combustion engine – or via a "fuel cell", in which case the energy is converted into electricity and used to charge a battery.

Because water is the only chemical product of the hydrogen-oxygen reaction, hydrogen-powered vehicles produce negligible tank-to-wheels emissions. It is possible that fuel cell vehicles could match the range of traditional vehicles, overcoming one of the potential issues with BEVs. However, this will not be achieved in the near future (Ajanovic, 2008).

Although there has been much discussion and research towards promoting a "hydrogen economy", most sources believe that fuel cell vehicles are decades away from large-scale production. Even in the IEA's low-carbon 450 Scenario, fuel cell vehicles are expected to have a minimal role by 2035, with PHEVs and BEVs being much more important (IEA, 2010, p. 431). Ajanovic (2008, p. 4223) believes that hydrogen-powered vehicles will only have "significant" penetration into transport "at the earliest by about 2030", and then only "under very favourable conditions". The New Zealand Government (2007, p. 58) stated that "storage, transportation and other technical issues are likely to prevent hydrogen having anything other than niche uses for the next 25 to 30 years".

There are a number of pitfalls with hydrogen as a transport energy source. Firstly, it is typically produced through the steam reforming of natural gas (Ajanovic, 2008), a non-renewable energy resource. Secondly, the infrastructural investments will be much larger than those needed for BEVs, with a "nearly complete lack of fuel distribution and production infrastructure" existing at present (IEA, 2009, p. 151). Thirdly, a shift to hydrogen-powered vehicles would be "disruptive" for the car industry, compared to the more evolutionary process of moving towards BEVs (IEA, 2009, p. 151). Fourthly, hydrogen is likely to be more expensive than electricity (IEA, 2009).

New Zealand researchers Page and Krumdieck (2009, p. 3330) argue that hydrogen "provides an inefficient link between a renewable electricity resource and demand for transport energy compared to an all-electric transport mode." They also note that "electricity offers the same environmental and security benefits as hydrogen" (Page & Krumdieck, 2009, p. 3329), and are sceptical of the benefits from large-scale implementation of hydrogen technology in vehicles.

The IEA notes that fuel cell vehicles could eventually reach a similar cost level to BEVs and achieve much greater range, and that they do offer "significant" potential to reduce emissions if the hydrogen is produced appropriately, although to no greater an extent than BEVs (IEA, 2009, p. 151). On the whole, though, the IEA believes that BEVs are more likely to become the preferred technology; these vehicles have "a natural advantage [over hydrogen vehicles] given the existence of the electricity grid system, and a clear transitional path from plug-in hybrids" (IEA, 2009, p. 114).

In summary, a range of sources agree that hydrogen vehicles are much further away from commercialisation than BEVs; will require greater infrastructural investment; and offer the same or perhaps fewer benefits than BEVs. BEVs and hydrogen vehicles both require infrastructure to reach their full potential, and this, along with network externalities, means that one or the other technology is likely to dominate. The points noted above suggest that hydrogen vehicles are unlikely to become the chosen technology, and as such, they have not been considered further in this thesis.

2.7.2 Current and Proposed Production PHEVs and BEVs

Table 1 below compares the BEVs and PHEVs that are currently in production, including their electrical efficiencies – measured in terms of kilowatt-hours (kWh) of electricity used for 100 km of travel – and the amount of energy stored in their batteries.

Table 1: Current Production PHEV and BEV Models

Vehicle Name	Description	Electrical Efficiency (kWh/ 100 km)	Battery Energy Storage (kWh)
Chevrolet Volt	4-door Sedan PHEV	22	16
BYD F3DM	4-door Sedan PHEV	16	16
Mitsubishi iMiev	5-door Hatchback BEV	19	16
Nissan Leaf	5-door Hatchback BEV	21	24
Tesla Roadster	2-door Roadster BEV	17	53
Volvo C30	3-door Hatchback BEV	16	24
CODA Sedan	4-door Sedan BEV	15	31 or 36
BYD e6	5-door Hatchback BEV	21	60
Renault Fluence Z.E.	4-door Sedan BEV	n/a	22

Note. This information is taken from a range of online sources. Electrical efficiency data is based on U.S. Environmental Protection Agency combined test cycles

A number of new makes and models of advanced vehicles are expected to be launched in the next few years. Table 2, below, shows some of these vehicles, along with indicative production dates.

Table 2: Future PHEV and BEV Models

Vehicle Name	Description	Indicative Production Date
Toyota RAV4	4-door SUV BEV	2012
Tesla Model S	4-door Sedan BEV	2012
Honda Jazz	5-door Hatchback BEV	2012
Toyota Prius	5-door Hatchback PHEV	2012
Ford Focus	5-door Hatchback BEV	2012
Ford C-MAX Energi	5-door Minivan PHEV	2012
Hyundai BlueOn	5-door Hatchback BEV	2012
Volvo V70	5-door Stationwagon PHEV	2012
BYD S6DM	4-door SUV PHEV	2013
Suzuki Swift	5-door Hatchback PHEV	2013
Volkswagen Golf	5-door Hatchback BEV	2014
Volkswagen Golf	5-door Hatchback PHEV	2015
BMW Active E	2-door Coupe BEV	-

Note. Vehicle descriptions and indicative production dates are taken from a range of online sources

Note that both of the above tables exclude small one- or two-seater BEVs. These smaller vehicles, also known as “neighbourhood” electric vehicles or “quadricycles”, have a limited range of applications. They are typically too small to be the primary vehicle for households with more than two members; furthermore, they are usually unsuitable for highway driving, as they have low top speeds and are built to lower safety standards than other vehicles. King (2007, p. 4) is generally negative on the opportunities for such vehicles in New Zealand, pointing out that allowing quadricycles “would require... a relaxation of our current safety standards”, and that “the limited application of quadricycles means the emission reductions from allowing them could be negligible”.

2.7.3 PHEV and BEV Batteries

The new generation of electric vehicles, such as the Volt and Leaf, use lithium-ion batteries, and there is broad consensus that lithium-ion technologies will make the most promising batteries for advanced vehicles in the near future (The Boston Consulting Group, 2010). In the longer term, radically different batteries may be developed and produced – however, this is unlikely to occur before 2020, according to industry experts interviewed by The Boston Consulting Group (2010).

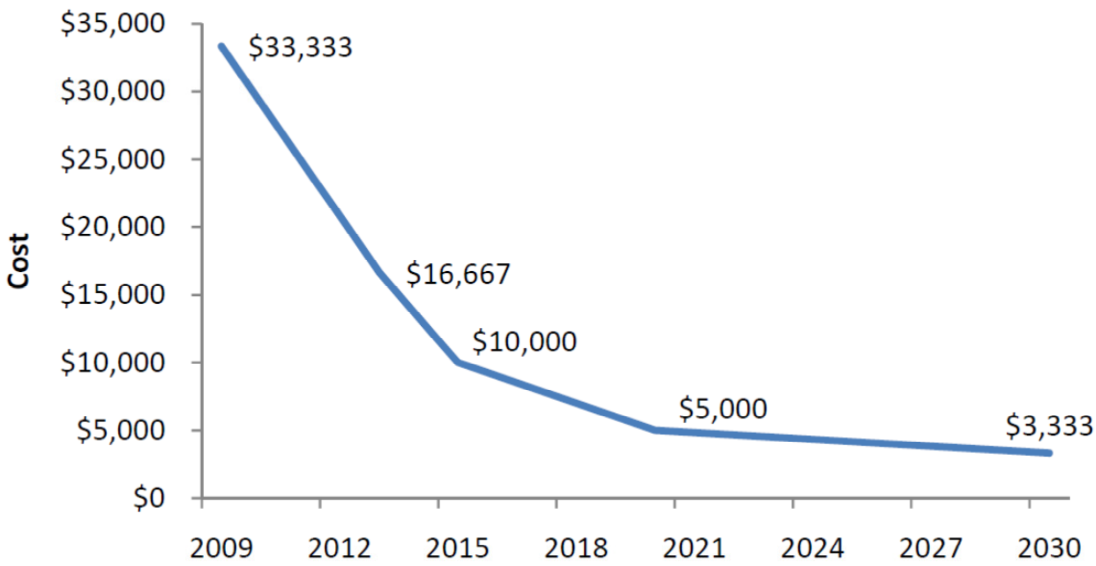
Relative to other commercially available batteries, lithium-ion batteries have high energy density, and a high charge/ discharge efficiency. There is some doubt over whether they can match the lifespan of NiMH batteries, but the main stumbling block for lithium-ion batteries at this point is their cost. At present, these batteries make up a significant part of the cost of PHEVs and BEVs, and this is probably the biggest barrier to the widespread adoption of these vehicles (King, 2007).

Battery costs are typically expressed in terms of dollars per kWh (Cheah & Heywood, 2010). As the energy storage of the battery pack increases, the cost per kWh decreases (IEA, 2009), meaning that PHEV batteries are likely to cost more per kWh than BEV batteries. In terms of total cost, of course, BEV battery packs are more expensive, since they are significantly larger than those for PHEVs. In the long term, if battery costs fall far enough, it is possible that BEVs could be cheaper than PHEVs, since they eliminate the engine which can form a large part of a vehicle's cost.

Battery costs are expected to decline in the future, driven by economies of scale and technological advances. However, as summarised in Cheah and Heywood (2010) there are a wide range of views as to how quickly costs will decrease: for example, PHEVs are predicted to cost between USD $6,000 and $16,000 more than a conventional car by 2015-2020. The uncertainty is compounded by the fact that information about manufacturing costs is generally seen to be commercially sensitive and is therefore hard to access; confusion can also arise as to what should be included in the cost. According to Cheah and Heywood (2010), the battery accounts for 80% of the cost premium associated with manufacturing a PHEV. For BEVs, the battery might account for more than 100% of the premium, as the lack of an internal combustion engine will bring down the manufacturing cost for these cars.

The U.S. Department of Energy (2010) forecasts the potential price change for BEV batteries over the next twenty years, as reproduced in Forecast Costs for a 33 kWh BEV BatteryFigure 5 below; they also predict that batteries for PHEVs with a 40-mile electric range will cost around 40% as much as the larger BEV batteries. Based on a comparison with figures in Cheah and Heywood (2010), the U.S. Department of Energy (2010) appears to be fairly bullish about the potential for cost reductions.

Figure 5: Forecast Costs for a 33 kWh BEV Battery, in $USD



Source: U.S. Department of Energy (2010)

McConnell and Turrentine (2010) take a more conservative line; their baseline forecast shows Li-ion battery costs declining from $1,450/ kWh in 2010 to $600/ kWh in 2030, and they also consider an “extremely optimistic” scenario in which prices fall from $600/ kWh in 2010 to $250/ kWh in 2030. McConnell and Turrentine (2010) also estimate the additional, non-battery costs of manufacturing a PHEV to be around $3,000 in 2010, declining to $2,000 or less in 2030.

Anderson (2009) estimates that Li-ion batteries cost $1,100/ kWh in 2000, and considers pessimistic, baseline and optimistic scenarios for cost reduction to 2030; in these scenarios, costs fall to $750/ kWh, $300/ kWh and $250/ kWh respectively. Anderson (2009, p. 21) acknowledges that “the optimistic scenario appears to be emerging as the more likely of the two extremes”.

Current or near-term costs for lithium ion batteries have been given as around $400 to $500/kWh, in US dollars (Cooke, 2009; IEA, 2009). According to Kanellos (2010), Better Place – a network operator such as described in section 2.7.4 below – will be purchasing batteries for $400/kWh in 2012. This would suggest that, if anything, costs are declining faster than the U.S. Department of Energy’s (2010) predictions.

2.7.4 Contracts, Charging Stations and Switchable Batteries

Despite the uncertain outlook for battery cost reductions, there are some proposals aimed at taking the guesswork out of the equation. These include schemes to lease electric vehicles, or to buy the vehicles but lease their batteries, along with the potential for electric vehicles to be sold with a range of battery sizes.

The up-front cost disadvantage of PHEVs and BEVs can be eliminated if their retail prices exclude the battery cost. The battery would be owned by another entity, who would charge the driver in such a way as to eventually recoup the cost of the battery. Such a scheme could be instigated by an electricity provider, for example, who would recover the battery cost through higher electricity charges (IEA, 2009). These kinds of contracts would be relatively straightforward to arrange, and involve little risk for the operator. It is also possible to envisage competing operators, each offering their own batteries and charging schemes.

Becker, Sidhu and Tenderich (2009, p. 1) argue for a more complex arrangement: “switchable batteries with pay-per-mile service contracts”. Under such a scheme, a network operator builds and maintains battery switching stations, or alternatively fast-charging stations. These facilities either switch out the battery of an electric vehicle for a fully charged one, or contain a power supply that enables the battery to be rapidly charged. The operator offers consumers service contracts which allow for the use of a battery, and access to the switching or charging network. Such contracts are of course intended to allow for the network operator to cover the cost of the vehicle batteries, along with the additional costs of building and maintaining the network to charge or exchange batteries. However, this scheme is inherently more risky for the operator, since it involves investments in costly infrastructure and low consumer uptake of advanced vehicles could mean that the cost of these investments may not be recovered. Given the investment in fixed assets, such a scheme is most likely to be set up as a regulated monopoly.

Importantly, the scheme described by Becker et al. (2009) would mitigate the concerns arising from the short range and long charge times of BEVs. Both types of scheme would eliminate consumer concerns over how long their batteries would last, although long-term warranties would also mitigate these concerns.

Morton, Schuitema, and Anable, (2011, p. 10) note that “public charging infrastructure [could] diffuse public awareness” of BEVs and, at the same time, “instil confidence in the technology”. This view is shared by the Boston Consulting Group (2009) and the IEA (2009, p. 149), the latter adding that insufficient investment “could constrain the widespread introduction” of these vehicles.

King (2007), on the other hand, points out that BEVs will have an adequate range for day-to-day use, and that charging infrastructure is costly, especially if it is designed to charge batteries very quickly. He argues that for New Zealand, “[public charging facilities are] by no means a pressing issue... fast adopting regions [overseas] will confront the issue first and ensure there will be no need to reinvent the wheel. A more thorough assessment should be undertaken after [BEV] uptake begins in earnest” (King, 2007, p. 13).

Another consideration is that public charging stations are likely to be most heavily used during and between the morning and evening rush hours. This reduces the opportunity for electric vehicles to “smooth” daily fluctuations in electricity demand – a subject covered in more detail in section 2.11 – and is likely to necessitate more investment in electricity generation.

2.7.5 Incentives and Subsidies

Many countries currently offer incentives to encourage the uptake of advanced vehicles (King, 2007), and countries such as Spain, Denmark and Sweden have set very aggressive goals for their adoption (de Sisternes, 2010). These incentives frequently take the form of a subsidy on the purchase price, as for the US. Other jurisdictions provide free parking or charging, allow the use of bus lanes, or waive annual licensing fees.

More complicated subsidies are of course possible, and McConnell and Turrentine (2010) suggest a subsidy which depends on the difference in fuel efficiency between two vehicles of similar size. For example, a consumer who buys a medium-sized hybrid would receive a subsidy which is proportional to the difference in fuel efficiency between the hybrid and a medium-sized petrol car.

Greene, Patterson, Singh, and Li (2005) suggest a revenue-neutral "feebate" scheme, imposing a tax on less efficient vehicles while offering rebates on more efficient vehicles. Greene et al. (2005, p. 758) argue that such a policy would work because "consumers appear to accurately reckon vehicle prices in their purchase decisions" – although no evidence for this is given in the paper. A further issue with the feebate scheme, not raised in Greene et al. (2005), is that consumers who travel long distances would be less affected by such a scheme than they would by a higher fuel tax. This means that the very consumers who should value fuel economy the most could actually be *less* inclined to buy fuel-efficient vehicles. On the other hand, as discussed later in this thesis, it is possible that consumers undervalue long-term costs compared to up-front costs, which would make the feebate scheme potentially more efficient.

The US government is investing in PHEVs and BEVs through loans and grants for manufacturing facilities, and subsidies on the purchase price of advanced vehicles. McConnell and Turrentine (2010, p. 24) note that the potential to develop economies of scale, and to promote "learning by doing", are two possible reasons to give loans for manufacturing plant or subsidies for advanced vehicles: they will reduce the long-term marginal cost of producing these vehicles. However, such arguments are less relevant for New Zealand, since we make up only a tiny fraction of world demand for new vehicles and can have little bearing on their production cost.

Given that the main barrier to the widespread adoption of advanced vehicles is their up-front cost, any initiative that reduces their cost premium is likely to boost demand. The Boston Consulting Group (2009, p. 5) argues that "subsidies will play a major role in bringing the [total cost of ownership] for electric vehicles down to an attractive level for the consumer".

In New Zealand, there are no up-front incentives or subsidies for advanced vehicles. However, BEVs have been granted an Road User Charges exemption until 2013 (MOT, 2009). If this policy were to continue indefinitely, it would actually be quite generous, and the net present value for a BEV owner would be around $5,800.[2] However, given the uncertainty over whether this scheme will be continued, plus the possibility that consumers adopt higher discount rates than the government, a direct subsidy on the purchase price of BEVs is likely to be more efficient.

King (2007, p. 22) argues that New Zealand should only implement incentives if they "relate to specific objectives... [for example, reducing] oil consumption and [decreasing] CO_2 emissions from the transport sector". Electric vehicles are certainly capable of achieving both these objectives in New Zealand. However, other efficient vehicles – such as mild hybrids, diesels or even LPG-fuelled cars – could give the same result, as could a shift to public or active transport. As such, there does not appear to be a strong argument for specifically aiming incentives at advanced vehicles.

Donovan et al. (2009, pp. 19-20) warn that incentives "must be carefully tailored so as to not detract from the potential for consumers to adopt more economically efficient and enduring responses to higher energy prices". If the government wants to target oil consumption and

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[2] Author calculations. Net present value adjusted for expected travel and probability of scrappage in each year of the vehicle's lifetime, and using an 8% discount rate, as per Table 4.

CO_2 emissions, for example, it should do so directly in order to avoid a prescriptive approach that may not provide the most efficient means of achieving these goals.

2.8 Fuel Price Elasticity

Transport fuel demand is usually thought of as being inelastic: for example, Kayser (2000), using microdata for the US, finds that gasoline demand is highly income and own-price inelastic. However, elasticities are likely to vary between countries, due to differing public transport availability, population density and so on.

There have been few published studies of fuel price elasticity for New Zealand. Kennedy and Wallis (2007) analysed petrol own-price and income elasticities, although they did not consider diesel. They found that much of the consumption response to a price rise happened relatively rapidly, i.e. within a year. Based on their own results, and their literature review, Kennedy and Wallis (2007) recommend that the short-run (0-1 year) elasticity for petrol consumption be assumed to be -0.15, and the long-run (5+ years) elasticity to be -0.30. However, these long-run results are not backed up by their own evidence, which finds that "further changes beyond 2 years [are] very small and difficult to detect with any confidence" (Kennedy & Wallis, 2007, p. 28).

Kennedy and Wallis (2007) recommend that the short-run elasticity for vehicle kilometres travelled (VKT) be assumed to be -0.12, and the long-run elasticity to be -0.20. That is, a 1% increase in the price of petrol leads to a 0.12% decrease in travel in the short run, and 0.20% in the long run. They acknowledge that these suggestions are "somewhat subjective" (Kennedy & Wallis, 2007, p. 54).

In the longer run, consumers may respond to petrol price increases by reducing their VKT, but also by driving more efficiently or when roads are less congested, or buying more fuel-efficient vehicles. Multi-vehicle households may also start to use their more efficient vehicle preferentially. As such, we would expect petrol consumption to be more elastic than VKT (Kennedy & Wallis, 2007).

Kennedy and Wallis (2007) note some other interesting points for New Zealand elasticities: firstly, rural travel appears to be less elastic than urban travel, and secondly, for urban travel, off-peak travel is relatively elastic, while peak travel is less elastic. The result that elasticities depend on time and place could have implications for managing travel demand in New Zealand.

2.9 Comparing the Energy Efficiency of Different Vehicle Types

As pointed out in King (2007), electric motors – such as those used in a PHEV or BEV – are around three times more efficient than internal combustion engines. However, this is only part of the picture. The production, transportation, conversion and consumption of "useful" energy tends to involve losses at each stage of the process. A vehicle may appear to be more, or less, efficient than another depending on how many stages are taken into account.

"Useful" energy is lost in several of the processes involved in charging and powering an electric vehicle. There are losses in the generation, transmission and distribution of electricity to the charging point. According to the MED (2011a, p. 102), the difference between "net" electricity generation and observed consumption is around 7%, due to these losses. Such losses, of course, are common to all household appliances, and retail electricity prices would include some provision for them. For advanced vehicles, additional losses arise from the conversion of electricity into stored energy in the battery, and the conversion of that stored energy back into electricity to drive the motor.

Similarly, for conventional vehicles, useful energy is lost in extracting, transporting and refining oil; large amounts of energy are lost within the engine as heat or friction, and so on. The overall efficiency of this process is referred to as "well-to-wheels" efficiency, and, although the process for advanced vehicles is substantially different and may not involve oil wells at all, the overall efficiency of generating electricity through to driving the car is also called "well-to-wheels" efficiency. Similarly, "tank-to-wheels" efficiency refers to just the latter stages of the process, from the fuel tank onwards for conventional vehicles or the battery onwards for advanced vehicles.

According to de Sisternes (2010, p. 40), a BEV with nominal energy consumption of 15 kWh/ 100 km may create "well-to-wheels" electricity demand of 26 kWh/ 100 km when these various losses are accounted for. Holdway, Williams, Inderwildi, and King (2010) suggest that the overall energy requirement of BEVs is slightly lower, at around 20 kWh/ 100 km. The exact figure will depend on the efficiency of the electricity network, as well as that of the car itself.

On average, petrol cars in New Zealand consume around 10 litres of petrol for every 100 km they travel (MOT, 2011), a "tank-to-wheels" measure of their energy use. Given the energy content of petrol at around 35 megajoules per litre (MED, 2011a), these cars use 350 megajoules per 100 km. A BEV with an electrical efficiency of 20 kWh/ 100 km, on the other hand, uses just 72 megajoules per 100 km, and this might be a reasonable estimate of its "well-to-wheels" energy use. This illustrates the potential for BEVs, or PHEVs for that matter, to be significantly more energy efficient than the current fleet average.

However, most cars entering the fleet today are more energy efficient than this average figure. Diesel cars, as noted earlier, are more efficient even after allowing for the higher energy content of diesel, while modern petrol cars and hybrids can also achieve significantly better efficiency.

Furthermore, the actual energy efficiency of the various types of cars is less important than the implications of their energy use for energy security and emissions.

2.10 Comparing the Greenhouse Gas Emissions of Different Vehicle Types

Cars are major contributors to New Zealand's greenhouse gas emissions. According to the Ministry for the Environment (2011), New Zealand produced net CO_2-equivalent emissions of

43.88 million tonnes in 2009, with the “road transport” subcategory accounting for 12.39 million tonnes.

From the MOT (2011), New Zealand’s car fleet accounted for 62.7% of our road transport emissions in 2009. This implies that the car fleet produced 7.77 million tonnes of CO_2-equivalent emissions in 2009, or 17.7% of the country’s net emissions.

Advanced vehicles could make a sizeable contribution to emissions reduction in New Zealand. BEVs generate zero tank-to-wheels greenhouse gas emissions, and PHEVs only produce emissions when using their internal combustion engines. However, the *well*-to-wheels emissions for advanced vehicles depend on the source of electricity used to charge the vehicle. These sources, of course, vary substantially between countries, with many countries generating the bulk of their electricity from coal or oil. In fact, for countries such as the US, UK, China and Australia, Matthew-Wilson (2010) estimates that the Tesla Roadster BEV would actually produce *higher* well-to-wheels CO_2 emissions than the conventional Lotus Elise on which it is based. Doucette and McCulloch (2011) and de Sisternes (2010) reach similar conclusions.

As such, the potential for PHEVs and BEVs to reduce greenhouse gas emissions depends on low-emissions sources of electricity. For much of the world, a shift towards these electricity sources will be needed if advanced vehicles are to play any part in reducing emissions. The difficulties in doing so would be one reason for The Boston Consulting Group’s (2009, p. 2) argument that conventional vehicle “technologies will be the most cost-effective way to reduce CO_2 emissions on a broad scale”.

Of course, New Zealand is in a much more favourable position, with a large renewable electricity base. The New Zealand Government (2007, p. 22) points out that our “energy resources are plentiful and cheap by world standards... it is easier for New Zealand to commit to a low emissions electricity system than almost any other country”. As shown below, we can reduce our emissions significantly by transitioning to advanced vehicles. Matthew-Wilson

(2010) estimates that in New Zealand, a Tesla Roadster would create less than one-third the CO_2-equivalent emissions of a Lotus Elise.

While advanced vehicles could be very advantageous for New Zealand in terms of their ability to reduce emissions, it is important to note that many of the major economies of the world will not be able to do the same, given their current power station networks. This is an important issue for New Zealand, because the availability and price-competitiveness of advanced vehicles will be determined by these large markets. We are reliant on these large markets to provide demand for advanced vehicles, as high levels of demand will generate economies of scale and faster learning in the production of these vehicles. The fact that other countries do not stand to benefit as much as we do from the introduction of such vehicles means that prices will not fall as quickly as they would if all countries had low-emissions electricity systems, and this will slow the uptake of PHEVs and BEVs in New Zealand.

Under New Zealand Government (2008) regulations, petrol and diesel are treated as producing the following emissions:

- 2.310 kg of CO_2-equivalent per litre of regular petrol;
- 2.367 kg of CO_2-equivalent per litre of premium petrol;
- 2.670 kg of CO_2-equivalent per litre of diesel.

Under the Emissions Trading Scheme, the prevailing CO_2-equivalent price and these emissions factors are used to determine fuel companies' liabilities. These emissions factors are important for the modelling in this thesis, described in chapter 5 onwards. Firstly, they are needed to calculate the impact of the Emissions Trading Scheme on fuel prices, and secondly, they are needed to calculate fleet emissions.

Given that the modelling in this thesis does not distinguish between regular and premium petrol, I have assumed petrol emissions to be 2.3214 kg of CO_2-equivalent per litre. This is based on an 80-20 weighting for regular petrol consumption to premium petrol consumption, which is in line with observed consumption figures for 2010 (MED, 2011a). An average petrol car in New Zealand, using 10 litres of petrol per 100 km, would therefore produce 23.2 kg of CO_2-equivalent emissions over this distance.

New Zealand's electricity emissions are more difficult to model than those for petrol and diesel. The level of electricity emissions can vary significantly from year to year, and tends to be especially high during "dry years" such as occurred in 2005 and 2008. Table 3 below shows average emissions per kWh of electricity generated between 2005 and 2010.

Table 3: New Zealand's Greenhouse Gas Emissions from Electricity

Year	Net Electricity Generation (GWh)	Electricity Emissions (kt CO_2-e)	Electricity Emissions per kWh (kg CO2-e/ kWh)
2005	41,514	8,970,000	0.2161
2006	42,123	8,852,000	0.2101
2007	42,284	7,488,000	0.1771
2008	42,306	8,330,000	0.1969
2009	42,081	6,678,000	0.1587
2010	43,401	5,940,000	0.1369

Sources: net electricity generation figures are from the MED (2011a); emissions figures are from the MED (2011b)

Over the 2005-2010 period, electricity emissions averaged 0.1826 kg of CO_2-equivalent per kWh of net generation. Assuming transmission and distribution losses of 7%, we can scale this emissions value up to 0.1963 kg of CO_2-equivalent per kWh of consumer energy.

However, this figure is likely to be skewed upwards due to the inclusion of two dry years in the period. Furthermore, average emissions per kWh can be expected to fall in the future, given recent increases in wind capacity and the New Zealand Government's (2007) goal to generate 90% of electricity from renewable sources by 2025.

Using this figure, though, we can calculate that a BEV using 20 kWh of electricity per 100 km of travel would produce emissions of 3.9 kg of CO_2-equivalent emissions over this distance, a well-to-wheels measure. This is around 17% of the level of emissions produced by a typical petrol car, illustrating the potential for major emissions savings.

2.11 Power Grid Considerations from a Shift to PHEVs and BEVs

Several sources have expressed concern that a significant shift to advanced vehicles could put pressure on New Zealand's electricity network, although these concerns appear to be overstated. In order to gauge the size of this effect, it is necessary to calculate the energy demand of a fleet of electric vehicles. A number of studies have estimated the electricity demands of such a fleet, although none of them have gone into detail about how these were calculated.

Dravitzki, Lester, & Cenek (2010) estimate that if *all* oil-based transport energy in New Zealand – including freight, air travel and so on – was replaced with electricity-based transport, some 17,000 to 20,000 gigawatt-hours of electricity would be required. This is equivalent to 40% to 46% of 2010 generation (MED, 2011a). Dravitzski et al. (2010) estimate that to replace all light vehicles – including cars and light commercial vehicles – with BEVs would require around 11,000 gigawatt-hours, 26% of 2010 generation.

Matthew-Wilson (2010) predicts that New Zealand's electricity requirements would increase by 60% if our vehicle fleet was completely replaced with electric vehicles, although it is unclear whether his figure refers to simply replacing the *car* fleet with electric vehicles, or to replacing *all* transport with electric-based transport.

Matthew-Wilson (2010) also argues that most of this significant additional electricity demand would be generated from coal plants. The New Zealand Government (2007, p. 55) appears to dissent from this view, arguing that "switching to electricity as a fuel for our vehicles would make the most of New Zealand's abundant renewable electricity supplies, particularly if transport was not competing for supply at times of peak demand".

Smith (2009) seems to use a rather different set of assumptions, with graphs showing a scenario in which electric vehicles make up 75% of New Zealand's fleet by 2040, and account for a similar proportion of travel. Total vehicle kilometres travelled by the car fleet is assumed to increase steadily from 2010 until 2040, rising from around 34 billion km in 2010 to 47 billion km in 2040. Electric vehicles, which travel around 35 billion km in 2040, create demand for approximately 5,200 gigawatt-hours of electricity per year (Smith, 2009). These graphs are part of a presentation, and again no calculations are given.

The Electricity Commission (2010) created a forecast of advanced vehicle uptake in New Zealand, which used as an input in some of their future electricity demand scenarios. In this forecast, advanced vehicles become available shortly after 2015 and become increasingly popular over the following 25 years – accounting for 1.5 million vehicles, or almost 40% of the fleet, by 2040. The Electricity Commission (2010) assumed that these vehicles would travel similar distances to non-electric vehicles, and that they would require around 2,600 gigawatt-hours of electricity per annum by 2040. Extrapolating these figures, it appears that an all-electric car fleet would require 6,500 gigawatt-hours of electricity generation.

Although none of the studies above provide calculations, it is relatively straightforward to estimate the energy demand arising from a hypothetical fleet of electric vehicles. Doing so involves just two steps: firstly, estimating the total distance travelled by advanced vehicles each year, or alternatively the total number of such vehicles and their average travel each year; and secondly, estimate their average energy consumption in terms of kWh per 100 km.

According to the MOT (2011), New Zealand's car fleet travelled 31.2 billion kilometres in 2010. We can imagine a scenario where this fleet is entirely replaced by BEVs, travelling the same distance as the actual fleet did in 2010, and using 20 kWh/ 100 km. The electricity demand of this advanced car fleet would be 6.24×10^9 kWh, or 6,240 GWh. This is equivalent to just 14.4% of New Zealand's 2010 electricity generation.

Although some uncertainty around this figure could be expected – the actual electricity use of BEVs could be somewhat higher or lower than 20 kWh/ 100 km, for example – it certainly appears that the estimates from Smith (2009) and the Electricity Commission (2010) are much more realistic than the others given above.

As such, concerns that a fleet of electric vehicles would require significant investment in new generation capacity seem to be unfounded, especially that these vehicles will take years or even decades to become firmly established in the market, and that PHEVs – which may account for a substantial share of their uptake – will only use electricity for a fraction of their travel. There does not seem to be any reason why New Zealand's electricity network could not accommodate the car fleet being partially or even entirely replaced with electric vehicles.

One further scenario, presented in Duke, Andrews, and Anderson (2009), is worth mentioning. This study does give more detailed calculations, although it makes some rather bold assumptions. The BEV fleet which is assumed to replace the current car fleet consists of just 2 million vehicles, compared with the current 2.6 million cars as at the end of 2010 (MOT, 2012a). These BEVs also do less travel: 23 billion km a year, compared to 31 billion km actually travelled in 2010 (MOT, 2011). Finally, only half of the 2 million BEVs are five-seat vehicles, with the remainder being one- or two-seat commuter vehicles. Duke et al. (2009, p. 18) justify these assumptions by noting that "in a future New Zealand where BEVs replace [conventional cars], car travel might be reduced as more people work from home and/or travel by improved public transport, walking and cycling".

Duke, Andrews, and Anderson (2009) estimate that their BEV fleet would use 2,500 GWh of electricity per year, excluding "supply losses" – this appears to be a "tank-to-wheels" measure. They then apply further assumptions: 90% battery charge/ discharge efficiency, electricity transmission losses of 10%, an "urban driving factor" of 1.3 and a "contingency factor" of 1.2, estimating that overall, 4,900 GWh of electricity generation would be a "conservative" estimate of the power required for their BEV fleet (Duke et al., 2009). This is essentially a well-to-wheels measure, and equates to around 21 kWh/ 100 km. Duke et al. (2009) conclude that overall, their hypothetical BEV fleet creates power demands equal to around 12% of New Zealand's electricity generation in 2006 – similar to my calculation above.

All things considered, the Duke et al. (2009) scenario represents a significant – and perhaps impractical – shift from current New Zealand transportation. With just one million five-seat vehicles, many households would need to rely on public transport, which might be inefficient for large or rural families.

Various studies mention the potential for PHEVs and BEVs to feed power back into the grid, e.g. Dyke, Schofield, and Barnes (2010), and Smith (2009). This could, in theory, help to smooth daily fluctuations in power demand, i.e. the daily peak/ trough cycle. Smith (2009) suggests that a fleet of electric vehicles could actually *reduce* New Zealand's requirements for new diesel and gas peaker plants relative to a business-as-usual scenario, as smart metering and charging allows these vehicles to recharge their batteries off-peak and feed energy back into the grid during times of higher demand. However, there are a number of issues with using electric vehicles to provide "security of supply" for electricity (Matthew-Wilson, 2010, pp. 143-144); these include the slow charge/ discharge times for vehicle batteries, the likelihood that many cars will only be plugged in at night, and the energy losses involved in transforming the battery's energy back into electricity.

Given these issues, plus the fact that "security of supply" concerns for electricity in New Zealand are usually focused on dry years rather than daily demand cycles, there is some justification for Matthew-Wilson's (2010, p. 144) conclusion that "the times and situations when [advanced vehicles feeding electricity into the grid] would be of much practical help would be few indeed". However, New Zealand's electricity generation profile is likely to evolve over the next few decades, with wind and perhaps solar energy becoming more important. The output of wind and solar plants tends to fluctuate, and a fleet of electric vehicles with the ability to feed electricity back to the grid would provide an excellent complement to such plants, smoothing out these variations.

Even if Matthew-Wilson (2010) is correct in arguing that there is limited potential for electric vehicles to supply energy back to the grid, there are certainly advantages to charging these vehicles outside of peak times; this allows for better use of existing grid capacity (McConnell & Turrentine, 2010). Schafer (2011) cites two studies as showing that, if advanced vehicles are charged off-peak, they will have a fairly small effect on New Zealand's electricity demand

and the need for new power plant capacity. This will of course depend on the number of vehicles, and an all-electric car fleet would probably require some level of increase in capacity. However, the analysis above suggests that New Zealand's power system will be able to cope with the demands of advanced vehicles, even if uptake is fairly rapid.

2.12 Vehicle and Road Use Taxation in New Zealand

In New Zealand, petrol vehicle owners pay licensing fees of around $300 a year, the bulk of which is made up of Accident Compensation Corporation levies designed to meet the costs of road accidents. Diesel vehicles pay around $420 a year; this higher rate is due to a higher Accident Compensation Corporation levy, as petrol drivers also pay levies of 10 ¢/L when they buy petrol whereas diesel drivers do not.

Retail petrol prices include an "excise duty on motor spirits", the Accident Compensation Corporation levy and some smaller charges, totalling 59.129 ¢/L as at 31st December 2010 (MED, 2011a, p. 142). Diesel is not taxed on a per-litre basis, except for two small charges totalling 0.375 ¢/L between them as at 31st December 2010 (MED, 2011a, p. 142).

Two other taxes on vehicle fuel are worth mentioning, although they have a wider scope than just the transport sector. Petrol and diesel prices both include Emissions Trading Scheme (ETS) charges, as detailed in section 2.10. Retail prices for these fuels also include Goods and Services Tax (GST), which adds 15% to the ex-GST price and accounts for 13.04% of the overall retail price.

Electricity could potentially be an important source of transport energy in the future, and it should be noted that GST is also included in the retail price of electricity. ETS charges are indirectly included in the price of electricity, as described in section 2.10.

New Zealand's Road User Charges scheme applies to all vehicles which do not have their fuel taxed on a per-litre basis, i.e. vehicles which do not run on petrol. Under this scheme, vehicles pay a charge per 1,000 km, based on their type and weight. For most diesel cars, Road User Charges are $44.31/ 1,000 km, including GST (New Zealand Transport Agency, 2011b).

The government allocates all revenue from the excise duty on petrol and the Road User Charges scheme to the National Land Transport Fund, which pays for new roads, road maintenance and other transport-related initiatives. Since the costs associated with the road network are primarily dependent on the weight and number of vehicles using the road – and not on the litres of fuel used – the Road User Charges scheme arguably provides a more equitable way of charging for road use.

The current taxation regime means that petrol car drivers are more incentivised to choose efficient cars than diesel drivers – if a consumer buys a petrol car that is twice as efficient as his previous one, he will only pay half as much tax, leaving aside licensing costs. A consumer who buys a more efficient diesel car, however, will essentially continue to pay the same amount of tax.

This system amounts to a hidden subsidy for consumers who use efficient petrol cars, as they contribute less towards the cost of road accidents and maintaining the road network. Such a subsidy may be welfare-enhancing if consumers undervalue fuel economy.

In the future, however, this regime could hamper the uptake of efficient non-petrol vehicles such as diesel cars, diesel-electric PHEVs and BEVs. At current price levels, BEVs have running costs that are only marginally lower than petrol-electric PHEVs, because these hybrids are only taxed on their petrol consumption. Furthermore, even though diesel-electric PHEVs are expected to be more efficient than petrol-electric PHEVs (King, 2007), they are likely to have higher running costs.

On the other hand, most of the cars New Zealanders buy still run on petrol, and the current system does encourage the uptake of more efficient petrol vehicles, including petrol-electric

PHEVs. Given the lack of other incentives to choose more efficient cars in New Zealand, this is perhaps an argument for retaining the current differential taxation system.

King (2007) notes that as efficient petrol cars become more common, the government's tax take will decline, meaning that the per-litre level of excise duty will have to be raised to maintain government revenues. He argues that "this could be justified as an incentive to adopt more efficient vehicles", while pointing out that "a more comprehensive solution is to apply Road User Charges... for all vehicles" (King, 2007, p. 4).

The Road User Charges Review Group (2009) recommended that the government level the taxation playing field, either adopting the Road User Charges scheme for all vehicles or replacing the charges faced by diesel cars with an excise duty, similar to that on petrol. The group stated that "preference is given" to the first option, i.e. making the Road User Charges scheme universal (Road User Charges Review Group, 2009, p. 12).

While the differential taxation systems on petrol and diesel do not appear to be a priority for the government at this stage, it is likely that they will need to be addressed at some stage in the future – especially as more advanced vehicles become available. However, King (2007, p. 19) notes that for the meantime, the petrol duty "is extremely efficient, easy to administrate and guarantees a steady flow of incoming funds".

2.13 Are Advanced Vehicles the Best Solution to New Zealand's Transport Issues?

While King (2007, p. 26) argues that "the benefits provided from electric vehicles are superbly suited to New Zealand", it must be remembered that electric vehicles will not solve all of New Zealand's transport-related problems. They can reduce our dependence on oil, reduce our emissions and provide several other benefits. However, unlike public transport, advanced vehicles cannot eliminate congestion, which is likely to be a growing issue for our major cities in the future.

The costs of congestion include travel times that are longer and less predictable, wasted fuel and unnecessary emissions, localised air pollution and noise. Public transport is one way to reduce congestion in our major cities, and it can also deliver many of the other benefits of advanced vehicles, all at a lower cost. The IEA (2002, p. 22) asserts that "bus systems… offer the most affordable, cost-effective, space-efficient and environmentally friendly mode of motorised travel".

Buses and trains can transport people more efficiently than cars. According to the IEA (2002, p. 11), "reasonably full buses are inherently efficient – in terms of both road space and fuel use per passenger kilometre". *Passenger* kilometres are a different measure than is used elsewhere in this thesis, which concentrates on *vehicle* kilometres. However, a single bus can of course transport many more passengers than a single car. A bus with sixty passengers also uses less road space than the cars required to transport the same number of people, especially if these cars may only have one or two occupants.

The IEA (2009) estimates that cars typically produce around 180 grams of CO_2-equivalent per passenger kilometre, compared with less than 50 grams for rail and bus transport. These factors depend on the number of people in each vehicle, and as Dravitzki and Lester (2007, p. 2) point out, "a poorly patronised public transport bus will be less sustainable than a high-occupancy car".

Public transport is more efficient and more readily available within New Zealand's larger cities, and Dravitzki and Lester (2007, p. 2) concede that "for typical trip purposes within rural settings, car travel is probably the most sustainable option." However, most potential BEV purchasers are also likely to live in these cities. City residents might be more likely to buy BEVs than rural residents, since they would typically have less need for long trips, and since any public charging infrastructure will probably be aimed at cities, in order to enable more efficient use of these facilities.

City dwellers are more able to substitute private travel for public transport, and this may well be more efficient – both in terms of energy efficiency and in terms of making efficient use of the road network – than purchasing and using BEVs. Matthew-Wilson (Matthew-Wilson, 2010, p. 41) recognises these issues when he writes that BEVs "would be unsuitable for many rural dwellers... [and] would simply change the way New Zealand's urban gridlock is powered". The IEA (2009, pp. 33-34) asserts that a shift towards public transport and away from private vehicle travel has major benefits, including "reduced traffic congestion, lower pollutant emissions and [improved] general liveability", a view shared by Dravitzki et al. (2010).

There is no clear answer as to whether advanced vehicles or public transport present the best solution to New Zealand's transport issues, and future strategies should consider and encourage both. Outside of New Zealand's main cities, public transport use is likely to be low and to remain low in the future. In these areas, advanced vehicles can certainly play a part, and there are advantages to replacing conventional cars with PHEVs, or even BEVs if consumers can adapt to the drawbacks associated with these vehicles. While this thesis concentrates on private vehicle travel rather than public transport, the role and potential of the latter should be acknowledged, and I would hope that future work can take a more integrated approach to find the best way forward for New Zealand.

3 VEHICLE CHOICE MODELS

The EPA (2010a, p. 4), in a wide-ranging literature review of fuel economy studies for the US, found that "there is no doubt that consumers do care about fuel costs, do value fuel economy, and that their interest in fuel economy increases when fuel prices increase". However, a key question in the transport energy discussion is whether consumers value fuel economy rationally, or if they place too low or too high a value on fuel economy. This issue is most pertinent when consumers are deciding on which car to purchase.

The EPA (2010a, p. vi) noted that "there is very substantial uncertainty about how consumers make decisions about fuel economy, as well as how much they value expected future fuel savings". Consumers may undervalue fuel economy, or indeed they may overvalue it, compared to the social optimum. Significantly, consumers may not actually be thinking about fuel economy in the 'rational' way at all.

3.1 The Rational Model of Vehicle Choice

Economists have tended to think about vehicle purchase decisions in terms of rational choice theory, along the lines of budget-constrained utility maximisation (Morton et al., 2011). Consumers choose between different vehicles based on factors such as their up-front cost, running cost, and various other attributes such as size, power, safety and so on. For this thesis, the main factors of interest are up-front costs and running costs, and the relationship between them.

As outlined in the EPA (2010a, p. vi), "rational" consumers are assumed to go through the following process when deciding which vehicle to buy:

1. Form an estimate of what the price of fuel will be in the future;
2. Estimate the lifetime of the vehicle, and the distance it will travel;
3. In comparing two types of vehicle, calculate the difference in lifetime fuel costs between them, using some discount rate to establish the net present value (NPV) of these savings.

Some studies may use a shorter period than the entire lifetime of the vehicle; for example, given that vehicles typically change ownership several times during their lifetime, a rational consumer might simply use this process to calculate savings over the time he expects to own the vehicle, and then estimate its resale value at the end of that time.

In order to make use of the rational model, the researcher must make assumptions about consumers' discount rates and their expectations of future fuel prices. These are perhaps the two main assumptions; it is relatively easy for a researcher to estimate how far a vehicle will travel during its lifetime, or during each year of its lifetime, as such data is usually readily available. Even so, many studies assume that cars travel the same distance each year regardless of their age, which for New Zealand at least is not the case (MOT, 2011).

3.1.1 Expectations of Future Fuel Prices

A key part of the rational model is the expectations that consumers have about future fuel prices over the lifetime of their car, or at least over the time that they plan to own it.

In most previous empirical studies of fuel economy, consumers are assumed to treat current fuel prices as the "best estimate" of future prices (EPA, 2010a); essentially, consumers are treated as myopic. Indeed, only two of the 57 households interviewed in Turrentine and Kurani (2007, p. 1219) were able to calculate "plausible" willingness to pay values for fuel economy, and both of these “implicitly assumed gasoline prices would not change (up or down) appreciably”.

However, the myopia assumption implies a market failure if future fuel prices are likely to deviate from current prices. Furthermore, it seems inconsistent to assume that consumers are poorly informed about the path future oil prices might take when they are also assumed to be well informed about all other matters relating to their future vehicle usage. Taking the rational model to its logical conclusion, it is more appropriate to assume that consumers are knowledgeable about the oil market, and estimate future fuel prices based on either long-term projections as described in section 2.4, or on prices in the oil futures market.

3.1.2 Discount Rates

Another key assumption in the rational model is the discount rate, representing the idea that money to be received in the future is less desirable than money in the hand. Discount rates, which commonly range between 5% and 15%, are used to find the NPV of a future income or expenditure.

The New Zealand Government (2007) used a 5% real discount rate to assess the costs and benefits of energy efficiency measures. It also pointed to a then-recent change in UK government policy, to use a 3.5% real discount rate in assessing costs and benefits (New Zealand Government, 2007).

However, our government usually applies an 8% real discount rate when carrying out cost-benefit analyses, and this is the rate that is currently applied to transport initiatives (Parker, 2009). Parker (2009, p. 16) suggests that this rate may be too high, and that “the appropriate value of the discount [rate] may lie between 3–5% real”.

It is telling that these discount rates are well below the ones which are typically assumed in economic studies of vehicle fuel economy. In McConnell and Turrentine (2010, p. 21), for example, vehicle manufacturers are assumed “to consider fuel economy improvements only for the first three years of vehicle life, and to use a 15 percent discount rate". Hyder (2009) assumes that New Zealand's social discount rate is 6%, but that consumers use a 10% private discount rate when buying cars, implying from the outset that consumers undervalue fuel economy.

There are several reasons why consumers might apply higher discount rates than the government. Firstly, cars depreciate rapidly in New Zealand, which is at least partly because of the prevalence of used imports. Under accounting rules given in Inland Revenue (2011), cars can be depreciated at 30% per year, with just 25% residual value remaining after five years. Secondly, consumers may take out loans when they buy vehicles, and these loans typically come with interest rates that are well above the social discount rate.

If there is a discrepancy between the discount rate that is used by consumers and the appropriate social discount rate, an argument can be made for implementing policies that are designed to shift consumer preferences towards the appropriate rate.

3.2 Applying the Rational Model to Cars in New Zealand

Table 4 below shows the results of applying the rational model to a typical car in New Zealand. The car is assumed to be purchased in 2011, and the ongoing operating expenses – comprising fuel costs and Road User Charges, and abbreviated as "opex" here and throughout this thesis – are calculated over a 43-year timeframe, assumed to be the vehicle's maximum expected lifetime.[3] Petrol prices during this time are based on oil and CO_2 prices from the IEA's (2011) New Policies Scenario; the process for estimating petrol prices based on these other prices is described in section 0. The hypothetical consumer, therefore, is assumed *not* to be myopic, but to estimate future fuel costs on the basis that oil prices are likely to increase in line with this scenario.

[3] Given the effect of discount rates, scrappage and reduced travel over time, the net present value of any opex expenses beyond the 43-year timeframe is very small.

The car is assumed to travel a certain distance each year, based on figures from the MOT (2011) which are described in more detail in section 5.2.6. These figures can be thought of as “unadjusted VKT”, because they have not been adjusted based on assumed future petrol price changes. This is equivalent to assuming that VKT for our hypothetical consumer is perfectly inelastic with respect to petrol prices.[4]

The car is also assumed to have a certain probability of being “scrapped” each year, as given in section 5.2.4 and again based on figures from the MOT (2011). This probability is not directly shown in Table 4, but I have shown the “cumulative survival probability”, which is the probability that the vehicle has survived to the end of the stated year.

Overall, the hypothetical consumer in this analysis estimates the lifetime fuel costs of the typical petrol car, assuming that oil prices follow a general upwards trend until 2035, while generally expecting to travel a shorter distance each year – but due to the car aging rather than due to any effect of the higher expected petrol prices. The consumer is also fully informed about the likelihood that the car will be scrapped in any given year. In short, the consumer is very well informed and behaves very rationally, except for having completely inelastic travel demand.

I have applied an 8% discount rate for this analysis, and this is reflected in the “discount factor” shown in Table 4. Future fuel costs can be multiplied by the discount factor to obtain their net present value (NPV).

In summary, the consumer’s expected opex costs in year *t* are given by equation 4 below:

$$Opex_t = VKT_t * \left(\eta_f E[P_{petrol,t}]\right) (1-r)^t \prod_{j=0}^{t} (1 - Scr_j) \qquad (4)$$

[4] The reason for not adjusting VKT figures is that I will later compare the lifetime opex of different types of vehicle, such as petrol cars and BEVs, assuming that they travel the same distance over their lifetime. These different cars may have a different VKT response to petrol price changes. BEVs, for example, should be completely unresponsive. If I adjusted VKT based on assumed elasticities, petrol cars would travel a shorter lifetime distance and have relatively lower lifetime fuel costs, which would skew the analysis.

VKT_t represents the distance travelled by the vehicle in year t, which depends only on the vehicle age. $E[P_{petrol,t}]$ is the expected price of petrol in year t, and η_f is the car's fuel efficiency – in this case, assumed to be 10 L/ 100 km. The discount rate appears as r, with $(1 - r)^t$ being the discount factor. Scr_j is the probability of being scrapped in a given year, with the entire capital pi notation term showing the cumulative survival probability.

The overall net present value of all expected future opex costs is given by equation 5 below:

$$NPV\ Opex = \sum_{t=0}^{43} Opex_t \tag{5}$$

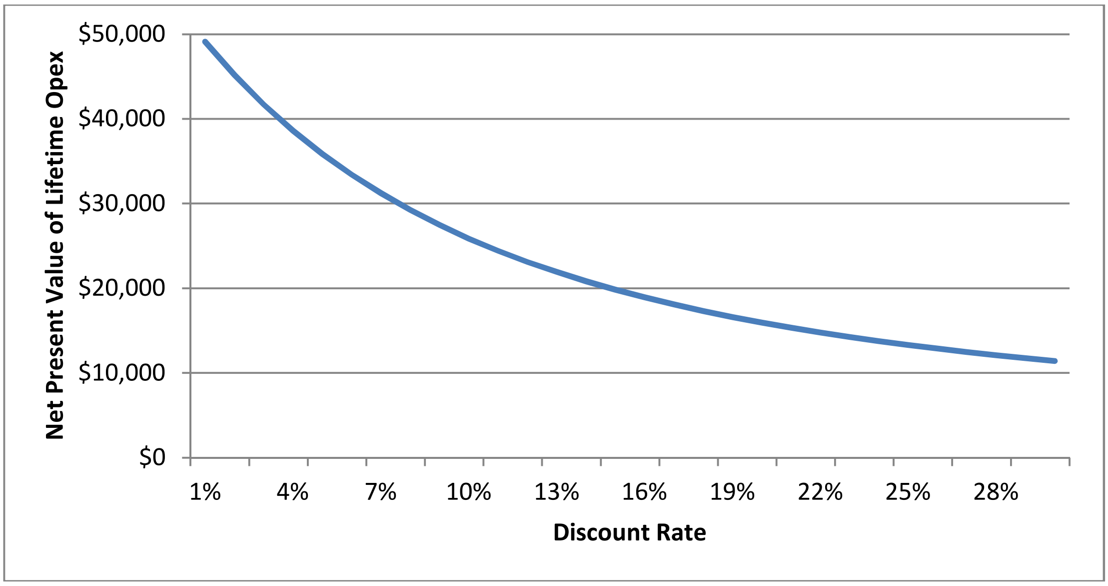
Table 4, overleaf, shows the results of the opex calculation for each year in the typical petrol car's 43-year lifetime.

Table 4: Calculating the NPV of Opex Costs for a Typical Petrol Car

Year	Petrol Price (2010 $/ L)	Unadjusted VKT (km)	Cumulative Survival Probability	Discount Factor	NPV of Opex (2010 $)
1	$2.00	9,151	1.000	1.000	$1,831.85
2	$2.06	18,999	0.998	0.960	$3,755.86
3	$2.12	16,774	0.996	0.883	$3,126.05
4	$2.17	15,423	0.994	0.813	$2,698.64
5	$2.21	14,139	0.991	0.748	$2,315.43
6	$2.25	12,924	0.983	0.688	$1,965.92
7	$2.28	12,692	0.975	0.633	$1,787.90
8	$2.31	11,902	0.966	0.582	$1,548.60
9	$2.34	11,967	0.955	0.536	$1,431.90
10	$2.36	11,515	0.943	0.493	$1,263.10
11	$2.38	12,135	0.928	0.453	$1,215.70
12	$2.40	12,184	0.910	0.417	$1,108.58
13	$2.41	12,008	0.885	0.384	$983.65
14	$2.43	11,778	0.854	0.353	$861.26
15	$2.44	11,571	0.817	0.325	$748.10
16	$2.45	10,983	0.773	0.299	$620.72
17	$2.46	10,237	0.713	0.275	$493.26
18	$2.47	9,718	0.641	0.253	$388.60
19	$2.48	9,335	0.560	0.233	$301.37
20	$2.49	8,793	0.479	0.214	$224.45
21	$2.50	8,213	0.400	0.197	$161.55
22	$2.51	7,747	0.324	0.181	$114.27
23	$2.53	7,263	0.259	0.167	$79.35
24	$2.55	6,631	0.210	0.153	$54.40
25	$2.55	6,258	0.172	0.141	$38.76
26	$2.56	5,934	0.144	0.130	$28.39
27	$2.56	5,700	0.125	0.119	$21.80
28	$2.56	5,392	0.112	0.110	$16.89
29	$2.56	4,897	0.101	0.101	$12.77
30	$2.56	4,911	0.092	0.093	$10.79
31	$2.56	4,845	0.086	0.086	$9.15
32	$2.56	1,137	0.082	0.079	$1.88
33	$2.56	1,137	0.079	0.072	$1.66
34	$2.56	1,137	0.076	0.067	$1.47
35	$2.56	1,137	0.073	0.061	$1.31
36	$2.56	1,137	0.071	0.056	$1.16
37	$2.56	3,003	0.069	0.052	$2.74
38	$2.56	3,003	0.067	0.048	$2.47
39	$2.56	3,003	0.066	0.044	$2.22
40	$2.56	3,003	0.065	0.040	$2.01
41	$2.56	3,003	0.065	0.037	$1.84
42	$2.56	3,003	0.064	0.034	$1.68
43	$2.56	3,236	0.063	0.031	$1.65

Overall, the NPV of lifetime opex costs for this car is just under $30,000. This is of course dependent on the discount rate, and Figure 6 below illustrates the way in which this lifetime cost changes under a range of discount rates from 1% to 30%.

Figure 6: Net Present Value of "Lifetime" Opex Costs for a Typical Petrol Car, Using Various Discount Rates



As shown in this figure, the NPV of lifetime opex costs is very sensitive to the discount rate used, ranging from almost $36,000 at a 5% discount rate to a little under $20,000 at a 15% discount rate.

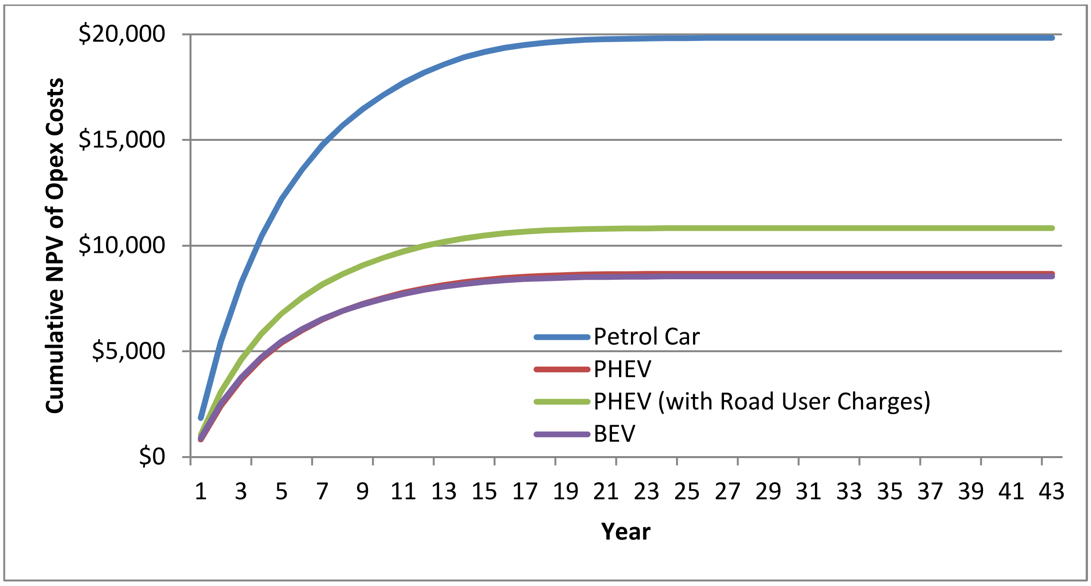
3.3 Using the Rational Model to Compare Different Cars in New Zealand

In this section, the analysis is extended to include two new types of cars: PHEVs and BEVs. As explained in section 2.12, the differential taxation regime faced by petrol and non-petrol cars means that PHEVs face a lighter taxation burden than BEVs. In fact, opex costs for PHEVs are likely to be almost identical to those for BEVs under the current system. As such, I have also estimated the opex costs of PHEVs under a universal Road User Charges scheme, in which these cars pay $44.31 per 1000 km of travel as opposed to being taxed based on their petrol usage.

This analysis assumes that BEVs use 20 kWh of electricity per 100 km of travel, and that PHEVs use 12 kWh of electricity and 3 litres of petrol per 100 km of travel. Again, the petrol car is assumed to use 10 litres of petrol per 100 km of travel. Electricity is assumed to cost 25 cents per kWh for the entire vehicle lifetime.

Figure 7 shows the cumulative NPVs of the opex costs for the three different types of car, over their assumed 43-year lifetimes. This calculation uses a relatively high 15% discount rate.

Figure 7: Cumulative Net Present Values of Opex Costs for Different Cars, Using a 15% Discount Rate



If Road User Charges are made universal, the opex costs for PHEVs will increase slightly. The opex costs for both PHEVs and BEVs are well below that of a typical petrol car, regardless of the road charging system. Over the lifetime of the car, opex costs for a petrol car approach $20,000, whereas the costs for a BEV are around $8,500, and the costs for a PHEV under a universal Road User Charges scheme are nearly $11,000.

The results of this analysis show that a perfectly rational consumer who plans to own a car for its entire lifetime would be able to pay a significant premium for a PHEV or BEV, if they were able to offer the same utility as a typical petrol car – even using a 15% discount rate.

The real-world situation is more complicated, especially given that most consumers will only own a car for a few years. If a perfectly rational consumer were to sell a car to another perfectly rational consumer, the sale price would take into account future fuel costs from the date of sale, and therefore more fuel-efficient vehicles would depreciate more slowly. While there is evidence of this occurring to a limited extent (Gilmore & Lave, 2010), it is unlikely that real-world sale prices incorporate such a detailed discussion of future fuel costs.

Donovan et al. (2009) undertook a similar analysis to the one above, although they used different assumptions which gave a different result. The most important difference is that the conventional car they used for comparison was a Honda Jazz, a small car with fuel efficiency of 5 L/ 100 km. This led Donovan et al. (2009, p. 19) to conclude that PHEVs are an "economically questionable investment" if petrol prices are below $4/ L or if the cost premium of PHEVs is more than NZD $5,000.

Donovan et al's (2009) comparison of a PHEV to a small car, rather than a medium or large car, can be justified. The Boston Consulting Group (2009) predicts that the most popular BEVs will be small commuter cars, and indeed, many of the advanced vehicles developed so far have been small or medium. However, as noted in McConnell and Turrentine (2010, p. 10), the largest potential for opex savings will come from larger cars. This is because electrification can give a similar *percentage* increase in fuel efficiency for all car sizes, resulting in a larger drop in *absolute* consumption for larger, less efficient cars. As such, it makes more sense for rational consumers who need a large car to buy an advanced vehicle than it does for consumers who need a small car.

3.4 Heterogeneous Consumers

The analysis above uses a single consumer, with travel demands equal to the New Zealand average. However, many consumers will be very different from this average; they may drive roughly the same distance each year, rather than the steadily declining distance above, but trade their car in every few years so that they always own a vehicle of roughly the same age. They may also own several vehicles, and be able to split their travel between them. Clearly, consumers are heterogeneous, and even two completely rational consumers might have very different needs and therefore choose different cars. A household consisting of a couple and five children would have greater need of a large car with more than five seats, or multiple cars, than a household consisting of just a couple.

Vehicle users in New Zealand can be divided into three main groups: households, government and businesses, and while there will be different characteristics within each group, it is also instructive to consider them as a whole. These two latter groups are also significant purchasers of cars in New Zealand; according to the Transport Registry Office, as cited by Hyder (2009), businesses own 13% of the cars in New Zealand, and account for 42% of new car purchases.

The government is one of the major new car buyers in New Zealand, and it could have a major effect on the uptake of advanced vehicles through its car procurement policies. King (2007, p. 22) argued that “fleet procurement policy is a powerful market influence and [the government’s] fleet assessment could look to electric vehicles where price and purpose render them appropriate”. In its *Energy Strategy*, the New Zealand Government (2007, p. 55) appeared to agree with this view, noting that “the government... will use procurement policies to encourage changes to more efficient and low carbon vehicles”.

While government is perhaps more concerned with greenhouse gas emissions than the average business, both the private and public sector should respond to cost-competitive PHEVs and BEVs. Businesses and government can also offset depreciation against their profits, which makes the up-front cost of new vehicles – including PHEVs and BEVs – less of an issue. Furthermore, they often have access to cheaper electricity, giving them a cost advantage relative to households. In 2009, commercial customers paid an average of 17.5 ¢/kWh for electricity, while "residential" customers paid 25.5 ¢/kWh (MED, 2011a). This is an average discount of around 30%, and is much larger than the discounts businesses can receive on petrol or diesel – increasing the incentive for them to switch their fleets to advanced vehicles.

Another consideration is that government and business-owned vehicles tend to travel further each year than household-owned vehicles, and this may make range more of a concern for these consumer groups. BEVs may not be suitable for organisations with high travel demand, although PHEVs would still be a viable solution.

As an overall consumer group, households are more likely to buy ex-overseas cars than businesses or government, which follows from the . Many households find the price point of new conventional cars to be too expensive, while the hefty price premium associated with PHEVs or BEVs puts them even further out of reach for the time being – even given the long-term savings in fuel costs. Income, therefore, is likely to be an important determinant of how likely – or able – a household is to buy an advanced vehicle.

Households also differ greatly in terms of their desires for different sizes of cars, and the distance they travel. This may depend on factors like income, but also on household size – the number of people in the household. Furthermore, multi-vehicle households may have different preferences than single-vehicle households; for example, a household might be more willing to purchase a BEV if it also has access to a petrol car which can be used for longer trips.

The places where households live also affect their use of transport energy. Urban households have greater access to public transport, while rural households are likely to rely exclusively on private vehicle travel. Location within a city is also important, as on average, households which are located more centrally will have a shorter distance to travel to work, as well as better access to public transport. Over the long term, urban planning and densification could play a major role in shaping transport demand patterns.

Given suitable data, it is possible to extend the rational model to include a treatment of these different customer groups, although – due to a lack of this data – such an extension has not been undertaken for this thesis. This would certainly be an interesting subject for future research.

3.5 Issues with the 'Rational' Model

In contrast to the clear-cut decisions of the rational model, Greene et al. (2005, p. 758) argue that "surprisingly little is known about how consumers estimate the value of improved fuel economy and factor that information into their car-buying decisions". A similar line is taken in EPA (2010a), who note that it can be difficult to determine how much consumers value fuel economy due to various data issues. These issues arise, for example, because different vehicle attributes are correlated or unobservable, or because consumers are heterogeneous. However, economists are used to dealing with these kinds of issues. The lack of agreement over how much consumers value fuel economy is likely to stem from something more fundamental: "that the presumed theory of consumer behavior is incorrect" (EPA, 2010a, p. vii).

Empirical evidence for this claim comes from Turrentine and Kurani (2007, p. 1213), who found that "when consumers buy a vehicle, they do not have the basic building blocks of knowledge assumed by the model of economically rational decision-making". Most consumers are unable to understand or calculate discount rates and payback periods; they are poorly informed about how far they travel, how much fuel they use, how much it costs them, and the fuel economy of their vehicles (Turrentine & Kurani, 2007).

These findings are all the more powerful because Turrentine and Kurani (2007, p. 1217) chose a non-representative sample of interviewees: they chose consumer groups such as financial sector workers, college students, hybrid car owners and "state resource agency employees”. The groups they chose would be comparatively well informed as to the issues around transport energy and cost, compared to a random sample.

Only a few of the households interviewed by Turrentine and Kurani (2007) had taken fuel economy into account in making past vehicle purchases. Those who did were usually those with low incomes or long commutes, or who were remembering purchases made during the 1970s era of high oil prices. The first two factors recall the heterogeneity of consumers, and the third factor suggests that fuel economy does become more important when fuel prices are high.

Turrentine and Kurani (2007, p. 1213) also found that consumers attach other meanings to fuel economy and fuel prices, beyond the mechanistic calculations in the rational consumer model: as such, their responses to changes in these parameters “are more complex than economic assumptions suggest”. Ozaki and Sevastyanova (2011, p. 2219) argue that consumption “communicate[s] people’s values, identities and memberships... and the purchase of new goods has both personal and social meanings... People’s consumption patterns, therefore, differ significantly from the mere expenditure of time and money”.

The Chief Executive Officer of Turners Auctions, Graham Roberts, said in April 2007 that car purchases are “more an emotional decision rather than a business transaction”, and that vehicle choice is based on appearance, engine capacity and safety features, among other things (Roberts, 2007).

Roberts (2007) believes that New Zealanders have “got a bit to learn about fuel efficiency”. Consumers may not realise that it is possible to improve the fuel efficiency of today’s cars at some cost. For example, the six hybrid owners interviewed in Turrentine and Kurani (2007, p. 1221) “did not in general perceive a specific price difference that they paid”, relative to a conventional vehicle. Hybrids are certainly more expensive than conventional cars, though, with McConnell and Turrentine (2010) suggesting that the retail price typically differs by up to $5,000 USD.

As such, there is evidence to suggest that real consumers do not follow the same decision-making process as those in the rational model. As eloquently stated by Turrentine and Kurani (2007, p. 1221) consumers simply "do not think about fuel economy in the same way as experts, nor in the way experts assume consumers do".

This model may also predict different outcomes than those that occur in the real world, "due to some type of market failure, such as incomplete information, or high [implicit] discount rates" (McConnell & Turrentine, 2010, p. 25). Greene et al. (2005, p. 758) point out that there may be high information costs involved in analysing the pros and cons of more efficient vehicles. In this case, consumers who do not carry out the detailed calculations described above may still be behaving rationally. Reading between the lines, a government which can decrease these information costs will be able to steer consumers towards more rational behaviour. The fuel economy labels which are now found on cars for sale in New Zealand are one way of doing this.

Jaccard, Murphy, and Rivers (2004, p. 32) argue that discount rates may not consider "the full social cost of technological change". Other costs may be involved, such as potentially higher risks of vehicle failure or operating problems; real or apparent qualitative differences; and costs that vary from one area to another (Jaccard et al., 2004). Applying this thinking to advanced vehicles, we can see the risks of vehicle problems in the risk of battery failure or explosion; qualitative differences in the significantly reduced range of BEVs compared with other cars; and area-specific costs in the availability of charging infrastructure. Looking at vehicle sales data, we would indirectly observe consumers' wariness of such risks through lower sales for advanced vehicles, which would lead us to think that consumers were simply applying a higher discount rate to the fuel savings from such vehicles.

3.6 In Defence of the Rational Model

Turrentine and Kurani (2007, p. 1215) state that "the rational actor model is not an accurate or useful view of how consumers think about fuel economy and automotive fuel costs". Whether or not consumers think rationally or even behave as if they do, I would argue that this model is still a useful way to look at potential long-term trends, and to evaluate government policy. Given that New Zealand consistently runs current account deficits, and is reliant on importing both vehicles and petroleum fuels, it is important to consider the long-term costs of vehicle ownership for the country.

The rational model is a sound platform for looking at consumer choice, and rational outcomes can be thought of as the "ideal" towards which we should aspire. It allows for consumers to choose a discount rate that suits them, and to trade off future costs against present costs; deviations from the rational outcome can be thought of as a market failure, one which could be mitigated with appropriately designed policies. It is also appropriate for larger organisations, such as the government, to use the rational model in order to compare costs and benefits of buying more fuel-efficient cars with other costly projects. This enables the government, for example, to decide whether it should invest in fuel efficiency or in building a new road that cuts travel times and fuel usage.

Furthermore, Turrentine and Kurani's (2007) study, groundbreaking though it was, only considered vehicle choices by households, not by government or businesses. Businesses and government bodies may potentially exhibit more rational behaviour than households – something that would be interesting to test in future research. We could hypothesise that they are more likely to view purchasing a car as a financial transaction than households, and that they would have a better appreciation of the time value of money. They might not consider *lifetime* costs of ownership, since business and government vehicles are usually only kept for a few years before being sold to the household sector. Nonetheless, businesses and government may well be more "rational" overall than households, and given the importance of these consumer groups in determining the type of cars entering the country, this could steer observed outcomes closer towards the rational ideal.

3.7 Implications of the Rational Analysis

My analysis suggests that, even with a 15% discount rate and a universal Road User Charges scheme, PHEVs will save $9,000 in opex costs over their lifetime, compared with a typical, medium-sized petrol car. If a PHEV offers its owner the same utility from driving as a petrol car, a perfectly rational consumer would choose the PHEV over the petrol car if its up-front cost was no more than $9,000 higher. For a PHEV with an 8 kWh battery, this implies a battery cost below NZD $1,125/ kWh, or actually somewhat less given the additional costs associated with such a vehicle.

Given that current or near-term battery costs appear to have already fallen below this level – at least for BEV-sized batteries – this analysis suggests that PHEVs may currently be competitive with conventional cars, or may become competitive in the near future. Using a more generous discount rate strengthens the case for this conclusion: at the New Zealand Government's (2007) 5% rate, the lifetime opex savings for a PHEV that pays Road User Charges grows to more than $16,500.

Much of the appeal of PHEVs is that they offer significant opex savings while offering potentially the same level of comfort, performance and versatility as a conventional car. The Chevrolet Volt, for example, has been very popular with reviewers, with the main disadvantages being that it seats four people rather than five – as the battery runs through where the rear middle seat would normally be – and an apparently small boot (U.S. News Rankings & Reviews, 2012). These seem to be fairly minor concerns, and such issues should be surmountable in the near future.

The economic rationale for BEVs appears to be a lot weaker for the time being. These cars offer limited additional cost reduction over PHEVs, and their larger batteries result in much higher purchase prices. At a 15% discount rate, a BEV offers $11,300 of lifetime opex cost savings compared with a conventional car, which – assuming a 33 kWh battery – implies a cost below NZD $340/ kWh to reach overall cost parity. Factoring in the low range and long charging times of BEVs, these vehicles are likely to be relegated to a niche position for some time to come.

It is important to note that a “typical” new petrol car being bought today is likely to achieve slightly better fuel economy than the 10 L/ 100 km assumed here. New Zealand’s top-selling new car in 2010 was the Toyota Corolla, accounting for 7.9% of all new car registrations in 2010 (New Zealand Transport Agency, 2011a). The Corolla is a medium-sized petrol car, with a 1.8 litre engine in current models, and lab-tested fuel efficiency of 7.4 L/ 100 km (Toyota, 2011). On-road fuel efficiency for the Corolla might be closer to 8 L/ 100 km, which would still lead to a lifetime opex cost that is significantly lower than the one assumed in this analysis. This, of course, weakens the case for buying a PHEV or BEV. Indeed, a still more efficient conventional car could be imagined, such as a hybrid or diesel, which would further erode the operating cost advantage of these advanced vehicles. It would probably be difficult to justify the additional up-front cost of a PHEV compared to the most efficient conventional cars in its size class.

Although consumers may not take a rational approach to fuel economy, initiatives such as those described in section 2.7.4 could guide them towards the rational outcomes. With a reasonable degree of competition, it is likely that battery-leasing schemes could enable the uptake of PHEVs and BEVs when they become cost-competitive, even if consumers undervalue the fuel savings from these vehicles. Companies who have access to capital at a reasonable interest rate will be able to alter the up-front cost/ ongoing cost balance of advanced vehicles in such a way as to make them more appealing to such consumers. An operator with a battery switching or recharging network could also do this, although with a view to recouping the higher costs associated with the network. Balancing these higher costs would be the additional utility that consumers would gain from having access to switching or charging stations.

3.8 Modelling Vehicle Purchase Decisions

Over the last few decades, an extensive literature has been developed on vehicle purchase decisions. In practise, researchers tend to use a more generalised model than the simple rational one described above.

3.8.1 Multinomial Logit

One common method of modelling vehicle choices is to use a multinomial logit specification (Arnberg, Bjørner, Fosgerau, & Larsen, 2008). At the micro level, consumers choose which vehicle they want to buy, choosing from J different types of vehicle, so *type = 1,2,...,J*. This is a "conditional" model, i.e. it finds the probability of a consumer buying a particular type of vehicle conditional on the consumer buying a vehicle.

In the standard multinomial logit model, consumers are assumed to buy the car that will give them the most utility (Boyd & Mellman, 1980). The utility that a consumer *n* derives from buying a car of a particular type is given by:

$$\text{Utility}_{type} = \beta' X_{type} + \epsilon_{n,type} \tag{6}$$

In this model, X_{type} is a vector of observed vehicle type-specific attributes – which might include such diverse factors as the car's purchase price (or "capex"), its fuel efficiency or derived fuel costs, number of seats, storage space, measures of performance or safety, its colour, or a host of other variables. β' is a vector of coefficients associated with these attributes, which we can attempt to estimate. We would expect, for example, that the coefficients associated with purchase price or fuel costs would be negative: as these costs increase for a particular type of car, consumers become less likely to buy the car.

The error term $\epsilon_{n,type}$ is assumed to be random, and independently and identically distributed " extreme value". Each consumer has a different error term associated with each type of car, and these terms are unobserved. The inclusion of these error terms means that not all consumers will buy the same type of car, even though they are otherwise homogeneous.

Given that the error terms are random and unobservable, the probability that any consumer will choose to buy a vehicle of a particular type is given by:

$$\mathrm{Pr}_{type} = \frac{\exp\,(\beta' X_{type})}{\sum_{type=1}^{J} \exp\,(\beta' X_{type})} \quad (7)$$

This model has a number of "desirable properties" (Train, 2003, p. 41). Each type of car has a probability between 0 and 1 of being purchased, and overall, each consumer will buy exactly one car. We can approximate the rational model described earlier in this chapter by attaching the same coefficients to both purchase price and the NPV of lifetime fuel costs; a $1 increase in either of these observable terms should give the same decrease in the probability of the car being bought. We can also consider other valuable features of the car beyond simply financial factors, such as the other example attributes mentioned above.

The model allows for some degree of heterogeneity through the random error terms, which gives a more nuanced picture than the rational model. The rational model would predict that, if a car has marginally higher opex costs than an otherwise equivalent car, no consumers would buy it. In practise, this would not occur; some consumers might prefer the colour or aesthetics of the more expensive car, and would buy it regardless.

The basic multinomial logit model has an "independence from irrelevant alternatives" property (Revelt & Train, 1998). This means that if different cars are added to or removed from the model, or if the attributes for a particular car change, the relative proportions with which the other cars are chosen remain unchanged. Depending on the researcher's goals, this property may be either beneficial or a source of error. I discuss this further in section 3.8.3.

3.8.2 Mixed Multinomial Logit

Mixed multinomial logit is a more generalised version of the basic multinomial logit model described above. Under this specification, a larger degree of consumer heterogeneity is incorporated, with each consumer having different coefficients associated with the various observable car attributes. In such a model, the utility that a consumer *n* derives from buying a vehicle of a particular type is given by:

$$\text{Utility}_{n,type} = \beta'_n X_{type} + \epsilon_{n,type} \quad (8)$$

This equation is the same as for multinomial logit, except that the unobserved β'_n is allowed to "[vary] in the population with density $f(\beta_n|\theta^*)$ where θ^* are the (true) parameters of this distribution" (Revelt & Train, 1998). The error term, as before, is uncorrelated with these consumer-specific coefficients.

The probability that a consumer n will choose to buy a vehicle of a particular type is given by:

$$\Pr_{n,type} = \frac{\exp\,(\beta'_n X_{n,type})}{\sum_{type=1}^{J} \exp\,(\beta'_n X_{n,type})} \quad (9)$$

Unlike standard logit, mixed logit does not display the independence from irrelevant alternatives property (Revelt & Train, 1998).

3.8.3 Independence from Irrelevant Alternatives

As noted above, the independence from irrelevant alternatives property may be either a positive or a negative one. Train (2003) gives a highly relevant example of where this property is undesirable: a situation where consumers can choose between small or large petrol cars, or small BEVs. If the government decides to subsidise BEVs, their market share will increase at the expense of small and large petrol cars. As Train (2003) explains, the logit model predicts that the market shares of small and large petrol cars will each fall in the same proportion, whereas a more probable outcome is that the share of small petrol cars will be more affected. Train (2003) notes that this may cause "a subsidy program to seem more beneficial than it actually is. This is the reason that the [California Energy Commission] uses models that are more general than logit to represent substitution across vehicles".

However, it is much easier to add new types of car to a standard multinomial logit model than a mixed logit model. In the standard model, the estimated β' parameters do not change when a new car type is added, whereas in the mixed logit model, they do. This can pose difficulties in trying to incorporate cars that are not currently available, e.g. PHEVs and BEVs, and it is necessary to make assumptions about the way in which the β' parameters will change.

Train's (2003) example is a relatively extreme case, given that PHEVs and BEVs are likely to come in all sizes – even if many of the early models have been small. When a range of advanced vehicles are available, covering all segments of the car market, there are no firm grounds for believing that substitution will be overwhelmingly away from particular segments. For example, it is hard to see how BEVs could ever become a viable mainstream technology if they are relegated to the role of small commuter vehicles. This is very much a niche role for countries like New Zealand or the U.S., and one that would probably be better served by public transport. Furthermore, the high cost of advanced vehicles would make it very hard to justify buying them if they are only to be used for short trips. Indeed, given that larger cars tend to be more expensive and also to range more in price (Sean Broughton, personal communication, 14 February 2012), it could be argued that substitution might come more from large car buyers.

Adams, Feeney and Yi (2010, p. 3) decide to estimate the uptake of BEVs and PHEVs in New South Wales using a standard multinomial logit model because this model "is transparent, easily understood by stakeholders and does not require assumptions on the degree of heterogeneity in vehicle choice". This is a well laid out argument for using such a model, and this is indeed the model that I have chosen to use in this thesis.

3.9 Future Car Fleet Trends

The extent to which consumers will embrace PHEVs and BEVs is very uncertain. There are only a few such vehicles currently in production, most of which have only been manufactured and sold in very limited quantities. Furthermore, early adopters of advanced vehicles seem to be influenced by environmental concerns, but these will be a much smaller issue for the general public (Morton et al., 2011). This casts doubt on the validity of drawing conclusions from preliminary sales data. The lack of suitable data around PHEVs and BEVs is an issue, whichever approach is taken to modelling their uptake.

A number of researchers and consultants have attempted to predict the speed with which advanced vehicles will become established in the market. However, in many cases, these studies are not published in academic journals, and their methodologies are often unclear. Morton et al. (2011) list a number of issues for predicting advanced vehicle uptake, stressing that advanced vehicles represent a radically new automotive technology that consumers know little about, making it difficult to predict consumer responses.

Because cars are durable goods and often remain in the fleet for 20 years or more, the proportion of advanced vehicles in the fleet will lag the "market share" of advanced vehicles as a percentage of all cars being added to the fleet. This is an important distinction to make, as if PHEVs grow to make up 10% of all vehicles being *added* to the fleet, for example, it will still be many years before the *overall* number of PHEVs in the fleet reaches 10%.

According to the European Automobile Manufacturers' Association (2010), "most stakeholders assume a realistic market share for electrically chargeable vehicles [i.e. BEVs and PHEVs] in the range of 3 to 10% of new sales by 2020 to 2025, depending on how quickly the most immediate challenges can be addressed". Although the sources for this statement are not given, this illustrates that advanced vehicles may remain a niche market for at least the next 15 years. The IEA (2011) appears to hold a similar view; in the New Policies Scenario, advanced vehicles account for almost 4% of new car sales by 2035, although this proportion rises to 37% in the 450 Scenario.

For a country like New Zealand, with a relatively old fleet (New Zealand Government, 2007) and where the majority of cars we import are used rather than new, it could take much longer for these vehicles to establish a beachhead. In the Reference Scenario presented in the MED's (2010) *Energy Outlook*, PHEVs and BEVs make up 10% of all new vehicle sales by 2030. Even under a scenario of higher oil prices, the MED (2010) predicts that they will only account for 14% of sales in 2030. King (2007) theorises that, given very favourable conditions, advanced vehicles could account for 25% of the fleet by 2030.

The “low carbon scenario” described by the New Zealand Government (2007) assumes that by 2050, New Zealand’s light vehicle fleet will be made up of 60% electric vehicles and 25% hydrogen vehicles. The 15% of conventional vehicles which remain are assumed to mainly run on biofuels.

The Transport Scenarios Model developed for this thesis aims to add to the discussion around the uptake of advanced vehicle, while steering clear of making concrete predictions. The model is instead intended to be used as a tool to test various scenarios and assumptions. Its modelling methodology is also completely transparent: the code is attached as an appendix to this thesis, and all MATLAB code files, graphical user interface files and data files will be available with the digital copy of this thesis.

4 CAR REGISTRATIONS IN NEW ZEALAND

This chapter details a number of regression analyses performed on vehicles entering the New Zealand fleet between 2002 and 2010. The results from these regressions are used to help calibrate the Transport Scenarios Model, described in chapter 5.

The data described in this chapter covers “light passenger vehicles”, essentially referring to cars and sports utility vehicles. Two-wheel vehicles such as motorcycles and mopeds are not included, and neither are “light commercial vehicles” such as vans, utility vehicles or light trucks.

The terms “used” and “ex-overseas” are used interchangeably to refer to cars which enter New Zealand’s fleet after a period of overseas use, while the terms “new” or “NZ-new” refer to cars which enter the fleet in brand-new condition. These terms are important for the New Zealand situation, because unlike most developed countries, many of our cars are used imports. These vehicles tend to be slightly less efficient and less safe than brand-new cars. They also have a shorter expected lifetime and higher maintenance costs, given that they have already been used overseas for an average of eight years (MOT, 2011). Balancing out these negative factors is their low prices; according to Dravitski et al. (2010), used imports cost 25% to 30% of the price of new cars.

4.1 The Regulatory Environment

The main change to the regulatory environment in the last decade was the 2007 Vehicle Exhaust Emissions Rule. This rule was signed in November 2007 and took effect at the beginning of 2008, requiring that used petrol vehicles would have to meet Japan 98 emissions standards, while used diesel vehicles would have to meet Japan 02/04 standards (Minister for Transport Safety, 2007).

The 2007 Vehicle Exhaust Emissions Rule made provision for emissions standards to be progressively tightened beyond 2008; ex-overseas diesel vehicles were required to comply with Japan 05 emissions standards by 2010, while ex-overseas petrol vehicles had to meet these standards by 2012, despite protests from used car dealers (McDougall, 2012).

It should be noted that the rule, and the Japanese standards to which it refers, are concerned with air quality, rather than global warming. The standards impose a limit on exhaust emissions of nitrogen oxides and harmful particulates, not on greenhouse gases.

The overall effect of the rule has been to prevent the importing of some older and less efficient ex-overseas cars. Ex-overseas diesel car registrations have shrunk to almost zero since the rule was implemented, although they had been declining for several years prior.

While regulatory changes come into force on a clearly defined date, their downstream effect is not always well defined. This means that it can be difficult to pinpoint the date of a structural break in the registration data. The MOT (2012b, p. 3) notes that "many imported vehicles [are] registered at particular times of the year to avoid having to comply with vehicle rules". As outlined by the Minister for Transport Safety (2007), Cabinet agreed to tighten emissions controls in January 2007, and the proposed rule was released for consultation in May. Importers of used diesel vehicles would have had a number of months to stockpile cars before the rule came into effect. Indeed, it seems that registrations of used diesel cars decreased gradually over 2008-2010, rather than dropping suddenly.

4.2 Data Overview

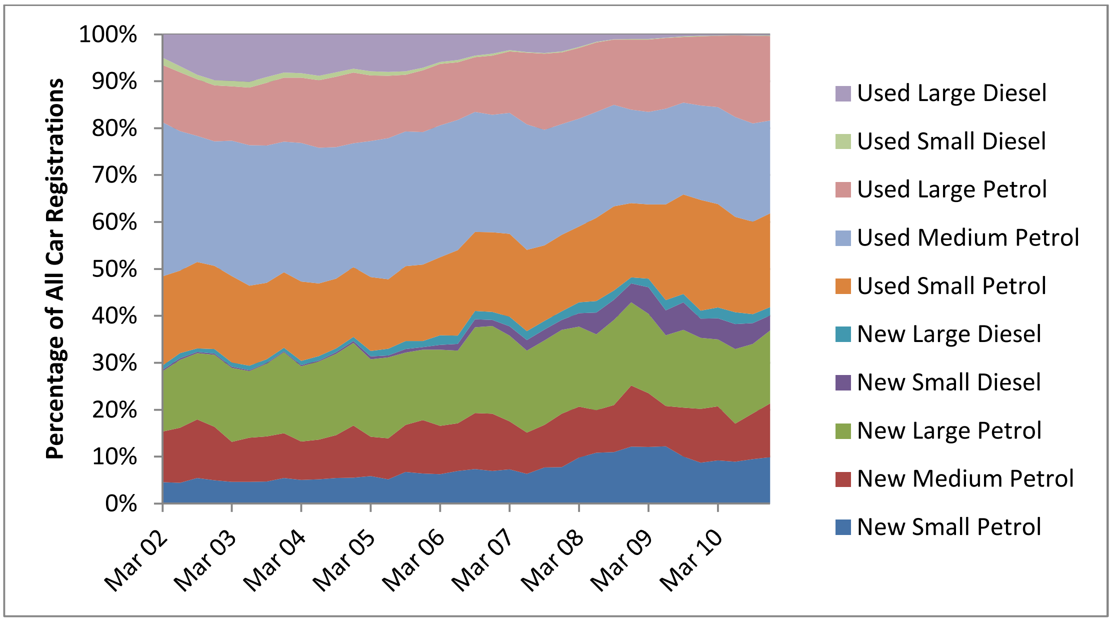
To carry out the regressions, I obtained data on car registrations, fuel prices and car prices for the 2002-2010 period. Stuart Badger (personal communication, 13 January, 2012) from the MOT provided me with quarterly data on light passenger vehicle registrations in New Zealand between 2002 and 2010. This data showed the number of cars being registered each quarter, broken down by whether they were diesel or petrol; NZ-new or ex-overseas; and by engine size.

The vehicles were classified into one of ten engine size bands, which I simplified to three bands for this analysis: less than 1.75 L, 1.75 to 2.249 L, and 2.25 L or more. As explained in MOT (2011), there is no authoritative long-term data series on vehicle sizes in New Zealand; the best available proxy variable is engine size. As such, I refer to these cars in these three engine size bands as “small”, “medium” and “large” respectively.

For diesels, I combine the first two categories, leaving me with just two categories: less than 2.25 L, and 2.25 L or more. The first category, which might be more accurately described as “small/ medium diesel”, is referred to as “small diesel” hereafter. This category has only ever made up a small proportion of car registrations in New Zealand.

Overall, this gives ten different car types, and Figure 8 below shows how their “market shares” of car registrations have changed over the 2002-2010 period.

Figure 8: New vs. Ex-Overseas and Diesel vs. Petrol Car Registrations, as a Percentage of Total Registrations between 2002 and 2010



Source: Stuart Badger (personal communication, 13 January 2012)

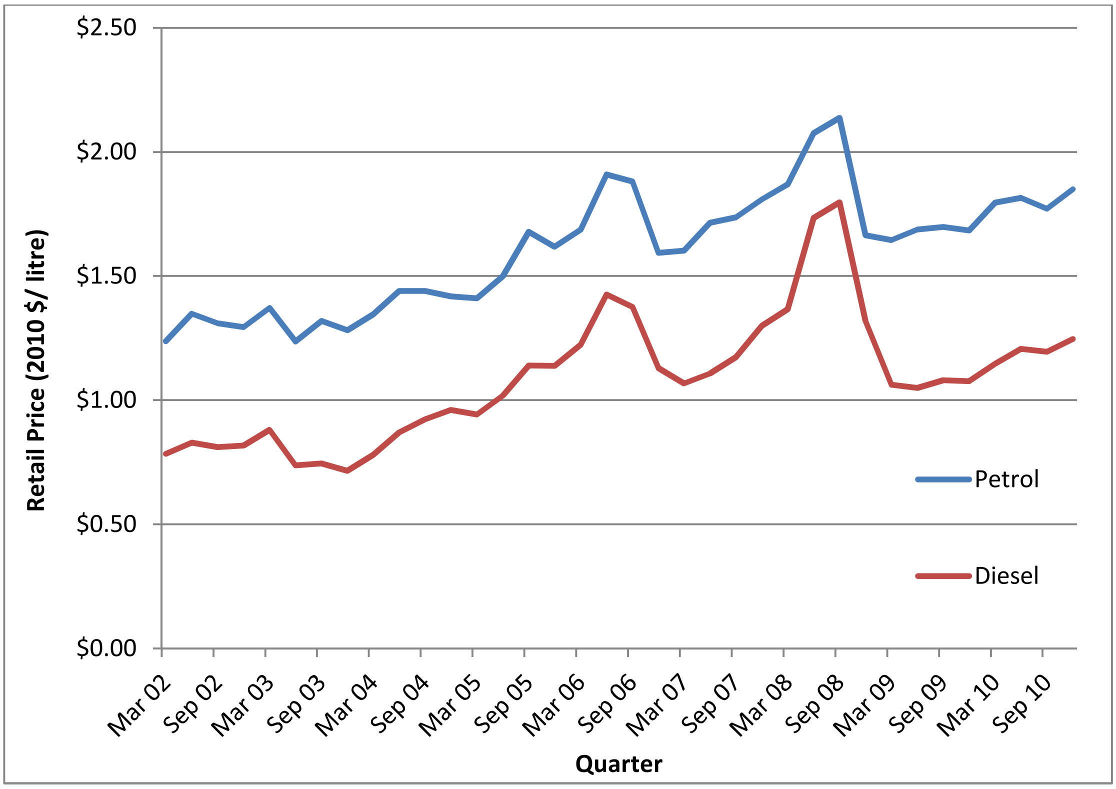
In the last decade, ex-overseas cars have accounted for between 50% and 70% of all cars registered. The percentage has fallen since 2006; this is partly due to the 2007 Vehicle

Exhaust Emissions Rule, and partly due to increased international competition for second-hand Japanese cars (Roberts, 2007). In 2010, 34.7% of cars registered were new petrol cars, 6.5% were new diesel cars, and 58.5% were used petrol cars.

Prior to 2005, most diesel car registrations were for ex-overseas cars, but these have now all but disappeared, due to the 2007 Vehicle Exhaust Emissions Rule. Despite an increase in the proportion of new diesel cars, the overall proportion of diesels entering the fleet has declined.

Fuel price information forms a necessary part of the data set. I obtained real retail price data for petrol and diesel from the MED (2012a), with prices given in December 2010 quarter $NZD. In real terms, petrol and diesel prices increased over the 2002-2010 period. This increased the operating expenses associated with driving both petrol and diesel cars. below shows these real petrol and diesel prices, with the difference between the two sets of prices mainly due to the different taxation regimes for petrol and diesel cars.

Figure 9: Real Retail Prices for Petrol and Diesel in New Zealand, 2002-2010

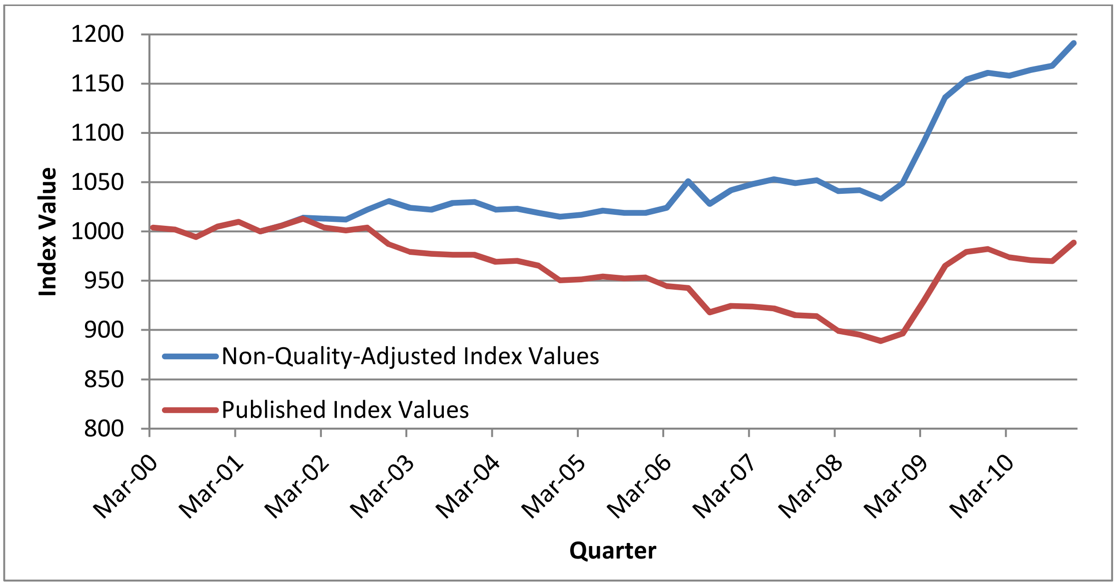


Source: MED (2012a)

My regressions also require information on the prices of new and ex-overseas cars. Fortunately, SNZ collects this kind of information for use in its Consumers Price Index (CPI). The CPI is a quarterly publication which tracks the prices of common consumer goods in New Zealand, including cars – which, in SNZ publications, are divided into new and second-hand, but with no distinction made between different sizes of car.

The CPI is a quality-adjusted index (SNZ, 2007), which is to say price changes are adjusted to reflect changes in the quality of the good in question. For example, one large sedan which was tracked by SNZ over a ten-year period added additional airbags, an improved stereo, and incorporated a smaller engine which still managed to deliver more power and torque than its predecessor (SNZ, 2011b). Published CPI data is adjusted to remove the impact of these quality changes. However, for the purposes of calibrating my regressions, I am interested in non-quality-adjusted car prices, as many of the quality improvements to new cars in the 2000s did not improve fuel economy. As such, I have used unpublished CPI data from Sean Broughton at SNZ (personal communication, 14 February 2012), which does not adjust for quality changes. Figure 10 below shows the two different methods of compiling the index for new car prices:

Figure 10: Published vs. Non-Quality Adjusted CPI Index Values for New Cars

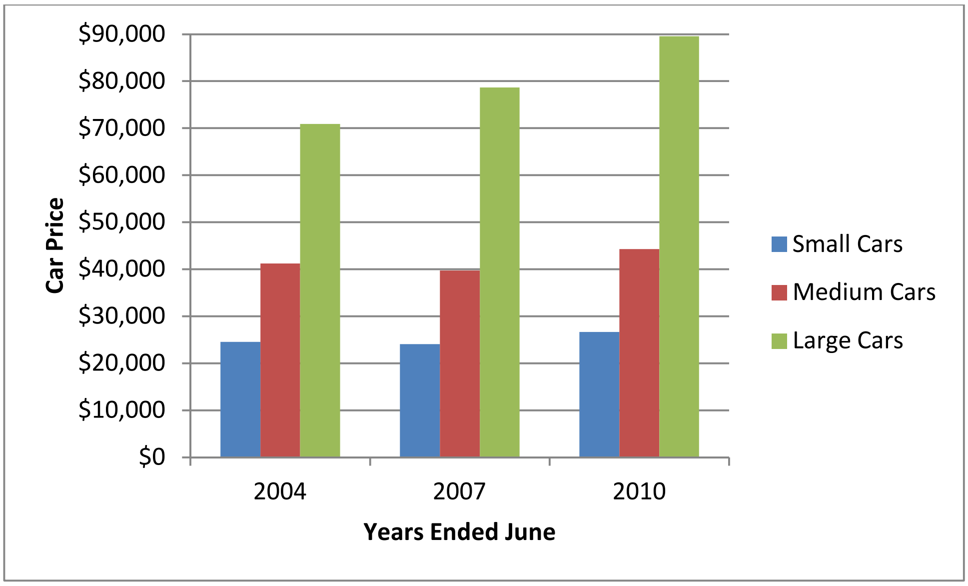


Source: Sean Broughton (personal communication, 14 February 2012). Index values have been rebased to March 2000 quarter = 1000

This figure illustrates that, without adjusting for changes in the quality of new cars, their prices rose slowly over 2000-2008 and more rapidly over 2009-2010. When quality changes are incorporated and assigned a monetary value, as in the published CPI index, the price of new cars actually fell over 2000-2008 and, despite an increase in 2009-2010, finished the period with prices slightly lower than in 2000.

SNZ only collects detailed information on new car prices sporadically, when reweighting the CPI index. During these times, SNZ categorised cars as small, medium or large based on their engine size, collect information on the cars' retail prices, and compile average prices for each size of car, weighting these prices based on registration data (SNZ, 2007). Figure 11 below shows the results of SNZ's analysis:

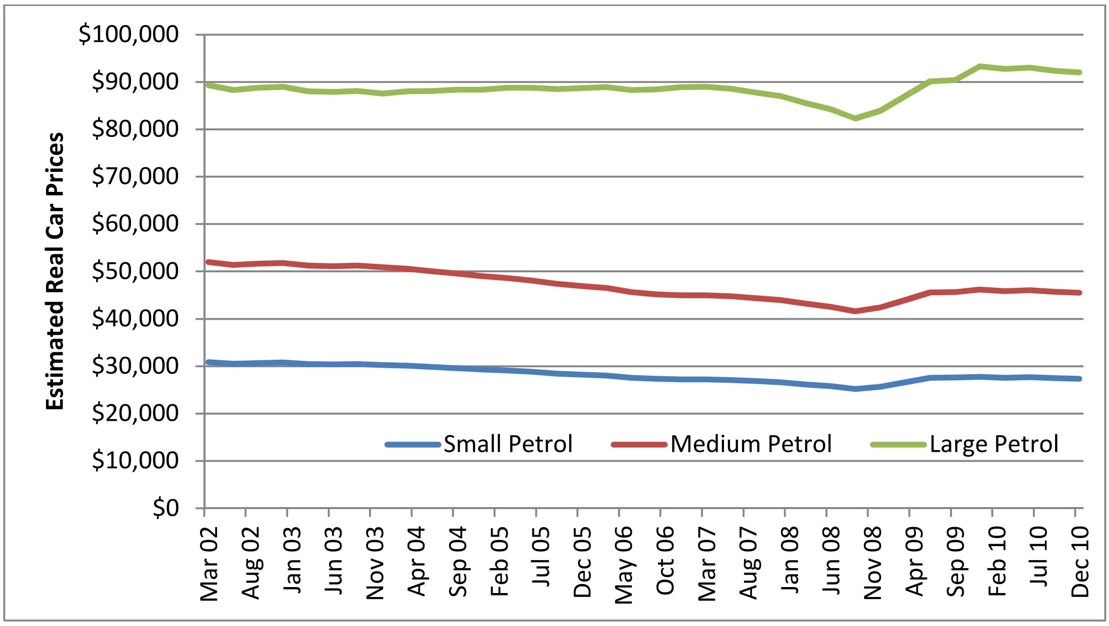
Figure 11: Average New Car Prices by Size, for the Years Ended June 2004, 2007 and 2010



Source: Sean Broughton (personal communication, 14 February 2012)

Given that the rest of my data is quarterly, it was necessary to estimate quarterly prices for new small, medium and large cars over the entire 2002-2010 period. I did this using the two data sources described above, sources which are not entirely comparable. These prices were deflated to December 2010 quarter prices, using the overall CPI index. The results of this process are shown in Figure 12 below:

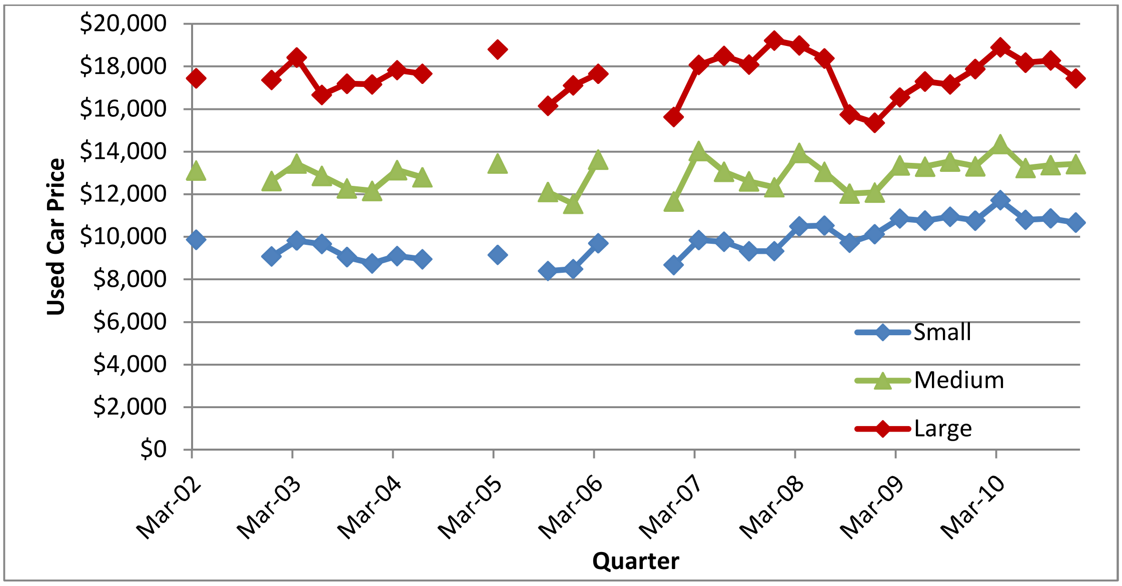
Figure 12: Estimated Real Prices for New Cars, 2002-2010



Note. Based on SNZ data from Sean Broughton (personal communication, 14 February 2012)

SNZ collect data on used car prices by vehicle size on a quarterly basis, making these more reliable than my interpolations for new cars above. However, there were some missing data points which I estimated using a similar process as for new cars, by using published CPI index values for used cars. As for new cars, prices were converted from nominal to December 2010 quarter prices. Figure 13 below shows the raw SNZ data:

Figure 13: Nominal Prices for Used Cars, 2002-2010



Source: Sean Broughton (personal communication, 14 February 2012)

4.3 Ordinary Least Squares Fit

This section details the results of a series of ordinary least squares regressions, using a standard multinomial logit model of the form given in equation 7. All regressions were carried out in Excel using Solver. As noted earlier, there are ten types of car in the dataset, so J = 10, and the observations are quarterly from 2002 to 2010 inclusive, so T = 36. Note that Regression 2 only uses eight car types, completely ignoring used diesels; these cars are simply deleted from the dataset, and the market shares for other cars are scaled up as per the standard multinomial logit model.

The market share of a car of a given *type* in period *t* is given by equation 10 below:

$$\text{Share}_{type,t} = \frac{\exp\left(\alpha\, Capex_{type,t} + \beta\, Opex_{type,t} + \gamma_{type} + u_{type,t}\right)}{\sum_{type=1}^{J} \exp\left(\alpha\, Capex_{type,t} + \beta\, Opex_{type,t} + \gamma_{type} + u_{type,t}\right)} \qquad (10)$$

The constants α and β are assumed to be the same across all periods and types of car. γ_{type} is a vehicle type-specific fixed effect. The probability of a given type of car being purchased increases with its gamma coefficient. This term can be thought of as incorporating some aspects of the utility given by the vehicle, and a range of other unobserved factors – including, for example, the availability of this type of vehicle. The *Capex* of a car type is its estimated purchase price in period *t*. $u_{type,t}$ is an error term, which we aim to minimise in the regression.

For Regressions 1 and 2, the *Opex* term is the estimated cost of driving the car 100 km in period *t*, incorporating fuel costs and Road User Charges if applicable.

For Regressions 3 and 4, the *Opex* term is a NPV calculation, summing up opex costs in a range of future periods in discounting them appropriately. Regression 3 calculates the lifetime NPV of opex costs over a 43-year period, as described in section 3.2; consumers are assumed to apply an 8% discount rate and to be very well informed about fuel prices. Specifically, they are assumed to have full knowledge of the petrol and diesel prices they will face in the future, which are as shown in Source: **MED (2012a)** between 2002 and 2010, and are based on the IEA's (2011) New Policies Scenario thereafter as for section 3.2.

Regression 4 uses a similar approach to McConnell & Turrentine (2010), with consumers assumed to consider their opex costs over the first three years of vehicle ownership and apply a 15% discount rate.

Table 5: Regression Results for New Zealand Car Registration Data, 2002-2010

Regression Number	1	2	3	4
Estimated capex coefficient α	-0.000013	-0.000021	-0.000024	-0.000017
Estimated opex coefficient β	-0.015788	-0.028918	0.000083	0.000088
Estimated Gamma Terms				
New Small Petrol	-0.023	-0.556	-0.069	0.018
New Medium Petrol	0.619	0.294	0.060	0.465
New Large Petrol	1.681	1.720	1.003	1.501
New Small Diesel	-0.965	-1.339	-1.052	-0.873
New Large Diesel	-0.917	-0.780	-0.262	-0.795
Used Small Petrol	0.614	-0.052	0.964	0.720
Used Medium Petrol	1.108	0.545	1.052	1.042
Used Large Petrol	0.650	0.168	0.264	0.441
Used Small Diesel	-2.318	n/a	-1.724	-2.127
Used Large Diesel	-0.448	n/a	-0.236	-0.393

For regressions 1 and 2, the coefficient on the opex parameter is significantly larger than the one on the capex parameter. This is what we would expect, given that the effect of a $1 increase in *Opex* per 100 km has a much larger effect on the lifetime cost of ownership than a $1 rise in the one-off *Capex*. The relative size of the estimated α and β coefficients implies that consumers are willing to pay an extra $1,216 for their vehicle in Regression 1, or $1,402 in Regression 2, in order to decrease running costs by $1 per 100 km. This suggests that consumers place a reasonable value on fuel savings. As per the analysis in Table 4, cars travel a discounted and survival-probability-adjusted distance of 130,684 km in their lifetime, using an 8% discount rate. Rational consumers should therefore be willing to pay an extra $1,307 up front to reduce their opex costs by $1 per 100 km.

On the other hand, regressions 3 and 4 respectively imply that consumers would pay $3.40 to $5.05 more up front in order to *increase* the NPV of their opex costs by $1, a much less satisfactory result. It suggests that consumers will switch towards larger, less efficient cars as fuel prices increase, which runs contrary to economic theory and to recent observed trends.

For the most part, the vehicle fixed effects in regressions 1 to 4 show the expected patterns. Larger cars are typically have higher estimated gamma values than smaller cars with the same fuel and new/ used status. Larger cars usually offer more interior and storage space, more features, and better vehicle performance – with the exception of fuel efficiency. As such, most consumers would be expected to prefer them, if the higher costs of these cars are left aside.

For all regressions, diesel cars have smaller estimated gamma coefficients than the equivalent size and new/ used status of petrol car. This could reflect a perception that diesels are dirty or smelly, the hassle of having to pay Road User Charges, or the higher maintenance costs associated with diesel cars.

The diesel coefficients might also be due in part to a lack of available diesel models in the New Zealand market. Vehicle fixed effects can represent not only unobserved features that are inherent to the type of vehicle, but also the range of models available within that type, or the ease of acquiring these vehicles. The coefficients on used diesel cars are likely to be picking up, at least in part, the difficulty in obtaining such vehicles in the later years of the 2000s, in the face of stricter emissions regulations.

As a probable example of this, the coefficient for used large petrol cars is lower than the one for used medium petrol cars for all regressions. This is likely to reflect the realities of the New Zealand market; most of our used imports are sourced from Japan, and most Japanese cars are small or medium, meaning that there is a lack of available ex-overseas large cars.

4.4 Further Discussion

The regression results described here suggest that consumers' choice of car depends much more on the gamma terms associated with each car than on fuel prices. The values of α and β are very small, which means that changes in either capex or opex do not have much effect on the market share of a given vehicle type. Looking at regression 1, for example, an opex increase of $39 per 100 km would be necessary to "cancel out" the vehicle fixed effect for a new medium petrol car.

The idea that the market share of different vehicle size classes does not change significantly in response to fuel price changes is not a new one: Boyd and Mellman (1980) found that while overall fuel economy improves in response to these changes, this is mainly due to "supply-side improvements in the fuel economy of cars in each size class... [as opposed to] market shifts among size classes of cars". McConnell and Turrentine's (2010, p. 34) modelling of the impact of subsidies for hybrids assumes "very little substitution between vehicle size classes".

In terms of the ratio of α to β, Regressions 1 and 2 produce plausible, near-rational values for consumers' willingness-to-pay for fuel economy, while regressions 3 and 4 suggest a completely different result. This illustrates that what should be a fairly straightforward and minor alteration to the model can change the results completely. The difficulties of inferring willingness-to-pay values for fuel economy are mentioned by the EPA (2010a), who reviewed the literature to find that different studies gave an extremely wide range of results, despite there being “no obvious flaws in the methods or data used by these studies”.

There are potentially issues with the data I have used; as noted earlier, I have not had access to ideal car price data, and there have been regulatory changes which can blur the picture. However, the registration data does show some counter-intuitive trends; for example, the proportion of new large petrol cars being registered rose from 2005 onwards, despite increasing fuel prices.

It is possible that the regressions should make allowance for the strong economic growth of the decade, as this may have prompted a shift towards larger and more expensive cars even while fuel prices were rising. It would be relatively straightforward to include a measure of average household incomes in the model, for example. Growth or income effects may be omitted variables, and future work should explore this possibility.

With 12 coefficients to estimate and only 36 observations, and a wide range of external factors that may have affected registration trends, it is possible that the analysis undertaken here simply cannot provide the level of detail required to explain car substitution patterns in New Zealand. It is entirely possible that changes in unobserved consumer preferences, rather than fuel prices, have given the impetus to the observed trends of the last decade. If so, advanced vehicle manufacturers should hope that future preference changes favour these vehicles, and the government should consider the actions that can be taken to encourage the uptake of PHEVs and BEVs should they prove to be economically viable.

4.5 Calibrating the Transport Scenarios Model

Regression 1 includes all car types and all observations. While it may give a better picture of *average* buyer preferences in 2000-2010 than *future* buyer preferences in a world of higher fuel prices and tighter emissions controls, it makes use of all the available data.

Regression 2, discarding all data for used diesels, is likely to misjudge several effects. Given that most used diesel cars which were registered between 2000 and 2010 were large, it is likely that in the latter years of the decade, consumers who would otherwise have bought a used diesel car will have opted instead for large used petrol cars, or for large new diesel cars. Given its standard multinomial logit specification, regression 2 instead assumes that market shares for all car types increase in the same proportions. Regressions 3 and 4 are problematic given that they suggest that consumers have negative willingness-to-pay for fuel economy.

Overall, I have elected to use the estimated coefficients from regression 1 to calibrate the Transport Scenarios Model described in the next chapter, although I acknowledge the deficiencies of the regressions and suggest future work to improve the quality of the calibration. Regression 1 gives a reasonable picture of recent vehicle registration trends, and suggests that consumers are near-rational with respect to their willingness to pay for fuel efficiency. Its simplicity is also an advantage; with the only two factors under consideration being capex and opex per 100 km in the current period, it eliminates a range of assumptions that would otherwise need to be made. To use a NPV calculation for opex, for example, requires making assumptions about consumers' discount rates, expectations of future fuel prices, and that they behave as if they have access to a large amount of data about their future travel patterns.

A key point is that no matter how detailed the exploration of historical data, and whichever coefficients are used, patterns will doubtless change in the future. The 2007 Vehicle Exhaust Emissions Rule, which has only affected registrations in the latter years of my sample, will continue to have an impact on car buying patterns. Indeed, given that ex-overseas petrol cars currently account for more than 60% of registrations, the January 2012 introduction of Japan 05 standards for these cars will probably prove to be the most significant change arising from this rule.

At least in the short term, the Japan 05 standards mean that a smaller range of ex-overseas petrol cars will be allowed to enter New Zealand, and the average age of such imports will decrease. This is likely to lead to higher prices for these vehicles, and decrease the proportion of used cars being sold. However, unless new regulations are passed, the 2007 Vehicle Exhaust Emissions Rule will have a diminishing effect over time: Japanese vehicles built after 2005 all meet its requirements, and such vehicles should be widely available within the next few years.

Other changes may shape the New Zealand car market in years to come; for example, if international demand for Japanese used imports continues to grow, New Zealanders may find these vehicles harder to obtain, and more expensive. Overall, it seems likely that new cars will become relatively more important in the future.

5 OVERVIEW OF THE TRANSPORT SCENARIOS MODEL

The Transport Scenarios Model was developed for this thesis as a Matlab computer program.[5] The model focuses on light passenger vehicles (or "cars") in New Zealand. Using various assumptions, the model forecasts changes in the car fleet, along with the distance travelled by cars, the amount of petrol, diesel and electricity they use, and the emissions they create.

The model incorporates real-world data on the vehicle fleet as at 31 December 2010, and creates future scenarios beginning in 2011.

There are two distinct modules in the Transport Scenarios Model:

- Module One creates or imports a scenario of future oil prices. These prices are then used to estimate retail prices for transport energy in New Zealand, including petrol, diesel and electricity;

- Module Two builds a future scenario of New Zealand's light passenger vehicle fleet. It predicts future changes in the composition of the fleet, distance travelled and fuel usage, based on the retail fuel price scenario developed in Module One.

The Transport Scenarios Model incorporates a graphical user interface (GUI), and the program user can alter various preferences – such as the simulation timeframe, and whether to subsidise new PHEVs – without having to modify the underlying code. Different scenarios can be selected for New Zealand's population growth, the fuel efficiency gains that will be possible for conventional cars, and the cost decreases for the batteries of PHEVs and BEVs.

[5] The Transport Scenarios Model is based on unpublished work by Dane Renner, working with Stephen Poletti and Basil Sharp of the Energy Centre over the summer of 2010-2011. Dane's work in Matlab was used as a foundation for the model, which was significantly modified and expanded for this thesis.

Other parts of the model cannot be changed without editing the program code. For example, the chance that a car will be "scrapped" or removed from the fleet in a given period is held constant, depending only on the car's age.

The full code for the Transport Scenarios Model is attached as appendix A, and screenshots of the various GUI screens are attached as appendix B.

5.1 Module One

This module creates future retail prices for petrol and diesel, which are dependent primarily on the world oil price – denominated in $USD. It also formulates retail prices for electricity.

A user can choose from the following options for determining future world oil prices, allowing for a wide range of possible outcomes:

1) Import a pre-saved scenario;
2) Manually input the desired prices;
3) Randomly determine oil prices, using a geometric Brownian motion (GBM) process.

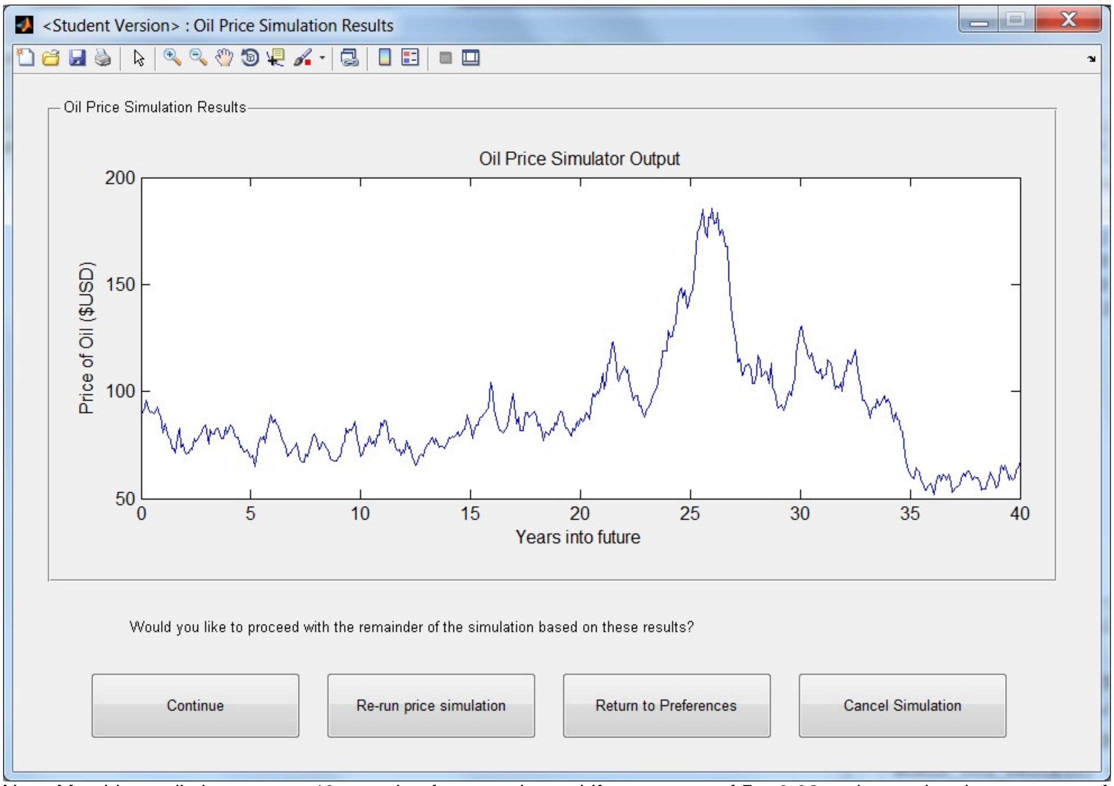
If the user chooses option 1, he or she can select one of the six scenarios from the IEA (2011) or the U.S. Energy Information Administration (2011), as shown in Figure 3. Given that these scenarios only predict prices up until 2035, prices are assumed to remain constant thereafter. If the user chooses option 3, he or she can then choose the underlying constants of the GBM process, described in section 2.3.

The user can also choose the frequency of observation – monthly, quarterly or annual – and the "timeframe", or the number of years of prediction.

5.1.1 Importing or Modelling World Oil Prices

Based on the selected option above, the Transport Scenarios Model creates a vector of world oil prices for each period in the simulation timeframe, in 2010 $USD. The results of one such forecast, using GBM, are shown below in Figure 14.

Figure 14: An Example GBM Oil Price Simulation



Note. Monthly predictions over a 40-year timeframe, using a drift parameter of $\delta = 0.02$ and a stochastic parameter of $\sigma = 0.15$.

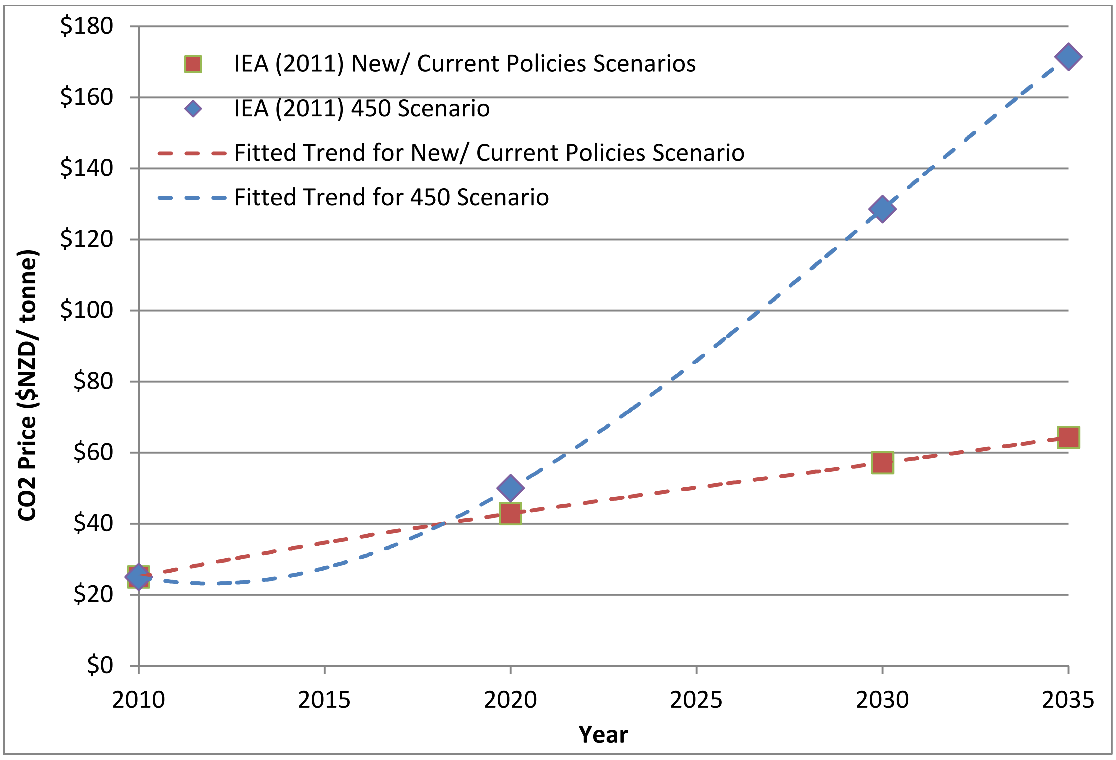
5.1.2 Importing World CO_2 Prices

The Transport Scenarios Model allows the user to choose from a range of CO_2 pricing regimes. CO_2 prices can be held constant throughout the simulation timeframe; as per the MED (2010), these can be set at NZD $0, $25, $50, $75 or $100 per tonne. Alternatively, the user can import a scenario based on the IEA (2011) – either based on the 450 Scenario, or the Current or New Policies scenarios, which have identical CO_2 prices. Given that ETS charges are a fairly small influence on fuel prices, the option to import custom CO_2 prices or model them through a stochastic process has not been included.

The IEA (2011) gives less detail on its pricing assumptions for CO_2 than it does for oil, only giving prices for the years 2020, 2030 and 2035. For modelling purposes, I have converted these prices into New Zealand dollars at a constant exchange rate of NZD \$1 = USD \$0.70, assumed a 2010 price of NZD \$25/ tonne, and approximated the resulting price trajectories with cubic functions. Prices are assumed to remain constant beyond 2035.

Figure 15 below shows the results of this process:

Figure 15: Assumed \$NZD Prices for Greenhouse Gas Emissions, for IEA-Based Scenarios



Source: adapted from the IEA (2011).

5.1.3 Establishing Petrol and Diesel Prices

The retail prices of petrol and diesel in New Zealand are primarily influenced by the following factors:

- The world price for crude oil, typically denominated in US dollars;
- The NZ dollar/ US dollar exchange rate;
- Importer costs and margins;
- The levels of taxation applied to petrol and diesel within New Zealand.

In the Transport Scenarios Model, the world oil price vector obtained above is converted into $NZD using a fixed and exogenous exchange rate of NZD $1 = USD $0.70. The model then estimates retail prices for petrol and diesel in New Zealand, based on assumptions about importer margins, taxation, and the ETS scheme.

As defined by the MED (2011a, p. 137), importer costs are made up of "the Singapore spot market price [for petrol] plus allowances for international freight, wharfage fees and insurance costs". The latter three costs appear to be relatively small, and as such I have simply assumed that importer costs are linearly dependent on the oil price in $NZD. Based on weekly price data from the MED (2012b), the importer costs for petrol and diesel in $NZD/ L averaged 0.00763 and 0.00779 of the price of a barrel of oil, respectively.

According to the MED (2011a, pp. 136-137), importer margins "cover domestic transportation, distribution, retailing costs and profit margins". In the Transport Scenarios Model, I assume that importer margins are fixed at 17.4 ¢/L for petrol and 19.4 ¢/L for diesel, their average level in 2010 (MED, 2012b).

As noted in section 2.12, petrol sales are taxed at the pump in New Zealand, and the various taxes and levies account for 59.129 ¢/L as at 31 December 2010 (MED, 2011a, p. 142). The Transport Scenarios Model includes an option for the user to make the Road User Charges scheme universal, and in this case, the above taxes are removed from the retail petrol price.

Petrol and diesel prices also incorporate ETS charges, although these are likely to account for a fairly small fraction of the overall price. As per section 2.10, the charge that applies to a litre of petrol under the ETS scheme is given by:

$$\mathrm{ETS_{petrol,t}} = 2.3214 * 10^{-3} * \mathrm{P_{CO2,t}} \quad (11)$$

The charge that applies to a litre of diesel under the ETS scheme is given by:

$$\mathrm{ETS_{diesel,t}} = 2.670 * 10^{-3} * \mathrm{P_{CO2,t}} \quad (12)$$

Based on the emissions factors above, even a high carbon price of NZD $100/ tonne would only lead to an ex-GST price increase of 23.1 to 26.7 ¢/L for petrol and diesel. Given the inelastic nature of transport fuel demand, a price increase of this size would have a fairly small impact on consumption.

Since 1st October 2010, the level of GST has been set at 15%, which is to say that 15% is added to the ex-GST price of petrol and diesel. GST affects most sectors of the economy, and forms a major component of the government tax take. Because GST is not targeted solely at the passenger transport sector, the Transport Scenarios Model treats it as being exogenous.

The following equations summarise the formulae used to determine the retail prices for petrol and diesel in the Transport Scenarios Model:

$$\mathrm{P_{petrol,t}} = \left(\frac{\mathrm{P_{oil,t}}}{0.70} * 0.00763 + 0.174 + 0.59129 + ETS_{petrol,t}\right) * 1.15 \quad (13)$$

$$\mathrm{P_{diesel,t}} = \left(\frac{\mathrm{P_{oil,t}}}{0.70} * 0.00779 + 0.194 + 0.00375 + ETS_{diesel,t}\right) * 1.15 \quad (14)$$

This series of equations assumes that consumers throughout New Zealand face the same retail prices for petrol and diesel, which is likely to be a reasonable assumption. Although prices do differ somewhat between areas, the difference is typically “quite a small fraction of the total price” (Polkinghorne, 2011, p. 13) and will have little effect given the inelastic nature of demand for these fuels.

5.1.4 Establishing Electricity Prices

The "ex-tax" price of electricity in the Transport Scenarios Model is assumed to be flat over the simulation period. This is a simplifying assumption, given that New Zealand electricity prices are not expected to change materially. For example, modelling by the Electricity Commission (2009) assumed that ex-GST residential electricity prices would increase slowly from 20.0 ¢/ kWh in 2008 to 22.2 ¢/ kWh by 2035, and remain constant thereafter. These prices were given in constant 2008 dollars, and appear to exclude the potential effects of the ETS.

Electricity prices in the Transport Scenarios Model are assumed to be independent of oil prices. In practise, fossil fuelled plants are usually the "peaking" plants in New Zealand. However, renewable sources provide the majority of our electricity, and they are expected to account for an even larger proportion in the future. In the long term, electricity prices are driven more by the cost of building new capacity, with renewable-based electricity usually the marginal investment (Fallow, 2011). It is relevant that, from MED (2010), wholesale electricity prices are very similar in both the "Oil: Low Price" and "Oil: High Price" scenarios, which assume oil prices of USD $70 a barrel and USD $105 a barrel respectively.

The Transport Scenarios Model also assumes that electricity prices are independent of changes in the vehicle fleet, and the analysis in section 2.11 suggests that this is a reasonable assumption.

Based on average New Zealand electricity emissions as described in section 2.10, electricity prices are assumed to include the following ETS charge, in 2010 $/ kWh:

$$\mathrm{ETS}_{\mathrm{electricity,t}} = 2 * 10^{-4} * \mathrm{P}_{\mathrm{CO2,t}} \tag{15}$$

The overall retail price of electricity, in 2010 $/ kWh, is given by:

$$\mathrm{P}_{\mathrm{electricity,t}} = \left(0.20 + ETS_{electricity,t}\right) * 1.15 \tag{16}$$

5.2 Module Two

5.2.1 Preferences in Module Two

In the second module, the user is presented with a series of GUI screens which allow for a number of important preferences to be changed. These include:

- Whether to subsidise the purchase price of NZ-new PHEVs or BEVs;
- Whether to make PHEVs or BEVs exempt from Road User Charges;
- Whether the imports of ex-overseas PHEVs and BEVs are “banned”;
- Whether to ban imports of ex-overseas used cars entirely;
- Whether to replace the current petrol taxation regime with Road User Charges;
- The rate at which New Zealand’s population grows;
- The rate of fuel efficiency improvement for new conventional cars;
- The rate of cost decline for PHEV and BEV batteries.

When these preferences have been assigned, another GUI is brought up on screen. This GUI simply allows the user to decide which graphs to show at the end of the simulation, and whether graphs should be shown for the entire country or at the per capita level.

5.2.2 Vehicles in the Transport Scenarios Model

In the Transport Scenarios Model, there are seven types of car, which can enter the fleet as either NZ-new or used import vehicles. This is, of course, a major simplification from the hundreds of car models available in New Zealand today.

The seven types of vehicle considered in the model are:

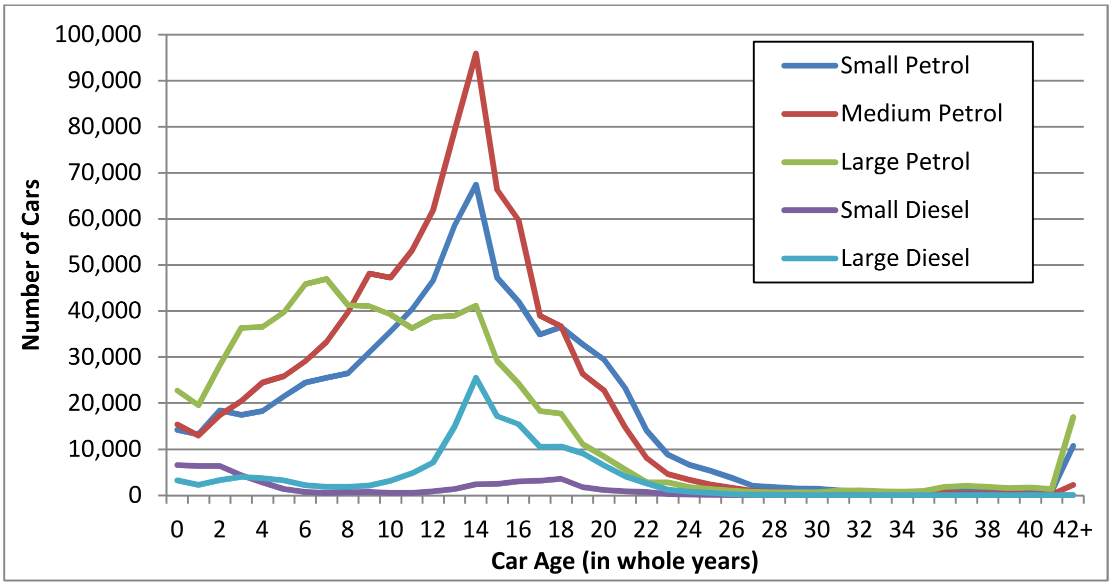
- Small petrol cars;
- Medium petrol cars;
- Large petrol cars;
- Small diesel cars;
- Large diesel cars;
- PHEVs, and
- BEVs.

All PHEVs are assumed to be petrol-electricity hybrids, and as such, they do not have to pay Road User Charges – unless the user decides to make this charging scheme universal. I assume that PHEVs and BEVs do not exist in the fleet at the beginning of the simulation.

Stuart Badger (personal communication, 13 January, 2012) from the MOT provided me with data on New Zealand's light passenger vehicle fleet as at 31st December 2010, which was used to initialise the car fleet in the Transport Scenarios Model. This data is a snapshot of the fleet, showing the number of cars broken down by age, fuel type and size, and using the same categories as for the quarterly registration data described in section 4.2. Unlike section 4.2, the model does not distinguish between new and ex-overseas cars, except when adding cars to the fleet as described in 5.2.5.

Vehicle age is an important input to the Transport Scenarios Model, because it influences how far vehicles are driven, and their likelihood of being "scrapped" or removed from the fleet in a particular period. Figure 16 below shows the number of cars in the New Zealand fleet as at 31st December 2010, broken down by car type and age.

Figure 16: New Zealand's Car Fleet by Type and Age, as at 31st December 2010



Source: Stuart Badger (personal communication, 13 January 2012)

As noted by the MOT (2011) there is a distinctive bulge for vehicles around 14 years old, i.e. those manufactured in around 1996. The number of cars in the fleet drops off fairly rapidly beyond this, with relatively few cars which are more than 25 years old. Small, medium and large petrol cars dominate New Zealand's car fleet, with each of these types accounting for between 27% and 35% of the fleet. Only 8.3% of cars in New Zealand are diesels, most of which are large.

The seven types of vehicle in the Transport Scenarios Model each have different characteristics with respect to their capex, fuel and electrical efficiencies, and fixed effect or "gamma", with these characteristics based on data or results described in chapter 4. Initially, NZ-new and ex-overseas vehicles only differ in their capex.

Table 6 and Table 7 show the initial attributes for NZ-new and ex-overseas cars respectively.

Table 6: Initial Attributes for NZ-New Vehicles in the Transport Scenarios Model

	Petrol			Diesel		Advanced	
Vehicle Attribute	**Small**	**Medium**	**Large**	**Small**	**Large**	**PHEV**	**BEV**
Capex ($)	$26,639	$44,300	$89,571	$48,300	$93,571	$58,586	$80,015
Fuel Efficiency (L/ 100 km)	7	10	12.5	7	9.5	3	-
Electrical Efficiency (kWh/ 100 km)	-	-	-	-	-	12	20
Gamma	-0.023	0.619	1.681	-0.965	-0.917	Special*	Special*

Note. Gamma values for PHEVs and BEVs are discussed below.

Table 7: Initial Attributes for Ex-Overseas Vehicles in the Transport Scenarios Model

	Petrol			Diesel		Advanced	
Vehicle Attribute	**Small**	**Medium**	**Large**	**Small**	**Large**	**PHEV**	**BEV**
Capex ($)	$10,668	$13,425	$17,436	$17,425	$21,436	$27,711	$49,140
Fuel Efficiency (L/ 100 km)	7	10	12.5	7	9.5	3	-
Electrical Efficiency (kWh/ 100 km)	-	-	-	-	-	12	20
Gamma	0.614	1.108	0.650	-2.318	-0.448	Special*	Special*

Note. Gamma values for PHEVs and BEVs are discussed below.

Of course, chapter 4 does not consider PHEVs and BEVs, making it necessary to form a reasonable estimate of their attributes. I assume a single size of each type of advanced vehicle, with both PHEVs and BEVs being comparable in size to medium petrol cars. The capex of advanced vehicles is based on that for medium petrol cars, with an additional cost premium. This starts at USD $10,000 for PHEVs and $25,000 for BEVs, and reduces over time as explained below. This cost premium is converted into New Zealand dollars using the same NZD $1 = USD $0.70 exchange rate used earlier, resulting in the capex values given in Table 6 and Table 7 above. Note that the same price premium is applied for ex-overseas PHEVs and BEVs as for new ones; this is equivalent to assuming that used PHEVs and BEVs are sold with brand-new batteries.

Table 6 and Table 7 show the gamma values obtained from regression 1 in Chapter 4 of this thesis. However, as noted in that chapter, this regression places very little weight on capex or opex changes, and gives significant weight to gamma changes. As such, it is appropriate to conduct sensitivity analyses, and I do this in different "runs" of the model in Chapter 6. The gamma values in the tables above are used only in certain runs.

The gamma values for PHEVs and BEVs are more problematic, given that these vehicles were not available during the 2002-2010 period. I argue that gamma coefficients are likely to represent factors relating to utility, as well as the availability of different models within each car type. As noted earlier, the limited range of advanced vehicle models is likely to disadvantage their uptake in the near future. With the ability to run off either electricity or liquid fuels, and similar range to conventional cars, PHEVs should be able to match the utility of other cars. In fact, both McConnell and Turrentine (2010) and Adams et al. (2010) use the assumption PHEVs with a 40-mile electric range are *more* desirable than petrol vehicles. However, it is difficult to see why PHEVs would be more desirable than conventional vehicles, ignoring their different capex and opex costs which are accounted for elsewhere in the vehicle choice equation. My usual assumption in Chapter 6 is that new and used PHEVs have the same gamma as new and used medium petrol cars respectively.

The gamma of BEVs should be chosen to be fairly low relative to other cars. This reflects BEVs' relatively limited range and long recharging times, even without considering the small number of available models. My usual assumption in Chapter 6 is that new and used BEVs have the same gamma as new and used small petrol cars respectively.

Some vehicle attributes are assumed to change over time: for example, petrol and diesel vehicles are assumed to become more efficient over time, while the cost premium for PHEVs and BEVs is assumed to decline over time. For simplicity, most runs of the Transport Scenarios Model assume that the gamma values for PHEVs and BEVs do not increase over time, although they would actually be expected to increase from a low base as more models become available and the technology becomes more widely accepted.

5.2.3 Improving Fuel Efficiency, and Decreasing Battery Costs

The fuel efficiency of conventional cars is expected to improve in the future, as outlined in section 2.6. The Transport Scenarios Model assumes that the fuel efficiency of new conventional cars will improve linearly over either a 20-year or 40-year period. The overall improvement over this time can be set at 20%, 30% or 40%, after which fuel efficiency remains flat. Used cars follow the same trend as new cars, but with an eight-year lag to reflect the assumption that used cars are already eight years old when they enter the New Zealand fleet.

For example, medium petrol cars which are in the fleet as at 31 December 2010 are assumed to use 10 L/ 100 km of travel. Cars which enter the fleet during the simulation timeframe will be more efficient than this; assuming 30% improvement over the 20-year period to 2030, a medium petrol car entering the fleet in 2020 will use 8.5 L/ 100 km, while the same type of car entering the fleet in 2030 or later will use 7 L/ 100 km.

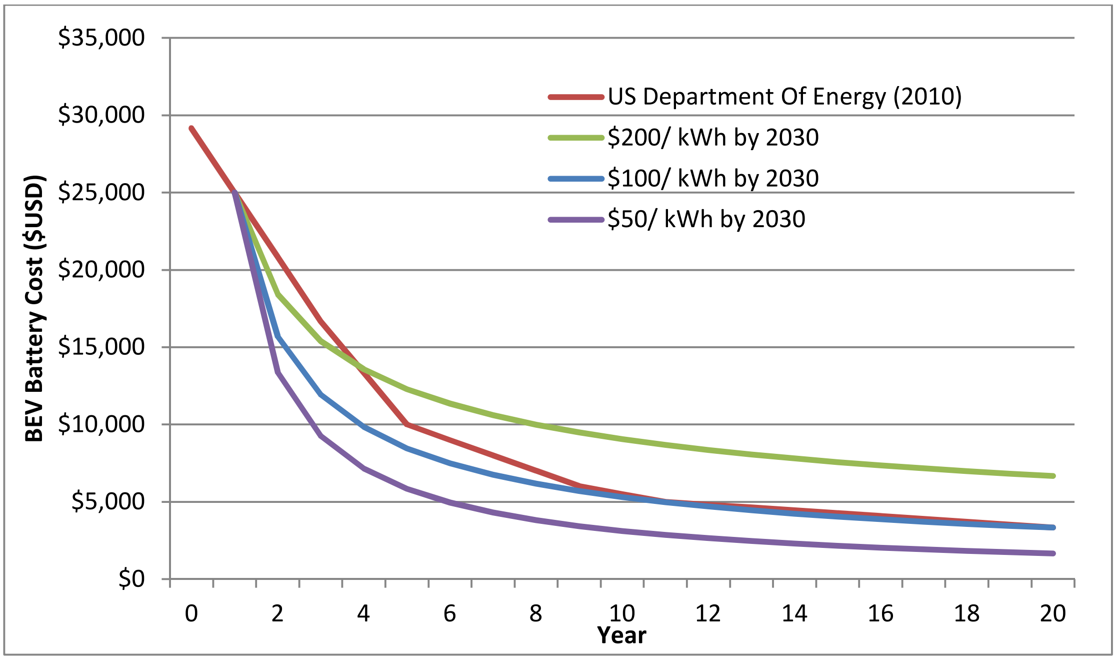
An important point to note is that the model assumes that these gradual fuel efficiency improvements have no effect on the capex of conventional vehicles – they are essentially “free”. The prices of conventional cars are assumed to remain flat in the future, in contrast with their decline in real terms over 2000-2010; this can be thought of as manufacturers incurring costs over time in order to improve fuel economy, with the manufacturing cost of other parts of the car declining over time, such that overall costs are unchanged.

Battery costs for PHEVs and BEVs are also expected to improve in the future, as outlined in section 2.7.3. As per the U.S. Department of Energy (2010), I have expressed battery costs in terms of U.S. dollars per kWh, and assumed a 33.3 kWh battery for BEVs. In the Transport Scenarios Model, costs are assumed to decline over either a 20-year or 40-year period, reaching a cost of USD $50, $100 or $200 per kWh over this time, and to remain flat thereafter. The total cost of BEV batteries is modelled using the following equation:

$$\text{BEV Battery Cost}_t = 25000 * t^{-\varphi} \tag{17}$$

The value of φ depends on the selected scenario, and is chosen to give the required cost decline at the end of the 20-year or 40-year period. For example, φ takes on a value of 0.673 to produce costs of $100/ kWh, or $3,333 overall, by 2030. Figure 17 below shows the three scenarios that give improvements over a 20-year period:

Figure 17: Scenarios for the Declining Battery Cost of BEVs



Source: Red line shown for comparison is from U.S. Department of Energy (2010)

As shown in Figure 17, in the default “$100/ kWh by 2030” scenario, battery costs initially fall faster than in the U.S. Department of Energy’s (2010) projections, but are almost identical from around year 10 of the simulation onwards.

5.2.4 “Scrapping” Vehicles from the Fleet

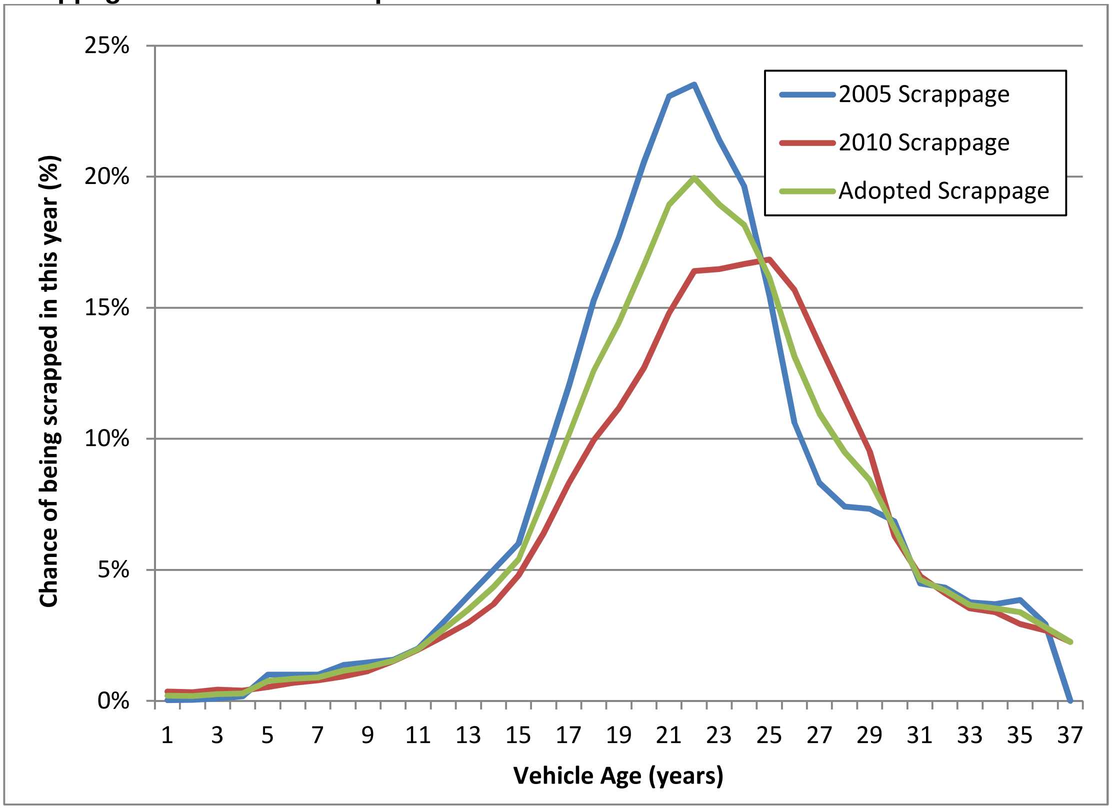
Cars have a finite lifetime, and the Transport Scenarios Model assumes that during each period, some of the vehicles in the fleet are “scrapped” or removed from the fleet. This represents vehicles being written off, sold off for parts, re-exported and so on.

Data from the MOT (2011) shows the percentage of vehicles that were scrapped in 2010, broken down by vehicle age. Newer vehicles, unsurprisingly, are less likely to be scrapped from the fleet, whereas scrappage rates are quite high for vehicles which are 15 to 30 years old. In 2010, for example, a 25-year-old vehicle which was in the fleet at the start of the year had a greater than 15% chance of being scrapped by the end of the year (MOT, 2011).

To incorporate the notion of scrappage into the Transport Scenarios Model, I obtained data on vehicle scrappage in 2010 from MOT (2011) – a year in which scrappage rates were low, with economic uncertainty causing New Zealanders to hold onto their cars longer – and supplemented this data with older MOT data for 2005 (S. Badger, personal communication, 10 June, 2011) – a peak year in terms of vehicles moving in and out of the fleet. I assumed that in the future, scrappage rates would be equal to the average of the 2005 and 2010 rates. These rates have been adopted in the Transport Scenarios Model; they are assumed to remain constant throughout the simulation timeframe, and to depend on vehicle age but not on vehicle type.

Figure **18** below shows scrappage rates by vehicle age for 2005 and 2010, and the “adopted” rates in the Transport Scenarios Model.

Figure 18: Scrappage Rates by Vehicle Age in 2005 and 2010, and "Adopted" Scrappage Rates in the Transport Scenarios Model



Sources: 2010 scrappage data is from the MOT (2011), and 2005 scrappage data is from Stuart Badger (personal communication, 10 June, 2011)

The notion of scrappage leads to the notion of cumulative survival probability, i.e. the probability that a vehicle will survive to a given age. For a "NZ-new" vehicle, i.e. a vehicle which was new when imported to New Zealand, the probability that a vehicle will survive to an age of *y* years is:

$$\Pr\,(survival)_{new,y} = \prod_{age=0}^{y} (1 - Scr_{age}) \tag{18}$$

Scr_{age} is the adopted scrappage rate for vehicles of a particular age, meaning that $(1 – Scr_{age})$ is the probability that a vehicle of that age will survive the period.

For "used import" vehicles, the scrappage formula is slightly different. The Transport Scenarios Model assumes that used vehicles are eight years old when they are added to the fleet, and thereafter have the same chance of being scrapped as new vehicles with the same age. The probability that a "used import" vehicle will survive to an age of *y* years is:

$$\Pr\,(survival)_{used,y} = \prod_{age=8}^{y} (1 - Scr_{age}) \tag{19}$$

5.2.5 Adding New Vehicles to the Fleet

In the Transport Scenarios Model, the number of vehicles per capita is assumed to remain constant into the future at 0.59207, a figure obtained by dividing the 2,598,007 cars in the fleet as at 31 December 2010 by New Zealand's estimated population of 4,388,000 as at 30 June 2010 (MOT, 2012a; SNZ, 2011c). The six-month discrepancy in these figures is necessary because SNZ's population projections are always given as at 30 June, whereas other information in the model is as at 31 December 2010.

As such, the overall number of cars in the fleet is assumed to increase at the same rate as New Zealand's population.

$$Car\ Fleet_t = 0.59207 * Population_t \tag{20}$$

New Zealand's population grows according to SNZ 2009-base projections (SNZ, 2009). The "medium" series of these projections can be very closely approximated with a polynomial equation given by:

$$Population_t = 4{,}388{,}000 + 42{,}400 * \frac{t}{FREQUENCY} - 309.9 * \left(\frac{t}{FREQUENCY}\right)^2 \tag{21}$$

The model also allows the user to adopt a different population projection, corresponding to SNZ's "low" and "high" series. These are approximated by polynomial equations as for the medium series above, but showing lower and higher rates of growth respectively.

Each period, the model updates the population figures and adds enough vehicles to maintain "cars per capita" at the same level, taking account of population growth and the number of cars that have been scrapped.

$$\text{Total Entering Cars}_\text{t} = 0.591384 * \Delta\text{Population}_\text{t} + \text{Scrapped Cars}_\text{t} \tag{22}$$

Having determined the total number of cars entering the fleet in a given period, the model finds the proportion of each car type that enters, and then the actual number of each car type that enters.

The proportion of each car type that enters is determined using the equation from [SECTION], and remembering the [COEFFICIENT] for advanced vehicles. The total number of each car type and status is given by:

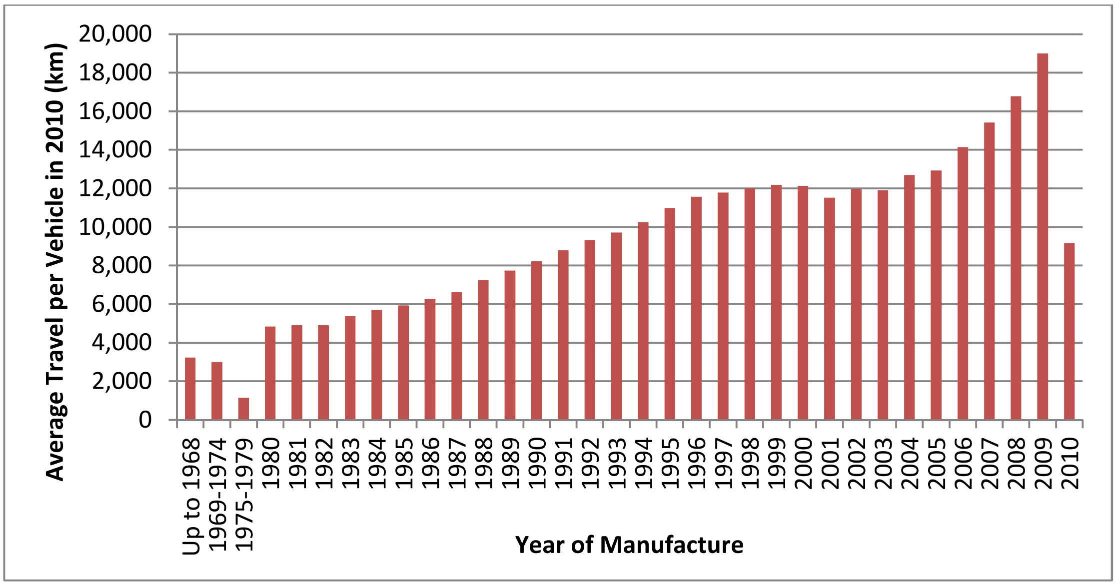
$$Entering\ Cars_{t,status,type} = Total\ Entering\ Cars_t * proportions_{t,status,type} \quad (23)$$

5.2.6 Vehicle Kilometres Travelled

MOT (2011) includes real-world information on VKT by light passenger vehicles in 2010, based on odometer readings taken during WOF and COF inspections. This data is available broken down by the age of the vehicle, showing that relatively new vehicles travel further in a year than older vehicles (MOT, 2011). As such, the model was calibrated to reflect the real-world observations. As shown in

Figure 19 below, the vehicles which travelled the furthest average distance in 2010 were 2009-year vehicles. 2010-year vehicles entered the fleet during the year, so they tended to do less travel. Pre-1980 vehicles, which only account for a small part of New Zealand's light passenger fleet, covered less than 4,000 km on average.

Figure 19: Average 2010 Travel per Car for New Zealand, by Year of Manufacture



Source: MOT (2011)

The Transport Scenarios Model uses this data, adjusted for the simulation frequency, in determining the VKT for each vehicle in the fleet each period. The VKT figure for 2010-year vehicles was doubled in the model, although this is effectively halved again given the assumption that cars entering the fleet do so halfway through each period.

Note that the “effective car fleet” in a given period includes all vehicles in the fleet at the start of the period – including those which are scrapped during the period – and those which enter the fleet during the period.

Cars which are in the fleet in the start of the period are assumed to travel the full distance implied here, whereas cars which enter the fleet during the period are assumed to enter halfway through the period and therefore only travel half this distance.

Consumers are also assumed to alter the distance they drive in response to fuel price changes. Following the short-term elasticity given in Kennedy and Wallis (2007), petrol car drivers are assumed to decrease their VKT by 0.12% for every 1% increase in petrol prices. Unlike Kennedy and Wallis (2007), the model assumes that the demand change is instantaneous and does not increase over time. This is because part of the reason for elasticities being higher in the long term is that consumers can purchase new vehicles, and this effect is accounted for elsewhere in the model.

Diesel car elasticities are assumed to be slightly lower, since part of their running cost is made up of Road User Charges and a 1% rise in the cost of diesel gives a smaller increase in their running cost per 100 kilometres. Their elasticity is assumed to be -0.10. The elasticity of PHEVs is assumed to be lower again, at 0.06, since they only drive half of their kilometres using petrol. BEVs are assumed to be completely unresponsive to changes in fuel prices, since the cost of electricity is assumed to remain constant throughout the simulation timeframe.

These vehicle-specific elasticities are assumed to remain constant into the future. However, as noted by the MED (2010), these historically observed elasticity relationships may change with higher oil prices.

5.2.7 Fuel Demand in the Transport Scenarios Model

Once the VKT for each car has been calculated, it is a straightforward process to estimate how much petrol, diesel and electricity is consumed. The VKT is simply multiplied by the fuel and electrical efficiencies of the various types and ages of vehicle, as typified for petrol by equation 24 below:

$$Petrol\ Demand_{t,} = Effective\ Car\ Fleet_{t,age,type} * VKT_{t,age,type} * Petrol\ Efficiency_{t,age,type} \quad (24)$$

5.2.8 Greenhouse Gas Emissions in the Transport Scenarios Model

Greenhouse gas emissions in the model are also simple to calculate, depending solely on the quantity of petrol, diesel and electricity that are consumed. Petrol and diesel emissions are based on the coefficients determined in section 2.10.

Electricity emissions are assumed to be constant throughout the simulation, at 0.2 kg of CO_2-equivalent per kWh. As noted in section 2.10, this is roughly equal to the average emissions for delivered electricity over 2005-2010, and is likely to be a conservative estimate of future average emissions. Given the potential for advanced vehicle owners to charge their vehicles off-peak, when marginal emissions tend to be lower, this estimate could be even more conservative.

6 RESULTS FROM THE TRANSPORT SCENARIOS MODEL

This chapter shows the results of several different runs of the Transport Scenarios Model. These runs illustrate the way in which different user preferences and oil price paths can lead to quite disparate results in terms of the types of vehicles purchased, fuel demand and emissions.

Each of these runs uses an annual frequency of observation and a 40-year timeframe, covering the period from 2011 to 2050. This is chosen to align with the horizon used in the New Zealand Government's (2007) *Energy Strategy*. New Zealand's population is assumed to grow in line with SNZ's medium projections, almost reaching 5.6 million people by 2050.

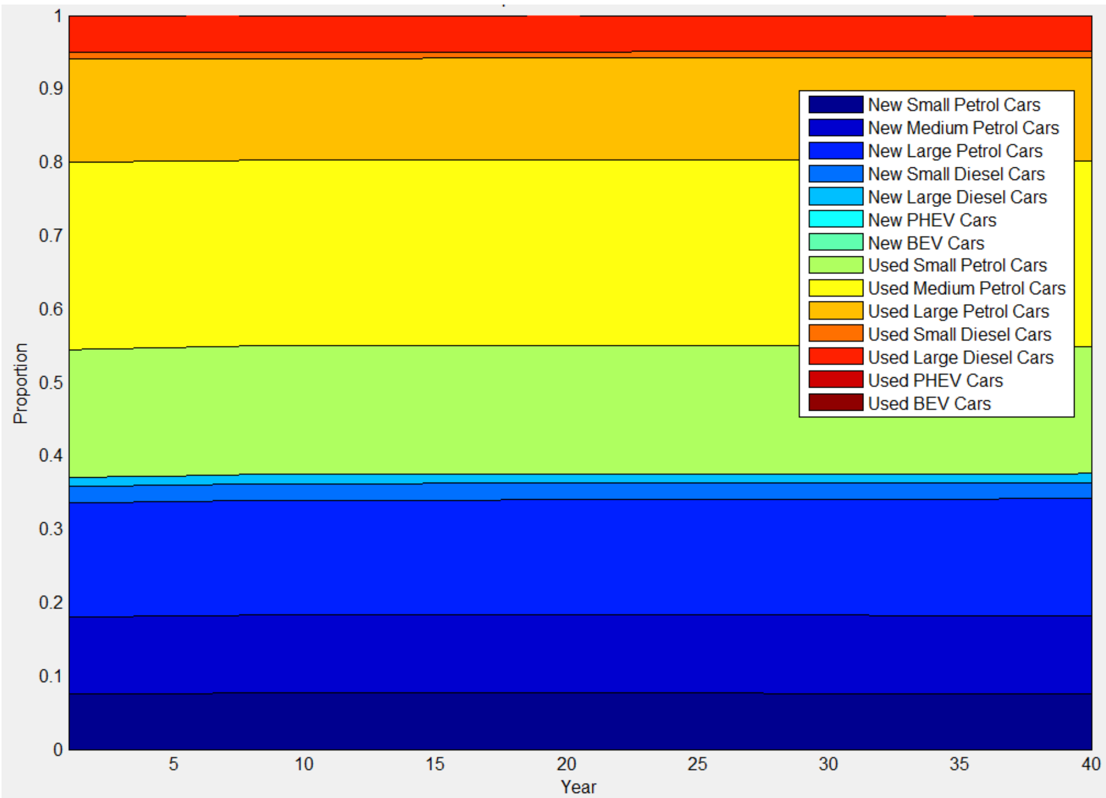
6.1 Initial Run: "Business as Usual"

The purpose of this run of the model is to explore possible trends in the absence of PHEVs and BEVs, using only the car types covered in the regressions of chapter 4. As such, advanced vehicles are completely *excluded* from this run of the model; these vehicles can be thought of as being available only in very limited numbers, or priced so high that they are purchased only in very limited numbers. This allows for an extrapolation of my 2002-2010 regression results, and eliminates the debate over the desirability of the "independence of irrelevant alternatives" property that arises when adding advanced cars to the vehicle choice process. As would be expected from the chapter 4 results, this run suggests that very limited substitution between car types will occur in the future.

This run of the Transport Scenarios Model uses the oil and CO_2 price paths set in the IEA "New Policies" scenario, as described earlier. It assumes a continuation of the petrol excise duty scheme, meaning that petrol prices rise from around $1.90 in 2011 to $2.50 in 2035, and remain flat thereafter. Diesel prices rise from around $1.35 in 2011 to $2.00 in 2035, and remain flat thereafter. The fuel efficiency of new conventional cars entering the fleet is assumed to improve by 30% by 2050. The results of this simulation are illustrated in Figure 20.

Each period, the model predicts the proportions in which different car types will be added to the fleet. Figure 20 below shows these proportions, or "market shares", over the 2011-2050 period.

Figure 20: Predicted Proportion of Car Registrations by Type for 2011-2050, for "Business as Usual" Run



The market shares of the ten car types entering the fleet remain very flat over the 40-year simulation timeframe. This reflects the observation – backed up by the regressions in chapter 4 and a number of previous studies – that the market shares of different car sizes do not change significantly in response to fuel prices changes. Figure 8 shows that market shares do indeed fluctuate over time, but most of this variation does not seem to be the result of fuel price changes.

Figure 21: Predicted Total Number of Cars by Type for 2011-2050, for "Business as Usual" Run

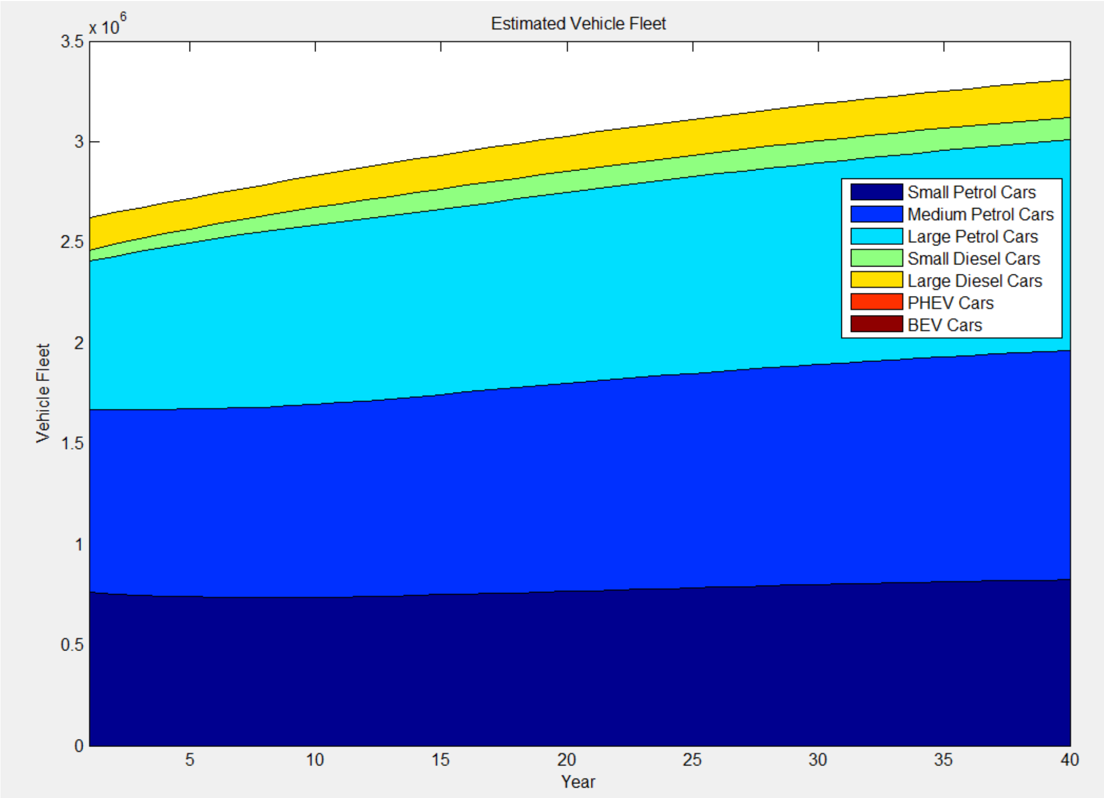
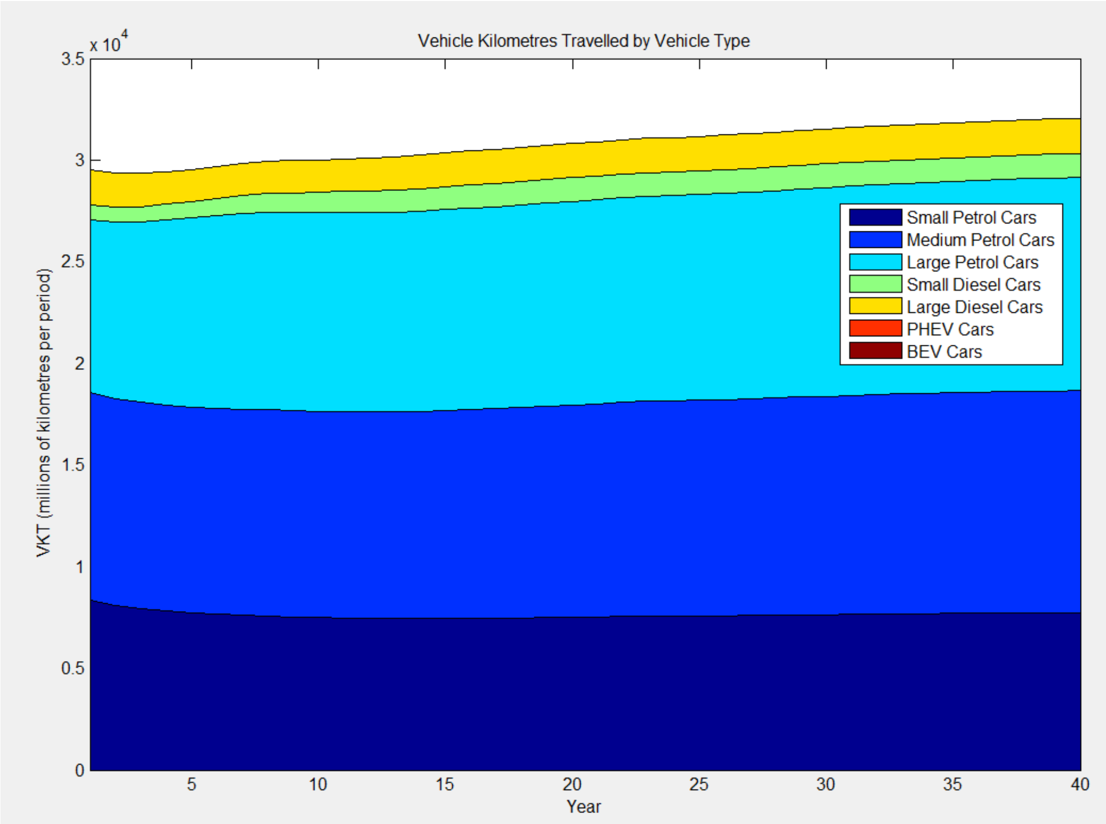


Figure 21 above shows the overall number of cars of each type in the fleet at the end of each period, based on the number and proportions of cars entering and exiting the fleet. The *total* number of cars in the fleet increases in line with New Zealand's population, from 2.62 million in 2011 to 3.31 million in 2050, given the assumption of constant "vehicles per capita".

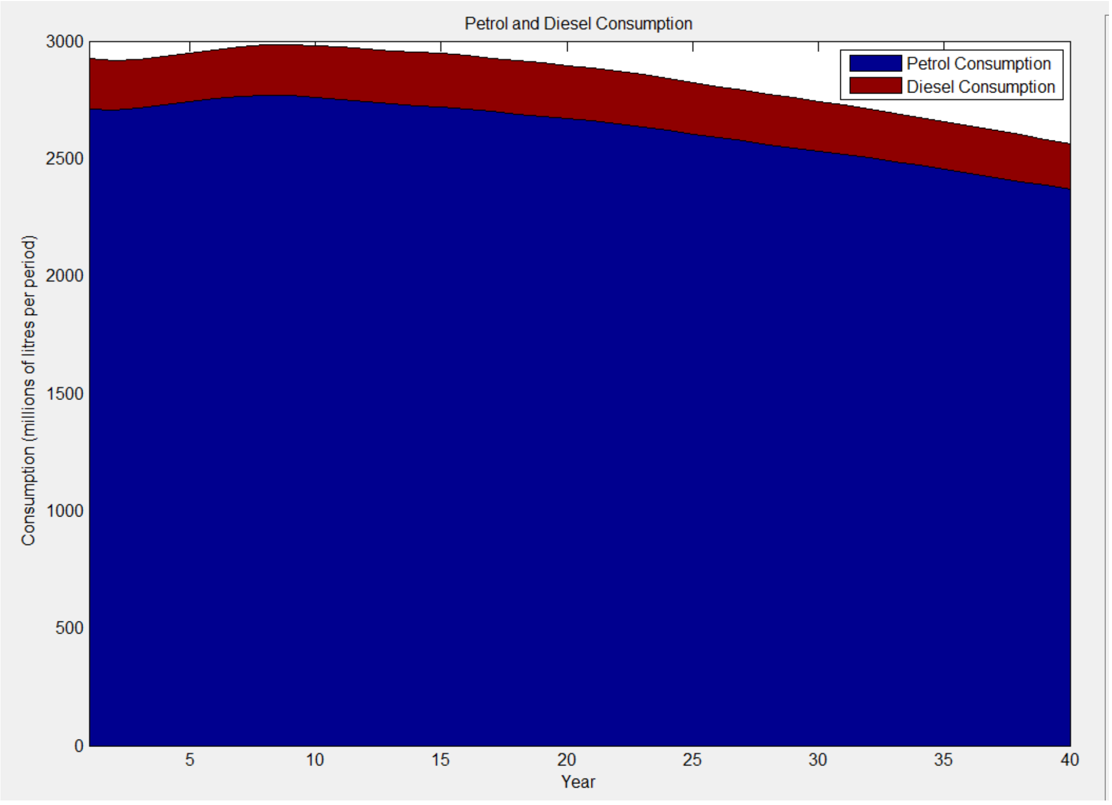
The car type that experiences the highest relative growth is small diesels, with the number of such cars more than doubling over the 40 years. However, the number of small petrol cars is relatively flat, with more growth occurring for medium and large petrol cars.

Figure 22: Predicted Vehicle Kilometres Travelled by Car Type for 2011-2050, for "Business as Usual" Run



As shown in Figure 22 above, the total distance travelled by New Zealand cars increases slightly over the simulation period, although per-capita travel falls by 14%. A number of factors are at work here; firstly, elasticity effects, which acts to decrease travel per vehicle by almost 4% by 2035. Secondly, the aging of the fleet from an average of 12 years to an average of 17 years by 2050 also dampens travel growth, given the assumption that older vehicles travel shorter distances. Thirdly, population growth acts to increase total travel demand, an effect which is large enough to overcome the other two.

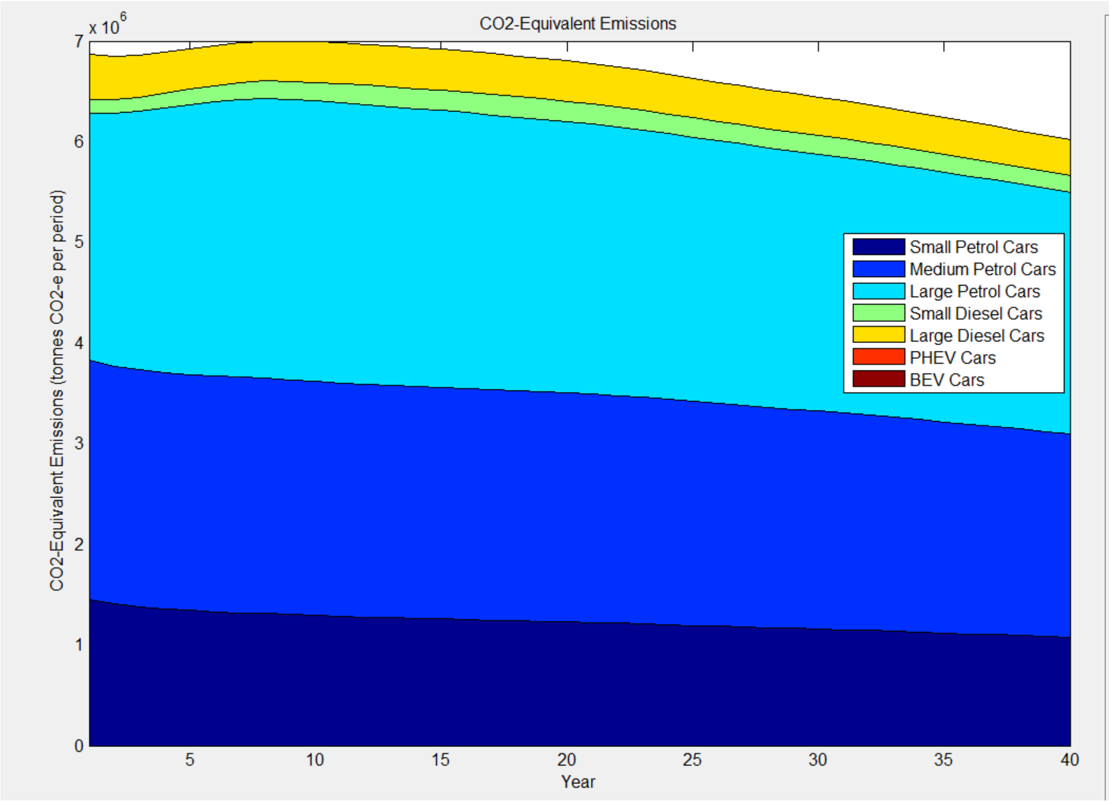
Figure 23: Predicted Petrol and Diesel Consumption for 2011-2050, for "Business as Usual" Run



Petrol and diesel consumption peaks late this decade at almost 3 billion litres, and declines thereafter, to 2.56 billion litres in 2050. In terms of actual energy consumption, the more than 100 petajoules consumed in 2011 falls to around 90 petajoules in 2050. The decline in consumption is due to the increasing efficiency of conventional cars, which over time becomes a greater influence than the increased travel done by the fleet.

These results are similar to those from the MED's (2010) Reference Scenario, which also predicts that New Zealand's petrol demand has already peaked or will do so in the future, and declines slowly thereafter. Compared with this of run of the Transport Scenarios Model, the MED's (2010) Reference Scenario makes more conservative assumptions about conventional vehicle efficiency improvements but more optimistic ones about the transition to diesel and advanced vehicles.

Figure 24: Predicted Greenhouse Gas Emissions by Car Type for 2011-2050, for "Business as Usual" Run



As shown in Figure 24 above, the CO_2-equivalent emissions from travel by New Zealand's car fleet falls over time, from 6.87 million tonnes in 2011 to 6.02 million tonnes in 2050, a 12.4% decrease. On a per-capita basis, emissions fall from 1.55 tonnes per person in 2011 to 1.20 tonnes per person in 2040 and 1.08 in 2050.

The New Zealand Government (2007, p. 31) made "an in-principle decision to halve domestic transport emissions per capita [relative to 2007] by 2040". Even this goal may stop short of what is required to combat global warming. As pointed out by the IEA (2009, p. 29), "the Intergovernmental Panel on Climate Change (IPCC) advises that, to avoid the worst impacts from climate change, global CO_2 emissions must be cut by at least 50% by 2050. To achieve this, transport will have to play a significant role". Given that developed countries account for the bulk of world emissions today, and that the emissions of developing countries are expected to increase in the future (IEA, 2011), countries such as New Zealand will have to make very substantial emissions reductions in order to play their part.

By comparison, the picture painted in the MED (2010) Reference Scenario is one of slow improvement, with New Zealand's per-capita transport emissions decreasing by less than 10% by 2030.[6] Likewise, this run of the Transport Scenarios Model suggests that, if advanced vehicles do not become established in New Zealand and there are no major policy changes, per-capita emissions will decrease by 22.6% by 2040, falling well short of the government's target.

6.2 Second Run: Universal Road User Charges and New Advanced Vehicles

This run of the Transport Scenarios Model uses many of the same preferences as the initial run; again, oil and CO_2 prices follow the IEA's New Policies Scenario, and conventional car efficiencies are assumed to improve by 30% by 2050. However, this run introduces advanced vehicles, which are available as new cars only from 2013, year 3 of the model.

Battery costs are assumed to fall to $100/ kWh by 2050, which represents a fairly conservative outlook. Additionally, the Road User Charges scheme is assumed to be made universal, which puts all vehicles on an equal footing but decreases the incentives for consumers to buy PHEVs or more efficient petrol cars. Both these assumptions are actually fairly unimportant for this run of the model, as the Chapter 4 results used to calibrate the model imply that capex and opex changes only affect vehicle choice to a very limited extent.

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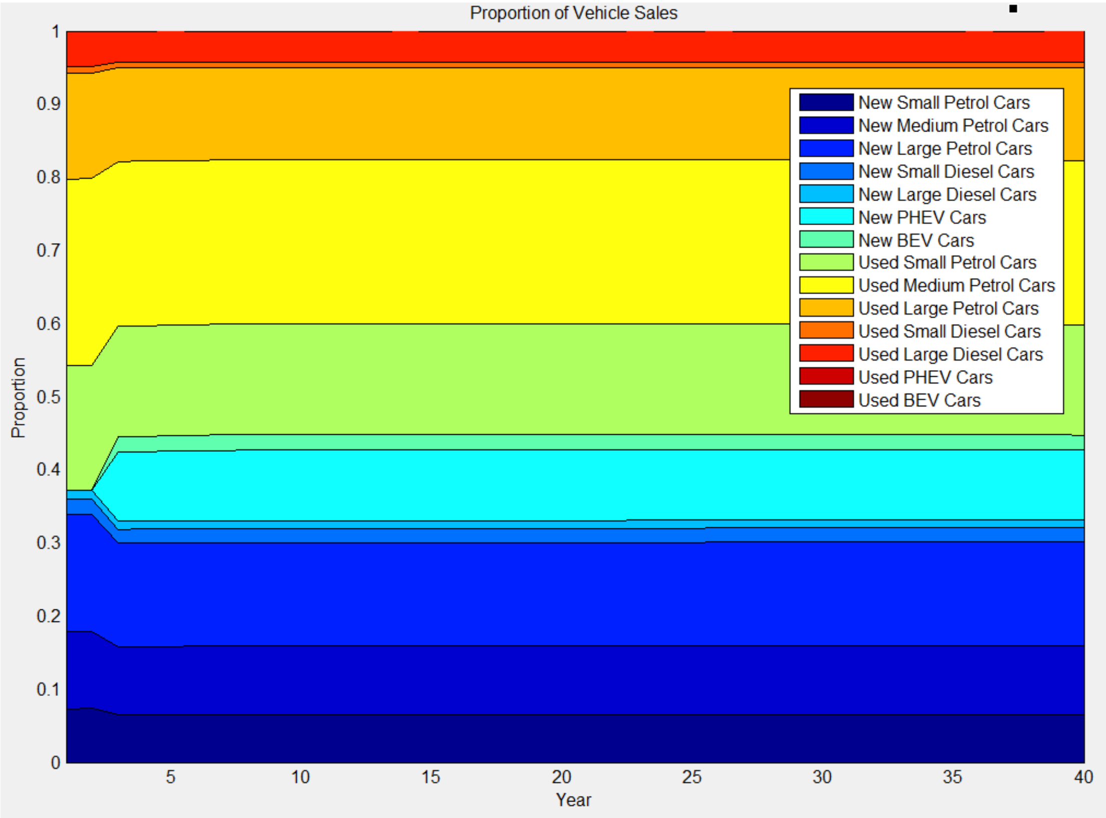
[6] Derived using transport emissions data from MED (2010), and the "medium" population projections from SNZ (2009).

Figure 25, below, shows the predicted proportions of car types entering the fleet for this run of the model:

Figure 25: Predicted Proportion of Car Registrations by Type for 2011-2050, for Second Run



There are now twelve car types that enter the fleet during the 40-year simulation timeframe, with PHEVs and BEVs entering from 2013, year 3. As for the initial run, market shares are almost completely flat, except for the sudden change between year 2 and year 3. New PHEVs achieve a market share of almost 10%, whereas new BEVs only achieve a 2% share. To put these shares in perspective, PHEVs achieve a share that is higher than new small petrol cars and comparable to new medium petrol cars. Used cars retain their dominance, continuing to account for around 55% of registrations once advanced vehicles are introduced.

6.3 Altering Key Model Parameters

It is fairly evident that, using the results from Chapter 4 to calibrate the Transport Scenarios Model, the changes that occur over time are quite limited. This may or may not prove to be the case, but it is certainly difficult to observe the full functionality of the model with such minor changes in market share.

As such, I have arbitrarily altered the α, β, and vehicle-specific gamma terms in the runs that follow, in order to explore the impact of changes in these parameters. These do not necessarily represent a probable future outcome, but show the way in which the model can be changed relatively easily to test new situations.

I have maintained the ratio of α to β that was obtained in regression 1, but I multiply each of these terms by 8, such that α is equal to YYY and β is equal to ZZZ. This means that capex and opex have a larger influence on vehicle choice than is suggested in Chapter 4, with the result that the market share of each car type becomes more responsive to changes in these parameters.

The vehicle-specific gamma terms are chosen somewhat arbitrarily to represent a situation in which all car types are readily available at the assumed price levels, and in which no penalty is attached to diesel vehicles. As such, the gamma terms essentially represent factors relating to utility. Therefore, new cars are assumed to have larger gammas than ex-overseas cars, larger cars are assumed to have larger gammas than smaller cars, and petrol cars are assumed to have similar gammas to diesel cars. As per section 5.2.2, PHEVs and BEVs are assumed to have equivalent gammas to medium and small cars respectively. Table 8 below shows the gamma terms used in the remainder of this chapter:

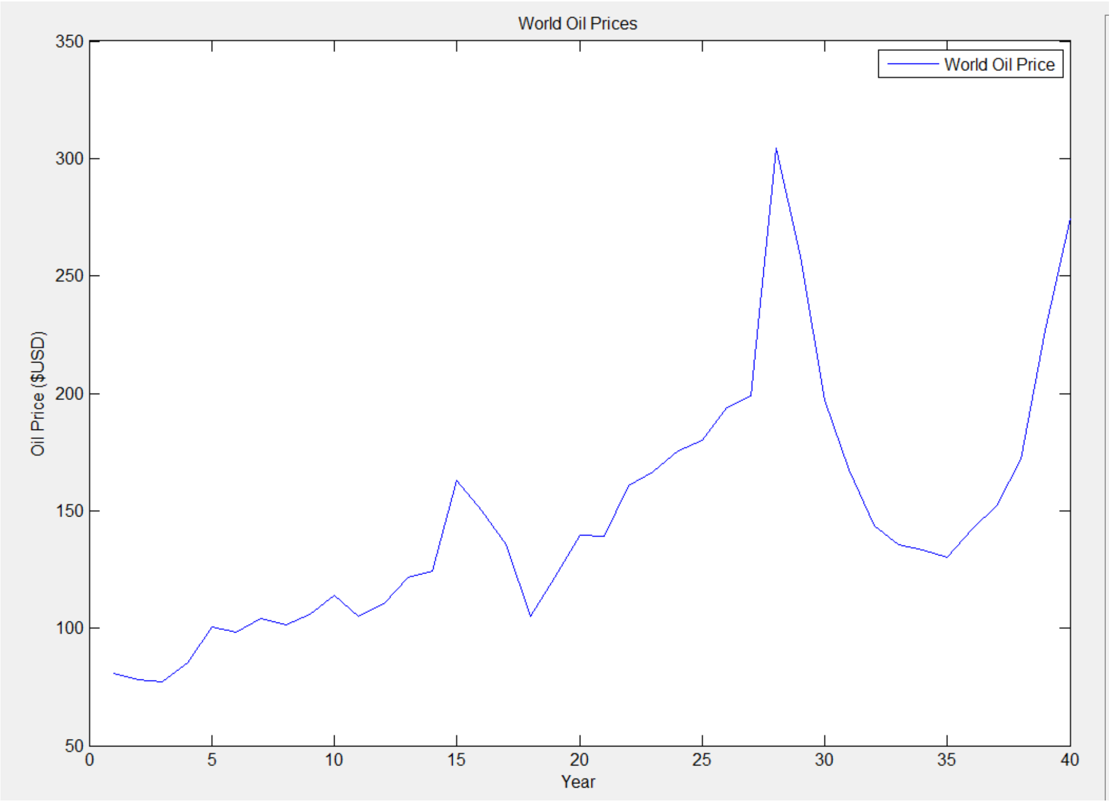
Table 8: Revised Gamma Terms by Car Type

	Petrol			Diesel		Advanced	
New/ Used Status	**Small**	**Medium**	**Large**	**Small**	**Large**	**PHEV**	**BEV**
New Cars	3.0	6.0	8.0	4.5	8.0	6.0	3.0
Ex-Overseas Cars	-1.0	2.0	3.0	1.0	3.0	2.0	-1.0

Note. Since the "small diesel" categories actually refer to small and medium diesel cars combined, I have assumed their gamma values to be equal to the average of the values for small and medium petrol cars.

The remaining runs of the model use a GBM simulation for oil prices, meaning that prices fluctuate rather than following the smooth price paths of the first two runs. The run uses a drift term of δ=0.02 and a volatility term of σ=0.15, although of course these parameters can generate an infinite number of oil price paths. Note that each of the runs uses the same oil price path, based on a single GBM simulation and shown in Figure 26 below:

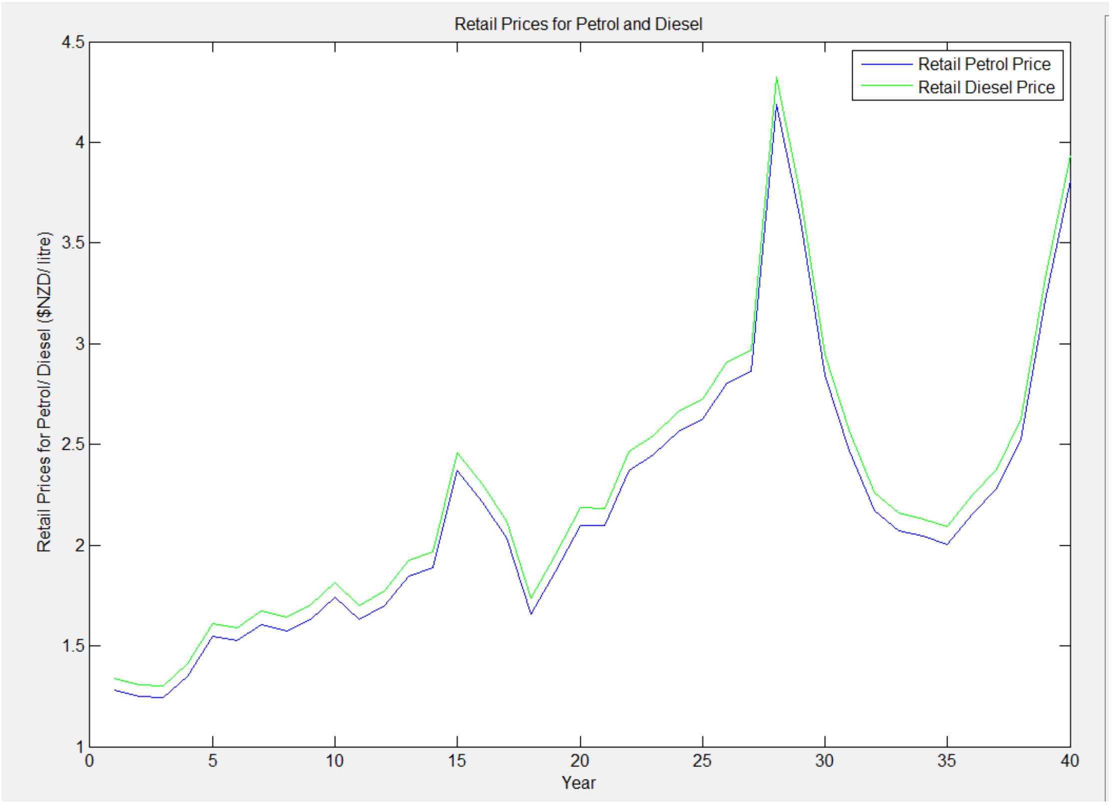
Figure 26: Oil Prices for 2011-2050, using a GBM Simulation



The price path here deviates significantly from the "expected" path shown in Figure 2, with the price briefly spiking to more than USD $300/ barrel in the late 2030s, and another spike occurring in the late 2040s. Of course, it must be remembered that many GBM simulations will diverge considerably from their expected path, and that the GBM equation means that oil prices do not revert to any mean value over time.

For each of the remaining runs described in this chapter, I have used the IEA's New Policies Scenario for CO_2 prices, and assumed a replacement of the Petrol Excise Duty scheme with universal Road User Charges. The abolition of the excise scheme means that petrol prices are no longer buffered by a fairly constant level of taxation, and the retail prices for petrol and diesel are very similar. These prices are shown in Figure 27 below:

Figure 27: Petrol and Diesel Prices for 2011-2050, Based on a GBM Simulation



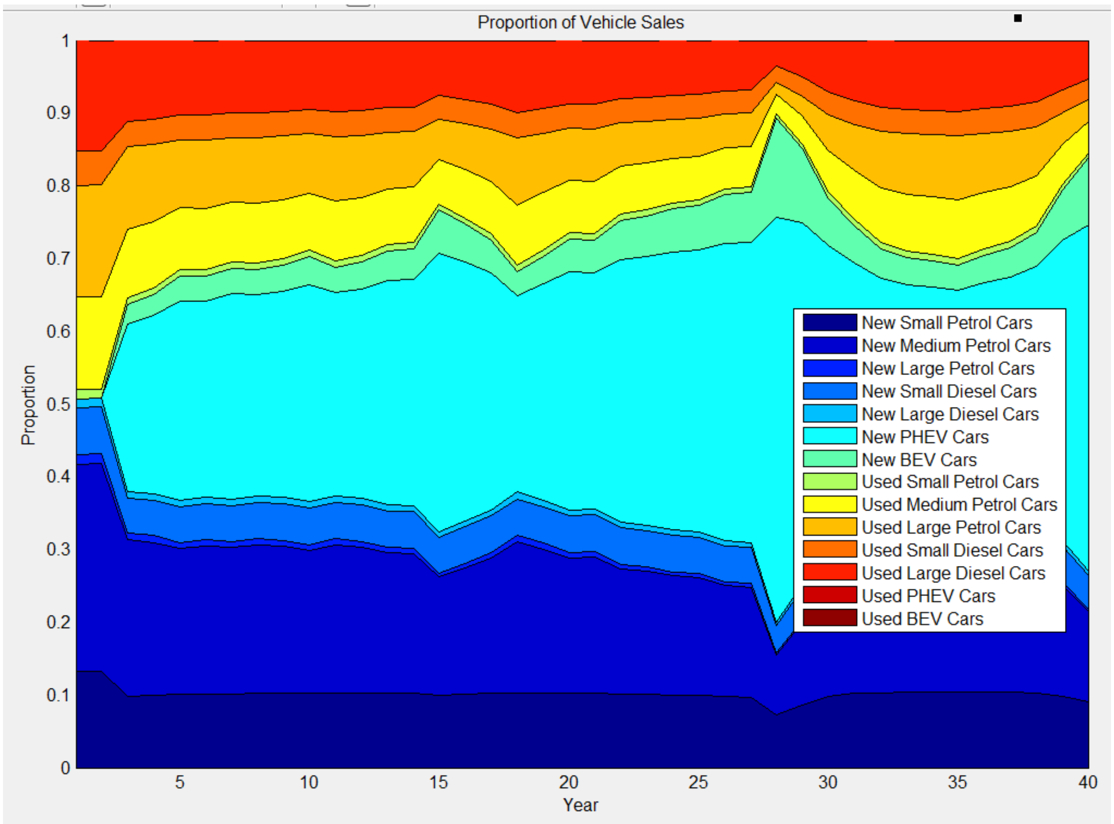
From less than $1.50 a litre in 2011, prices peak at over $4 a litre in the late 2030s, and fall back to around $2 a litre before increasing again in the late 2040s.

6.4 Third Run, Using GBM and Revised Model Parameters

This run, and those that follow, all use the revised parameters and price regime as described in section 6.3 above, and assume universal Road User Charges. In this run, I assume that the efficiencies of conventional new cars improve by 30% by 2050, and that battery costs fall to $100/ kWh by 2050, which – as noted earlier – represents a fairly conservative outlook. Furthermore, PHEVs and BEVs are assumed to only be available new, with no supply of "used import" advanced vehicles.

Figure 28 below shows the predicted proportion of car registrations using these preferences:

Figure 28: Predicted Proportion of Car Registrations by Type for 2011-2050, for Third Run

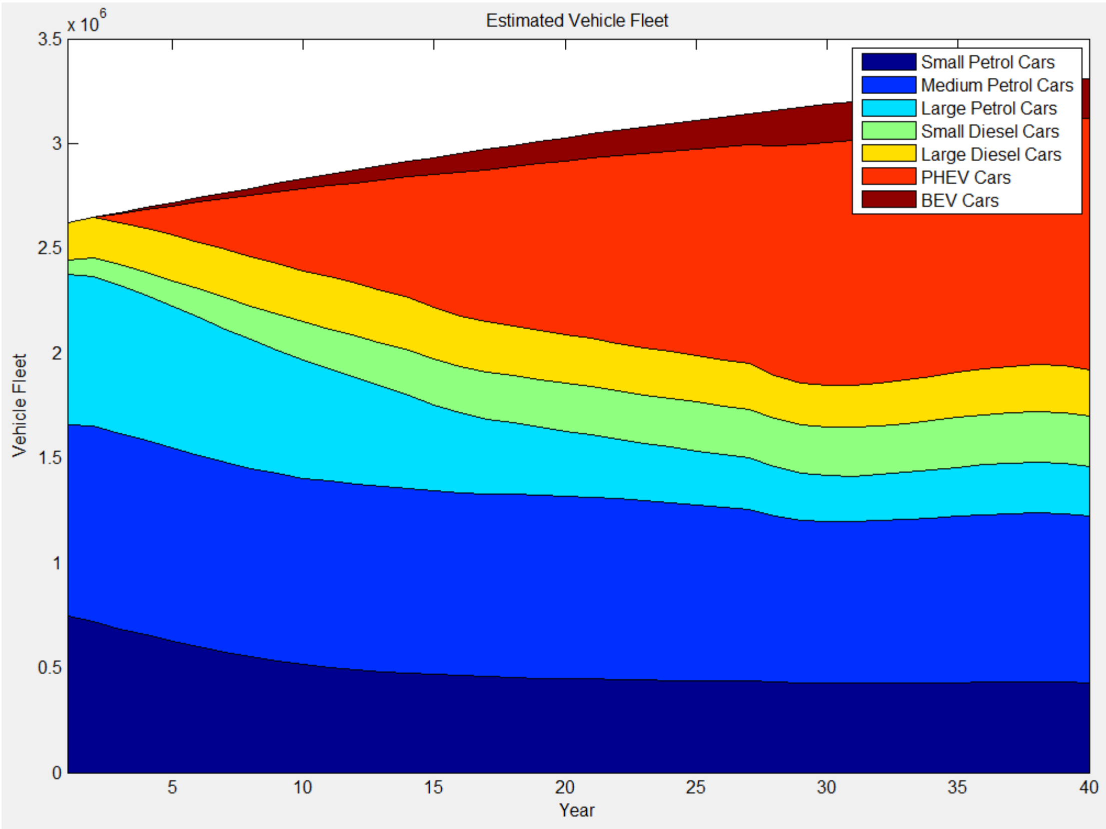


As shown in this figure, during the first two years of the simulation, the mix of new and ex-overseas car registrations is fairly even at around 50% for each. When advanced vehicles are introduced in 2013, PHEVs quickly become popular – given the assumption of constant gammas, with these vehicles instantly being able to offer comparable utility to medium petrol cars – and this popularity grows somewhat as fuel prices increase. BEVs are less popular, although they enjoy more dramatic increases in market share during the price spikes of the late 2030s and 2040s, i.e. years 27-30 and 38-40 in the simulation. The combined market share of advanced vehicles peaks at 69% in 2028, a year in which fuel prices exceed $4 a litre.

Certain car types have a low share of registrations throughout, i.e. used small petrol cars, and new large petrol and diesel cars. This will be due in large part to the gamma values I have chosen, and different values would give different results.

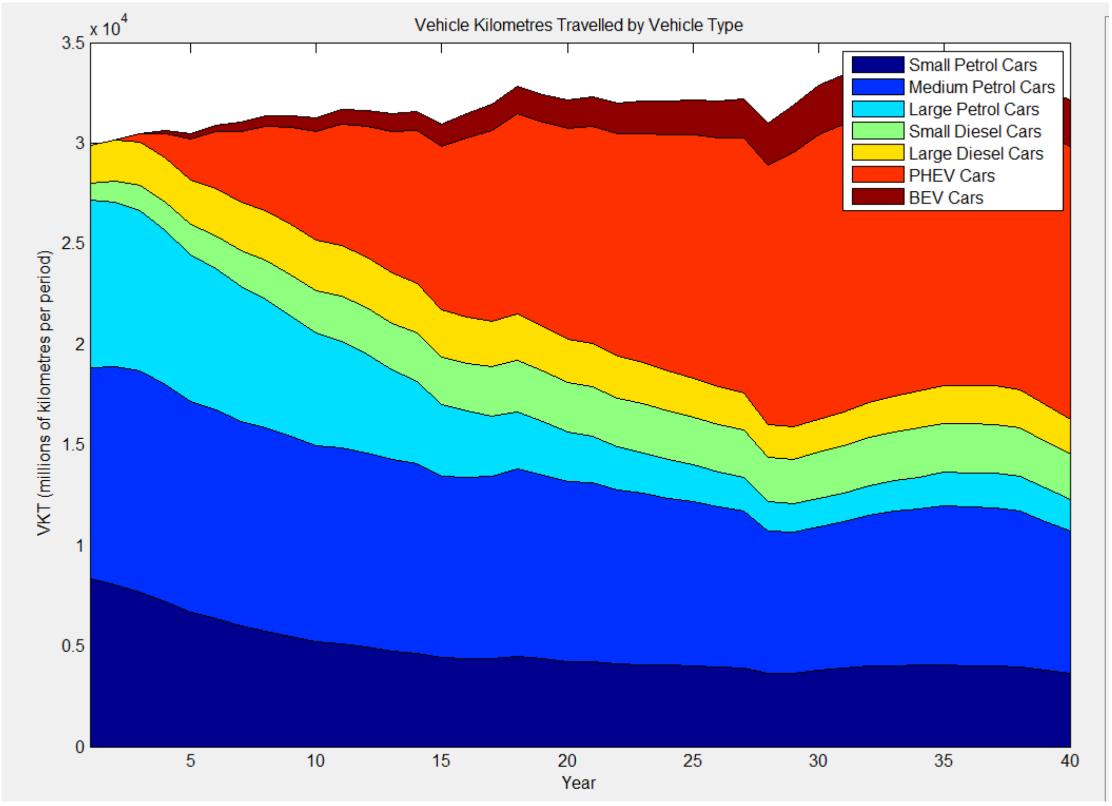
These vehicle registration patterns influence the makeup of the overall vehicle fleet, shown in Figure 29 below:

Figure 29: Predicted Total Number of Cars by Type for 2011-2050, for Third Run



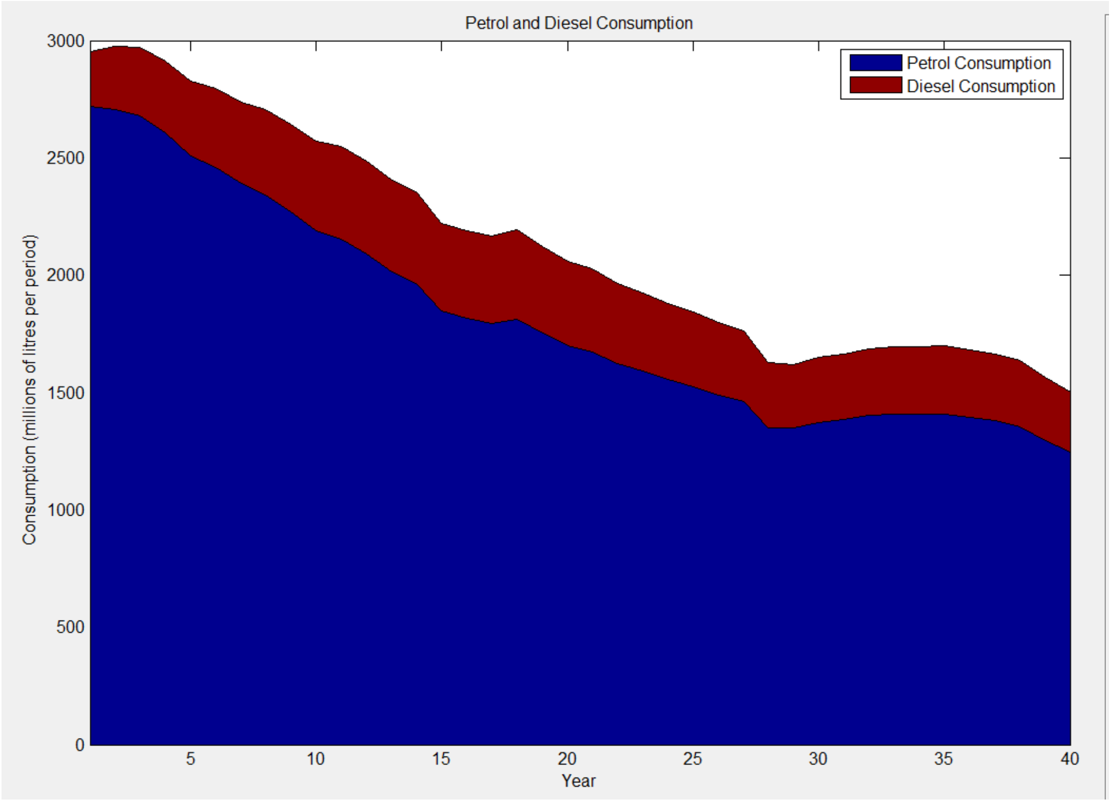
As shown in this figure, the durable nature of cars means that overall vehicle fleet changes much more slowly and smoothly than registration trends. This figure indicates that the number of PHEVs in the fleet grows significantly, with the number of BEVs growing to a much smaller extent. The number of small diesel cars increases, with the number of other types of conventional car decreasing.

Figure 30: Predicted Vehicle Kilometres Travelled by Car Type for 2011-2050, for Third Run



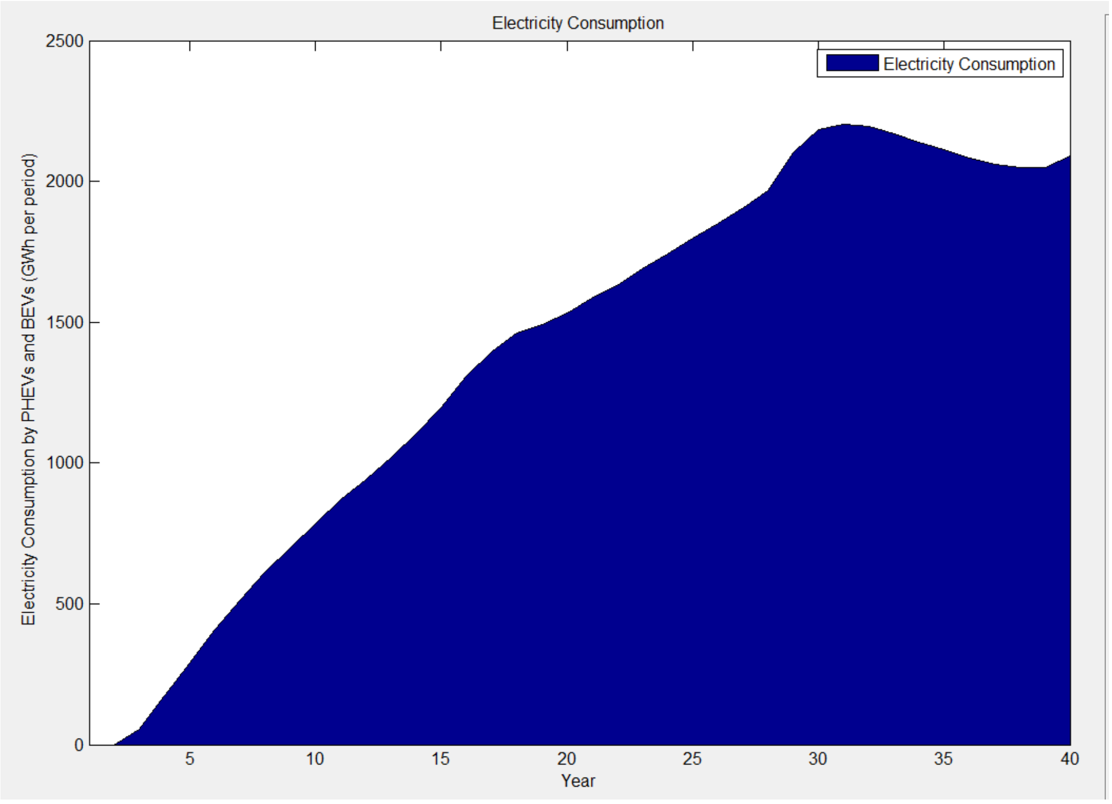
As shown in Figure 30 above, the total distance travelled by New Zealand cars is fairly flat into the future, and per-capita travel falls. Advanced vehicles make up a rapidly growing share of VKT; this is mainly because they are newer than the fleet average, and to some extent because of their smaller VKT response to changes in petrol and diesel prices.

Figure 31: Predicted Petrol and Diesel Consumption for 2011-2050, for Third Run



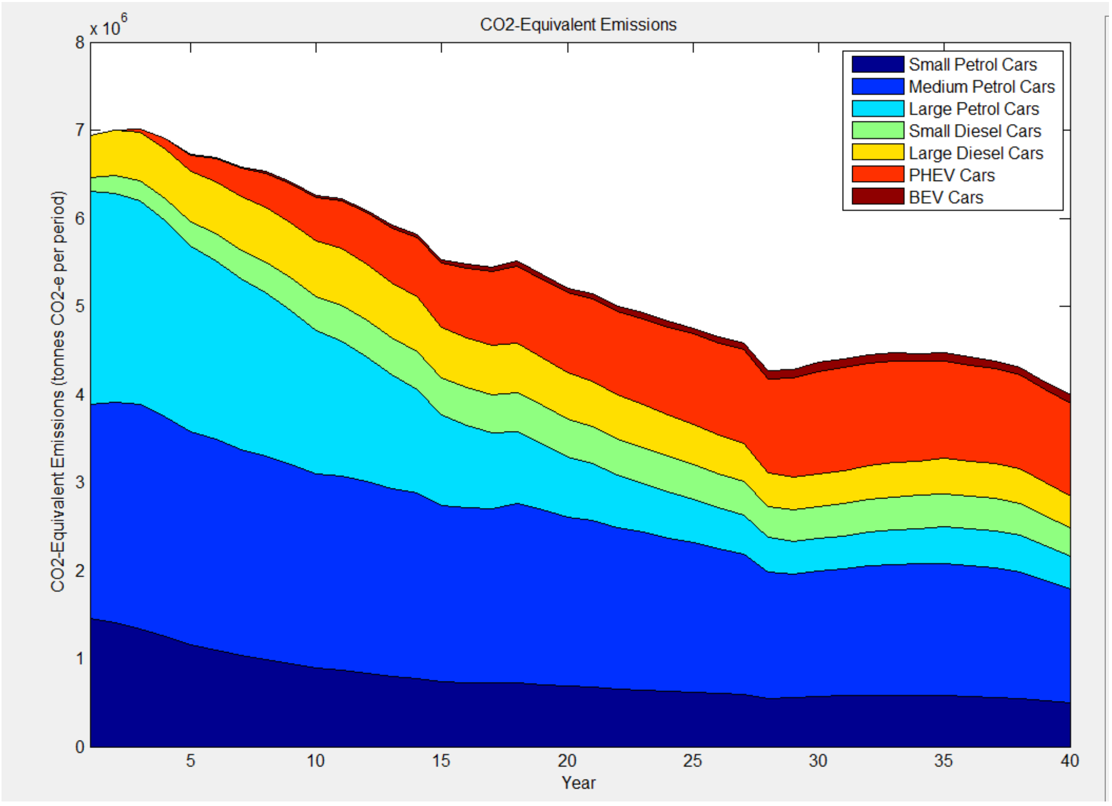
Petrol consumption falls dramatically over 2011-2050, whereas diesel consumption is fairly constant. Overall, the quantity of liquid fuels consumed falls by around 50% over the simulation period.

Figure 32: Predicted Electricity Consumption for 2011-2050, for Third Run



Electricity consumption rises steadily over the simulation period, reaching around 2,000 GWh in the 2040s. This is equal to around 5% of New Zealand's 2010 generation, a level that could easily be accommodated.

Figure 33: Predicted Greenhouse Gas Emissions by Car Type for 2011-2050, for Third Run



As for petrol and diesel consumption, this run indicated that emissions will be significantly reduced in the next 40 years. Despite accounting for more than half of all vehicle travel in 2050, advanced vehicles only make up around a quarter of greenhouse gas emissions.

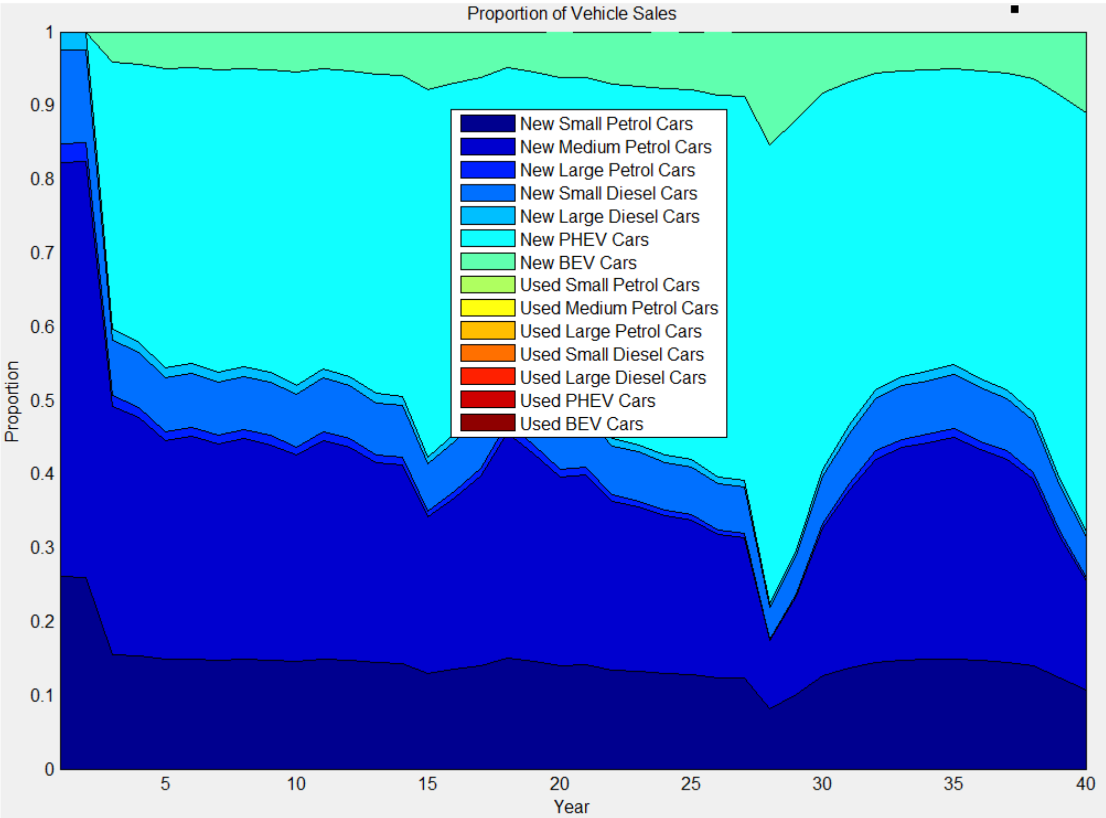
On a per capita basis, emissions fall from 1.57 tonnes per person in 2011 to 0.77 in 2040 and 0.68 in 2050 – sufficient to meet the New Zealand Government's (2007) goal of halving per-capita transport emissions by 2040. It should be noted that light commercial travel, freight and air travel also contribute to transport emissions, and that emissions reductions could come from any of these sectors in varying proportions. However, the scale of reduction in the car travel sector implied here is sufficient to take up some slack from other sectors.

6.5 Sensitivity Testing

As part of my work with the Transport Scenarios Model, I tested the effects of using different assumptions in the model, while keeping the parameters and fuel prices from section 6.3.

Duke et al. (2009, pp. 22-23) note that "perhaps the greatest impediment to NZ being a world leader in the uptake of BEVs is the existing arrangement of importing large volumes of used vehicles". The Transport Scenarios Model allows used imports to be completely banned; in this case, given the mixed logit specification, the market shares of all new vehicle types are scaled up accordingly. This is a misleading result; since most used imports are small or medium cars, it is unlikely that the market share of new large petrol cars would change much if ex-overseas imports were banned. Figure 34 below shows the shares predicted by the model, which are simply those from Figure 28 scaled up such that the market share for all new car types combined is equal to 100%.

Figure 34: Predicted Proportion of Car Registrations by Type for 2011-2050, with Used Imports Banned



Secondly, I looked at the effect of vehicle subsidies in the model. The user can choose whether to subsidise the purchase price of new PHEVs and/ or BEVs, and choose the size of this subsidy – immediately reducing the "price premium" and higher up-front expenditure associated with these advanced vehicles. The Transport Scenarios Model does not allow the user to specify more complex subsidies, such as Greene et al's (2005) "feebate" scheme or the vehicle type-specific subsidy in McConnell and Turrentine (2010). It is not straightforward to incorporate these schemes, since the model does not allow for variation in fuel efficiency for vehicles of the same type and age – that is, consumers cannot choose between more efficient and less efficient medium-sized petrol cars – and since the model currently only includes one size for PHEVs and BEVs.

Given the logit specification of the model, subsidies are found to be more effective in increasing the market share of advanced vehicles if consumers are already buying these vehicles in reasonable numbers; the sigmoid shape of the logit function implies that subsidising a particular choice gives a fairly small change in market share if that choice originally has a small market share. Given that BEVs have a much smaller share than PHEVs in most settings, for example, a subsidy on PHEVs is likely to be more effective. Of course, this must be carefully considered given that BEVs can give higher emissions reductions than PHEVs.

The user can also exempt PHEVs and/ or BEVs from having to pay Road User Charges, which is a less direct and potentially less efficient way of subsidising these vehicles. For BEVs, this essentially represents the current exemption – which is to expire in October 2013 – becoming permanent. The Transport Scenarios Model only allows for the decision on Road User Charges to be made once; the user cannot, for example, continue the current BEV exemption until 2020 and require BEVs to pay for their road usage thereafter. This eliminates the credibility issues – and the incentive to renege – that a real-world government would face in deciding its taxation scheme. With the near-rational ratio of α to β that I have used, a Road User Charges exemption for advanced vehicles has an equivalent effect to a $5,800 up-front subsidy. Of course, if consumers undervalue opex savings, an up-front subsidy will be more efficient, as well as being more straightforward to administer.

The Transport Scenarios Model allows the user to choose from low, medium or high population growth scenarios. The “constant vehicles per capita” assumption is maintained throughout, meaning that higher population growth means more vehicles in the fleet, more travel, more fuel demand and more CO_2 emissions. However, interestingly, per capita demand for petrol and diesel, and per capita emissions, tends to be lower in the “High” population growth scenario. This is because more vehicles are added to the fleet each period, and these new vehicles tend to be more efficient than the existing vehicles in the fleet. As such, they improve the average fuel efficiency of the fleet and reduce average per capita emissions.

In the real world, it is debatable whether per capita energy demand and emissions would actually drop if New Zealand’s population grows rapidly. While a growing population should increase the uptake of more efficient vehicles, these gains might be cancelled out by the effects of increased congestion. On the other hand, a larger and denser population would presumably make public transport more effective, and encourage a switch towards buses and trains. Such considerations are outside the scope of the model but could be influential in determining transport energy demand in the future.

7 FURTHER DISCUSSION

This chapter discusses some of the underlying assumptions in the Transport Scenarios Model, and suggests ways to expand or improve the model in the future.

7.1 Scrappage and Vehicle Entry Assumptions

The Transport Scenarios Model assumes that scrappage rates remain constant throughout the simulation timeframe. Since the number of vehicles being scrapped each period is a determinant of the number of vehicles entering each period, these numbers are also relatively steady.

In practise, scrappage and vehicle entry rates are likely to fluctuate based on economic conditions, and perhaps change permanently in response to other stimuli – for example, a "cash for clunkers" policy like that implemented in the US would cause scrappage rates to rise, while government restrictions on importing used vehicles could have the opposite effect.

Over the longer term, fluctuations in scrappage and vehicle entry will tend to average out, barring external factors such as changes to the regulatory environment or increased competition for ex-overseas vehicles. The question therefore becomes whether the "adopted" scrappage rates are higher or lower than the likely long-term average.

Using these adopted rates, the average age of cars in the fleet increases slowly over time under most runs of the model, often to around sixteen years from the current twelve. This does reflect recent trends, with the average age of light vehicles in New Zealand increasing by around two years over the 2000-2010 period, most of this increase occurring during the second half of the decade (MOT, 2011).

However, the Transport Scenarios Model also assumes that older vehicles do less travel, so the ageing of the fleet results in a predicted decrease in average VKT per vehicle, even without taking account of any fuel price changes. Since the number of vehicles per capita is also held constant, the model also predicts a decrease in per-capita VKT. This is a slightly problematic result, and the model should be revised to correct for this tendency.

7.2 Other Travel Assumptions

The model assumes that, if fuel prices remain at 2010 levels, all cars of a particular age will travel the same distance each period, regardless of their type.[7] However, VKT does appear to depend on the vehicle type; the MOT(2011) notes that larger-engined cars tend to travel further, especially in their first few years on the road. The limited range of BEVs might mean that they do less travel than other vehicles of the same age. The model also ignores the possibility of rebound effects, where consumers who switch to advanced vehicles would drive them further because of their much lower fuel costs.

It would be possible to allow VKT to vary by vehicle type, but this would require a lot of additional data, and assumptions about the likely travel of PHEVs and BEVs. In practise, it might be better to take a consumer-driven approach to this issue, such that consumers decide which vehicle to buy based on their own level of travel demand. We might expect that high-demand consumers, such as taxi drivers, would be more likely to buy PHEVs, whereas consumers with fairly regular travel patterns might be more likely to buy BEVs. Again, such an approach would require more data, and a fairly substantial overhaul of the Transport Scenarios Model.

7.3 Capacity Constraints

In the next few years, New Zealand's supply of advanced vehicles is likely to be constrained, both in terms of the number of cars available, and the variety of different models available. These are both important considerations when projecting the uptake of advanced vehicles.

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[7] Since elasticity differs between vehicle types, some differences in VKT can emerge when fuel prices deviate from 2010 levels.

Electric vehicle manufacturers are likely to slowly increase their manufacturing capacity over the next few years, testing the market and trying to minimise the risk of over-investing in new and unproven technology (U.S. Department of Energy, 2011).

It is a common practise for vehicle manufacturers to launch a new car in one or two key markets initially, before rolling it out to other markets if the vehicle is selling well. Important "early adopter" markets for PHEVs and BEVs are likely to include California, Japan and various European countries – all of which offer significant subsidies for such vehicles. New Zealand, which does not offer such subsidies and which imports many of its cars second-hand, is likely to be a fairly low priority. Hyder (2009, p. 7) test an "indicative" scenario where New Zealand's advanced vehicle supply is constrained until 2035, although such a long timeframe seems excessive; if demand is strong, the price mechanism should eventually give signals for manufacturers to increase production, even given the long lead times for designing and producing new cars.

A stated policy goal of the Obama administration is to have one million additional BEVs and PHEVs on the road by 2015. The U.S. Department of Energy (2011) estimates that, between 2011 and 2015 inclusive, there is production capacity for at least 1.2 million such vehicles to enter the US fleet, with BEVs accounting for up to 500,000 of these. Production will ramp up and could reach an annual level of 368,000 advanced vehicles in 2015 (U.S. Department of Energy, 2011).

According to the IEA (2011, p. 118), the sales targets for PHEVs and BEVs which have been adopted by various countries imply that there will be 25 million advanced vehicles in use worldwide by 2020, with annual sales of 7 million by 2020; this is equivalent to "almost 8% of global [car] sales and just over 2% of the global stock by 2020". However, based on the plans announced so far by manufacturers, annual production capacity may only reach 1.4 million advanced vehicles by 2020, indicating that sales could fall well short of governmental sales targets (IEA, 2011).

The limited variety of PHEV and BEV models will also be a factor in the rate at which they enter the New Zealand vehicle fleet. Only a handful of models will become available in New Zealand in the next few years, compared with the hundreds of new car models on offer, and an even wider range of used imports.

In modelling terms, it is possible to mimic the effect of capacity constraints by simply changing the gamma terms to disadvantage PHEVs and BEVs in the first few years of the model. As such, capacity constraints have not been included in the Transport Scenarios Model.

7.4 Areas for Future Research

The Transport Scenarios Model described in this thesis can be used as a tool to analyse a wide range of future trends, and chapter 6 illustrates its flexibility. However, there is much that could be done to further extend or improve this model, and it is my hope that further research by myself or others can build on this model as a platform for analysis.

7.4.1 Gross Domestic Product (GDP) Effects

Gross Domestic Product (GDP) has not been included as an input in the model, as it seems to have questionable value for determining future trends. While GDP is correlated to a number of relevant variables – e.g. oil prices, the rate at which New Zealanders replace their cars, and so on – it is not considered a key variable.

Since oil prices are essentially exogenous, New Zealand's GDP has no real effect on them, except to the extent that our GDP is correlated with real GDP. However, all else being equal, higher oil prices will *reduce* New Zealand's GDP, since oil is an important input for the economy and we are a net oil importer. In practise, though, high oil prices are likely to coincide with periods of strong world economic growth – during which time New Zealand is also likely to be growing. The relationship is further complicated by the fact that the value of the NZD is likely to rise when the economy is doing well relative to other countries, which actually makes it cheaper to buy oil.

As such, the link between oil prices and New Zealand's GDP is likely to be complex, and may not greatly add to Module One's usefulness. Furthermore, unravelling the nature of the link could be complicated by the declining use of diesel for industrial purposes over the last few decades.

GDP might be seen as being more useful in Module Two. However, here also, any effects from including GDP are likely to be overshadowed by other influences. Results from Kennedy and Wallis (2007) suggest that a 1% increase in GDP per capita increases petrol consumption per capita by 0.3%, although there is a large uncertainty around this estimate. Kennedy and Wallis (2007) also analysed the effect of GDP on traffic volumes; this effect was found to be insignificant in most of their regressions, although always with the expected sign, i.e. higher GDP increases traffic volumes.

The MED (2010) carried out a sensitivity analysis on the effect of different GDP growth rates as part of the modelling work for their *Energy Outlook*, with petrol demand in 2030 changing very little between the low and high growth scenarios.

Kennedy and Wallis (2007) note that GDP may increase fuel demand and traffic volumes because of higher levels of car ownership, and income effects, while Polkinghorne (2011) refers to a number of studies which have found a link between transport energy demand and household income. Typically, demand is found to increase inelastically in response to an increase in household income, with such studies often being cross-sectional in nature.

However, the link between GDP and transport energy demand from cars – which already seems to be rather weak – may change in the future. Looking ahead, rising GDP could have a smaller or even negative effect on energy consumption, due to saturation of vehicle ownership levels and indeed vehicle travel, and the potential for new vehicles to be more efficient than the ones they replace. Higher incomes and GDP could speed the shift towards advanced vehicles or other fuel-efficient technologies.

7.4.2 Exchange Rate Effects

Given that essentially all of our vehicles are imported, and that our petrol and diesel prices are also influenced by the world price, there is an argument for including exchange rate sensitivities, or a stochastic exchange rate, in the Transport Scenarios Model.

However, world oil prices are usually given in US dollars, while the relevant currency for our vehicles is the Japanese yen, given that we buy most of our cars from Japan. This means including two exchange rate series, NZD/ USD and NZD/ JPY, or constructing a single trade weighted index. Furthermore, while Module One expressly calculates retail fuel prices based on a (fixed) exchange rate, an additional exercise would need to be carried out to determine the relationship between retail *car* prices and the exchange rate.

The MED (2010) notes that exchange rate fluctuations have a moderating impact for the transport sector; for example, a high exchange rate means that we can import vehicles more cheaply, increasing the rate of technological change, but petrol and diesel become cheaper too, making PHEVs and BEVs less economic. Given this moderating effect, and the computational difficulty of adding stochastic exchange rates to the model, they have not been included. Future research should attempt to incorporate stochastic exchange rates, and to test their effects.

7.4.3 Biofuels

While not considered in depth in this thesis, biofuels could potentially reduce New Zealand's consumption of oil-based fuels and greenhouse gas emissions in the future. Module One of the Transport Scenarios Model could be expanded to look at biofuels.

7.4.4 New Modes of Travel, and Multi-Vehicle Households

Adding in the ability for consumers to utilise different modes of travel, such as public transport or air travel, would allow for a comprehensive look at private travel patterns. Public transport, in particular, is likely to play a growing role in New Zealand cities in the future.

Urban and rural consumers have different travel needs, and different levels of access to public transport. The model could be extended to incorporate these differences; for example, it could calculate results separately for Auckland, other major cities and the rest of New Zealand. Urban dwellers might attach higher utilities to BEV ownership than rural dwellers, and the interplay with new modes of travel – such as bus and rail – would also be very interesting.

Many New Zealand households have access to more than one vehicle. Multi-vehicle households are likely to behave differently from single-vehicle households (Morton et al., 2011); for example, they may buy a BEV and continue to use a conventional car for long trips, making range less of an issue. Older cars may not be scrapped, but instead held in reserve.

7.4.5 A More Complete Analysis of Car Ownership Costs

This thesis has focussed on the up-front costs of car ownership, i.e. the purchase price of a vehicle, and the ongoing fuel costs of car ownership. While fuel costs are important, other factors such as depreciation, interest – imputed or otherwise – and insurance can all be major costs.

The Automobile Association (2011b) divides the "operating costs" for a vehicle into "fixed costs", which do not depend on distance travelled, and "variable costs" which do depend on distance. They estimated these costs for 2010, for petrol cars less than five years old, driving 14,000 km a year and with an assumed petrol cost of $2.10 per litre (Automobile Association, 2011b). Their cost estimates are shown in Table 9 overleaf, broken down for four sizes of petrol car:

Table 9: 2010 Operating Costs for Small, Compact, Medium and Large Petrol Cars

Petrol Car Type	Small	Compact	Medium	Large
Fixed Costs				
Relicensing	$288.00	$288.00	$288.00	$288.00
Insurance	$768.00	$889.00	$991.00	$1,319.00
Warrant of Fitness	$46.00	$46.00	$46.00	$46.00
Interest on Outlay	$890.00	$1,110.00	$1,567.00	$2,113.00
Depreciation	$2,589.00	$3,393.00	$4,098.00	$6,459.00
Total Fixed Costs	***$4,581.00***	***$5,726.00***	***$6,990.00***	***$10,225.00***
Running Costs				
Fuel	$1,874.25	$2,160.90	$2,910.60	$3,434.97
Oil	$70.00	$70.00	$70.00	$70.00
Tyres	$247.50	$267.04	$351.86	$511.00
Repairs/ Maintenance	$600.24	$608.18	$610.86	$635.81
Total Running Costs	***$2,791.99***	***$3,106.12***	***$3,943.32***	***$4,651.78***
Overall Operating Cost	**$7,372.99**	**$8,832.12**	**$10,933.32**	**$14,876.78**

Source: Automobile Association (2011b)

As shown in Table 9, operating costs are much higher for the larger sizes of car. However, most of the difference is due to higher fixed costs, rather than higher fuel and other running costs. Larger cars are typically more expensive than smaller cars, and as such they have higher depreciation, insurance and interest costs.

Given that many technologies which enhance fuel efficiency are costly, and add to the value of the car, fuel-efficient cars are likely to have higher fixed costs than less efficient vehicles of the same size. A truly rational consumer, who considers the entire operating cost of his or her vehicle and not just the fuel cost, might find that fuel-efficient cars actually provide no cost savings at all.

For PHEVs and BEVs, which may cost many thousands of dollars more than conventional cars of the same size, it is entirely possible that the higher costs of depreciation, insurance and interest for such an expensive vehicle mean that they actually have higher operating costs than more traditional vehicles. In fact, data from the Automobile Association (2011a; 2011b) suggests that this is the case for diesel cars, which have slightly lower fuel costs than petrol cars, but a higher up-front cost.

It should be noted, however, that the Automobile Association's (2011b) analysis is for fairly new cars aged less than five years old, and that the fixed costs described above will be much lower for older cars, which have already lost much of their value. Furthermore, fuel-efficient technologies are intended to "pay back" their cost over time, which means that depreciation – which at any rate is an accounting concept rather than an economic one – should arguably be excluded from any rational analysis. The same cannot be said for insurance and interest costs, which are real costs and which may not always be fully taken into account.

Future work should aim to quantify the impact of these various additional costs on the rational model described in chapter 3, the real-world regressions of chapter 4 and the Transport Scenarios Model. It seems likely that the inclusion of insurance and interest costs would make PHEVs and BEVs less attractive, and reduce the rate of their uptake in the model.

7.4.6 Analysing the Financial Costs and Benefits of Advanced Vehicle Subsidies

The Transport Scenarios Model can already be used to look at the emissions and long-term fuel savings from a subsidy-driven transition to advanced vehicles, but this is very dependent on the assumed coefficients in the logit model used to predict vehicle choice. The quality of the calibration must be improved in order to quantify the costs and benefits of such subsidies.

8 CONCLUSIONS

This thesis is an investigation into the future of light passenger vehicles, looking specifically at New Zealand. I have focused on the potential role of new types of vehicles – PHEVs and BEVs – and the potential for existing types of vehicles to become more fuel-efficient.

Although the rational analysis carried out in chapter 3 is somewhat simplistic, it serves to illustrate that PHEVs could make good economic sense in the New Zealand context, whereas BEVs seem much further away from doing so. Such an analysis can show that perfectly rational consumers are likely to buy PHEVs when they become available, given reasonable expectations about future fuel prices and assuming some level of battery cost decrease. If consumers are not perfectly rational – perhaps adopting higher discount rates or estimating costs over a shorter timeframe – then governmental intervention could perhaps be justified in the interests of increasing total welfare.

If consumers do not correctly value fuel price savings – and, despite the lack of consensus in the literature, reasonable arguments can be made to suggest that consumers undervalue these savings – they will make purchase decisions that are not in their long-term self interest. There is a role for government to play in this case, either through subsidies/ taxation, fuel economy standards, or through improving the quality of information that is available for car buyers.

Furthermore, I would argue that the government should consider opex costs for the entire vehicle lifetime, even if consumers only consider costs over a period of a few years. Few vehicles are re-exported from New Zealand, so even if consumers ignore future cost savings beyond the point where they sell their car, the government would be well advised to adopt a longer timeframe. However, fuel-efficient cars should, in theory, command higher resale prices. This is one aspect of vehicle purchase decisions which is perhaps currently overlooked. If fuel-efficient cars have higher resale values, and if consumers are educated about this, they could be more likely to buy fuel-efficient cars in the first place.

Private and public sector fleets account for a large proportion of new vehicle sales in New Zealand, and this suggests a need for research to determine whether these consumer groups are more rational than households. Fleet buyers – and, for that matter, small businesses – should be encouraged to think about long-term costs when buying their vehicles.

The economics of fuel economy should be made more accessible to vehicle buyers, through giving them better information. This should be an aim for both government and for motivated vehicle dealers who want their customers to choose the most appropriate vehicles, providing a better service in the process. For example, it would be a low-cost initiative to provide information on calculating net present values on government websites, or indeed including a tool to do so on these websites.

Chapter 4 of this thesis used aggregate market share data to analyse substitution between different types and sizes of car. My findings suggest that such substitutions have little to do with fuel price changes, which is corroborated by other evidence. However, these results are not particularly satisfactory for calibrating the Transport Scenarios Model, and it may be that my analysis – and the model – should be expanded to include different models of car within the size classes. Households who prefer large cars, for example, are more likely to switch to more fuel-efficient large cars rather than to medium cars.

A major part of the work for this thesis lay in developing the Transport Scenarios Model. While the initial runs of this model predict limited substitution between car types, this result is based on assumptions that consumer preferences and the availability of different types of car remain the same over time; this is, of course, quite unlikely. Some of the runs described in this thesis show the potential effects of greater substitution.

With a significant amount of modelling work done, the model can be viewed as being fairly stable. Perhaps the most interesting task would be to change the way in which new cars enter the fleet – for example, replacing the multinomial logit model with another model, or allowing gammas to change over time – and this would be fairly straightforward, as only one of the 22

MATLAB files needs to be changed. Of course, with the limited data available to predict future rates of advanced vehicle uptake, the model is more useful for testing different scenarios than for making definitive predictions.

A number of results emerge from this thesis. There is a wide divergence of opinion on the energy, emissions and power grid implications of a shift towards advanced vehicles, which I believe is unjustified. It is in fact quite straightforward to estimate these effects, as I do towards the end of Chapter 2. Advanced vehicles seem ready to offer New Zealand energy security and emissions reduction benefits, without putting undue pressure on the country's electricity network. I note the potential of biofuels and public transport to deliver such benefits – with public transport offering the additional advantage of reducing congestion – and I hope that future work will be able to tie these different pathways together.

Some of the runs of the Transport Scenarios Model described in Chapter 6 suggest that subsidies for advanced vehicles may be effective, although they will not be if the estimated parameters of Chapter 4 are anything to go by. It is likely that consumers would be more responsive to subsidies for fuel-efficient vehicles within a size class, although the possibility of including different models of car within a particular type has not yet been explored.

In conclusion, the various topics explored in this thesis have provided some interesting results and suggest a number of avenues for additional work, which I hope to investigate in the future. Like the transport sector itself, this thesis has only scratched the surface of what is possible.

APPENDIX A: MATLAB CODE FOR THE TRANSPORT SCENARIOS MODEL

Module_One_Start.m

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                              THE TRANSPORT SCENARIOS MODEL                             %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% MODULE ONE: FINDING OIL PRICES AND RETAIL FUEL PRICES

% Clearing the workspace and the command window
clear all
clc

global TIMEFRAME FREQUENCY DRIFT_TERM VOLATILITY_TERM MANUAL_IMPORT_INDICATOR...
       SCENARIO_INDICATOR UNIVERSAL_RUC_SCHEME

TIMEFRAME = 40;                 % Number of years of prediction required
FREQUENCY = 12;                 % Frequency of predictions per year
DRIFT_TERM = 0.02;              % GBM drift term
VOLATILITY_TERM = 0.15;         % GBM volatility term
MANUAL_IMPORT_INDICATOR = 0;    % Boolean (1 = user has manually imported oil prices)
SCENARIO_INDICATOR = 0;         % Can be changed to a number between 1 and 6, which
                                % indicates that the user has chosen to use a pre-saved
                                % oil price scenario, and shows which scenario
UNIVERSAL_RUC_SCHEME = 0;       % Boolean (1 = all vehicles must pay Road User Charges,
                                % except those which are given an exemption)
POPULATION_PROJECTION = 2;      % 1 to 3 indicates, respectively, the use of SNZ's Low,
                                % Medium or High population projections

% Calling the first GUI screen, which lets the user decide how they want to determine
% oil prices over the simulation.
GUI_1;
```

GUI_1.m

```
function varargout = GUI_1(varargin)
% This function contains the underlying code for the GUI_1.fig GUI

% --------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% --------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_1_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_1_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% --------------------------------------------------------------------------------------
% SETTING UP THE GUI
% --------------------------------------------------------------------------------------
% --- Executes just before GUI_1 is made visible.
function GUI_1_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = GUI_1_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% --------------------------------------------------------------------------------------
% BUTTONS TO EXIT THIS GUI. ALL OF THESE BUTTONS LEAD ON TO OTHER GUI SCREENS
% --------------------------------------------------------------------------------------
% --- Executes on button press in pushbutton1, the "Use a pre-set oil price scenario"
% button.
function pushbutton1_Callback(hObject, eventdata, handles)
close
GUI_2a

% --- Executes on button press in pushbutton2, the "Import a custom oil price scenario"
% button.
function pushbutton2_Callback(hObject, eventdata, handles)
close
GUI_2b

% --- Executes on button press in pushbutton3, the "Determine oil prices through a GBM
% process" button.
```

```
function pushbutton3_Callback(hObject, eventdata, handles)
close
GUI_2c
```

GUI_2a.m

```
function varargout = GUI_2a(varargin)
% This function contains the underlying code for the GUI_2a.fig GUI

% ---------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% ---------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_2a_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_2a_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% ---------------------------------------------------------------------------------------
% SETTING UP THE GUI
% ---------------------------------------------------------------------------------------
% --- Executes just before GUI_2a is made visible.
function GUI_2a_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;

global OIL_PRICE_SCENARIO TIMEFRAME

% Putting in the default timeframe
set(handles.edit2,'String',num2str(TIMEFRAME))
% Ensuring that when radiobuttons are changed, there will be a variable change
set(handles.uipanel1,'SelectionChangeFcn',@uipanel1_SelectionChangeFcn);
set(handles.uipanel3,'SelectionChangeFcn',@uipanel3_SelectionChangeFcn);
load Oil_Price_Preset_Scenarios.mat
% Plotting the IEA's "Current Policies Scenario"
axes(handles.axes1)
scenarios_timeline = (1:25);
plot(scenarios_timeline,Current_Policies_Scenario)
title('Current Policies Scenario')
xlabel('Years into future')
ylabel('Price of Oil ($USD)')
set(hObject, 'toolbar', 'figure')
guidata(hObject, handles);

% Ensuring that if the user clicks through to the next screen without changing the
% selected radio button, the IEA's "Current Policies Scenario" is selected
OIL_PRICE_SCENARIO = 1;

% --- Outputs from this function are returned to the command line.
function varargout = GUI_2a_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% --- Executes during object creation, after setting all properties.
function edit2_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% ---------------------------------------------------------------------------------------
% APPLYING CHANGES MADE BY THE USER
% ---------------------------------------------------------------------------------------
% --- Executes when selected object is changed in uipanel1.
function uipanel1_SelectionChangeFcn(hObject, eventdata, handles)
handles = guidata(hObject);

% Imports the six pre-set scenarios, which come from the U.S. Energy Information Administration
and IEA and are saved as "Current_Policies_Scenario", "New_Policies_Scenario" etc
load Oil_Price_Preset_Scenarios.mat

% Imports the scenario selected by the user as "selected_scenario"
global FREQUENCY TIMEFRAME OIL_PRICE_SCENARIO
switch get(eventdata.NewValue,'Tag')
    case 'radiobutton1'
        selected_scenario = Current_Policies_Scenario;
        selected_scenario_title = 'Current Policies Scenario';
        OIL_PRICE_SCENARIO = 1;
    case 'radiobutton2'
        selected_scenario = New_Policies_Scenario;
```

```
        selected_scenario_title = 'New Policies Scenario';
        OIL_PRICE_SCENARIO = 2;
    case 'radiobutton3'
        selected_scenario = Four_Fifty_Scenario;
        selected_scenario_title = '450 Scenario';
        OIL_PRICE_SCENARIO = 3;
    case 'radiobutton4'
        selected_scenario = Low_Oil_Prices_Scenario;
        selected_scenario_title = 'Low Oil Prices Scenario';
        OIL_PRICE_SCENARIO = 4;
    case 'radiobutton5'
        selected_scenario = Reference_Case_Scenario;
        selected_scenario_title = 'Reference Case Scenario';
        OIL_PRICE_SCENARIO = 5;
    case 'radiobutton6'
        selected_scenario = High_Oil_Prices_Scenario;
        selected_scenario_title = 'High Oil Prices Scenario';
        OIL_PRICE_SCENARIO = 6;
end
% Changing the graph to reflect the selected scenario
axes(handles.axes1)
scenarios_timeline = (1:25);
plot(scenarios_timeline,selected_scenario)
title(selected_scenario_title)
guidata(hObject, handles);

% Saving the user's changes to the simulation timeframe
function uipanel3_SelectionChangeFcn(hObject, eventdata, handles)
handles = guidata(hObject);
global FREQUENCY
switch get(eventdata.NewValue,'Tag')
    case 'radiobutton7'
      FREQUENCY = 12;
    case 'radiobutton8'
      FREQUENCY = 4;
    case 'radiobutton9'
      FREQUENCY = 1;
end
guidata(hObject, handles);

% Saving the user's changes to the simulation timeframe
function edit2_Callback(hObject, eventdata, handles)
global TIMEFRAME
TIMEFRAME = str2double(get(hObject, 'String'));

% ---------------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% ---------------------------------------------------------------------------------------
% --- Executes on button press in pushbutton1, the "Continue Simulation" button. This
% finalises the oil price, and initialises the TIMELINE_VECTOR global variable, and
% then continues with the simulation.
function pushbutton1_Callback(hObject, eventdata, handles)

global TIMELINE_VECTOR FREQUENCY TIMEFRAME WORLD_OIL_PRICE OIL_PRICE_SCENARIO

TIMELINE_VECTOR = (1/FREQUENCY:1/FREQUENCY:TIMEFRAME);

% Setting up the "WORLD_OIL_PRICE" global variable. This stores information on
% oil prices over the simulation timeframe.
WORLD_OIL_PRICE = zeros(1,FREQUENCY*TIMEFRAME);

for t = 1:(FREQUENCY*TIMEFRAME)
    if OIL_PRICE_SCENARIO == 1
        WORLD_OIL_PRICE(t) = min(140, (0.004891*(t/FREQUENCY)^3 - 0.271127*(t/FREQUENCY)^2 +
6.203858*(t/FREQUENCY) + 78.890514));
    elseif OIL_PRICE_SCENARIO == 2
        WORLD_OIL_PRICE(t) = min(120, (0.005285*(t/FREQUENCY)^3 - 0.274650*(t/FREQUENCY)^2 +
5.240304*(t/FREQUENCY) + 79.192411));
    elseif OIL_PRICE_SCENARIO == 3
        WORLD_OIL_PRICE(t) = min(97, (0.005959*(t/FREQUENCY)^3 - 0.281575*(t/FREQUENCY)^2 +
4.062856*(t/FREQUENCY) + 79.721067));
    elseif OIL_PRICE_SCENARIO == 4
        WORLD_OIL_PRICE(t) = max(50.89, (-0.000938*(t/FREQUENCY)^3 + 0.054884*(t/FREQUENCY)^2 -
1.197643*(t/FREQUENCY) + 60.869649));
    elseif OIL_PRICE_SCENARIO == 5
        if t<= (FREQUENCY*25)
            WORLD_OIL_PRICE(t) = -0.000702*(t/FREQUENCY)^3 - 0.047491*(t/FREQUENCY)^2 +
3.479322*(t/FREQUENCY) + 80.296119;
        else WORLD_OIL_PRICE(t) = 126.99;
        end
    elseif OIL_PRICE_SCENARIO == 6
        WORLD_OIL_PRICE(t) = min(203.23, (0.004440*(t/FREQUENCY)^3 - 0.331272*(t/FREQUENCY)^2 +
9.368455*(t/FREQUENCY) + 108.074008));
    end
end

close
GUI_3a;
```

```
% --- Executes on button press in pushbutton2, the "Return to previous screen" button.
% This will close the window, clear all variables and go back to the initial GUI screen.
function pushbutton2_Callback(hObject, eventdata, handles)
close
clear all
Module_One_Start

% --- Executes on button press in pushbutton3, the "Cancel Simulation" button. This will
% close the window, end the simulation and clear all variables
function pushbutton3_Callback(hObject, eventdata, handles)
close
clear all
```

GUI_2b.m

```
function varargout = GUI_2b(varargin)
% This function contains the underlying code for the GUI_2b.fig GUI

% -------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% -------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_2b_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_2b_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% -------------------------------------------------------------------------------------
% SETTING UP THE GUI
% -------------------------------------------------------------------------------------
% --- Executes just before GUI_2b is made visible.
function GUI_2b_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = GUI_2b_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% -------------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% -------------------------------------------------------------------------------------
% When the "Continue Simulation" button is pressed, the Oil_Price_Imported_Data.mat file
% (containing the "imported_data" variable) is loaded. The inputted price data is saved
% to the WORLD_OIL_PRICE vector, and the TIMEFRAME, FREQUENCY and TIMELINE_VECTOR global
% variables are updated. The simulation then continues.
function pushbutton3_Callback(hObject, eventdata, handles)

global WORLD_OIL_PRICE TIMELINE_VECTOR TIMEFRAME FREQUENCY

load Oil_Price_Imported_Data.mat

if imported_data(2,1) - imported_data(1,1) == 1
    FREQUENCY = 1;
elseif imported_data(2,1) - imported_data(1,1) == 0.25
    FREQUENCY = 4;
else FREQUENCY = 12;
end

TIMELINE_VECTOR = transpose(imported_data(:,1));
TIMEFRAME = max(imported_data(:,1));

WORLD_OIL_PRICE = transpose(imported_data(:,2));
clear Oil_Price_Imported_Data.mat

close
GUI_3a;

% --- Executes on button press in pushbutton4, the "Return to previous screen" button.
% This closes the window, clears all variables and returns to the initial GUI screen.
function pushbutton4_Callback(hObject, eventdata, handles)
close
clear all
Module_One_Start

% --- Executes on button press in pushbutton5, the "Cancel Simulation" button. This
```

```
% will close the window, end the simulation and clear all variables.
function pushbutton5_Callback(hObject, eventdata, handles)
close
clear all
```

GUI_2c.m

```
function varargout = GUI_2c(varargin)
% This function contains the underlying code for the GUI_2c.fig GUI

% ------------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% ------------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_2c_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_2c_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% ------------------------------------------------------------------------------------------
% SETTING UP THE GUI
% ------------------------------------------------------------------------------------------
% --- Executes just before GUI_2c is made visible.
function GUI_2c_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;

global DRIFT_TERM VOLATILITY_TERM TIMEFRAME

% Ensuring that when radiobuttons are changed, there will be a variable change
set(handles.uipanel8,'SelectionChangeFcn',@uipanel8_SelectionChangeFcn);
% Placing default numbers in the drift, volatility and timeframe text boxes
set(handles.edit8,'String',num2str(DRIFT_TERM))
set(handles.edit9,'String',num2str(VOLATILITY_TERM))
set(handles.edit10,'String',num2str(TIMEFRAME))
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function edit8_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes during object creation, after setting all properties.
function edit9_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes during object creation, after setting all properties.
function edit10_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Outputs from this function are returned to the command line.
function varargout = GUI_2c_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% ------------------------------------------------------------------------------------------
% APPLYING CHANGES MADE BY THE USER
% ------------------------------------------------------------------------------------------
% Saving the user's changes to the simulation timeframe
function uipanel8_SelectionChangeFcn(hObject, eventdata, handles)
handles = guidata(hObject);
global FREQUENCY
switch get(eventdata.NewValue,'Tag')
    case 'radiobutton15'
      FREQUENCY = 12;
    case 'radiobutton16'
      FREQUENCY = 4;
    case 'radiobutton17'
      FREQUENCY = 1;
end
guidata(hObject, handles);

% Saving the user's changes to the simulation timeframe
function edit10_Callback(hObject, eventdata, handles)
```

```
global TIMEFRAME
TIMEFRAME = str2double(get(hObject, 'String'));

% Saving the user's changes to the GBM drift term
function edit8_Callback(hObject, eventdata, handles)
global DRIFT_TERM
DRIFT_TERM = str2double(get(hObject, 'String'));

% Saving the user's changes to the GBM volatility term
function edit9_Callback(hObject, eventdata, handles)
global VOLATILITY_TERM
VOLATILITY_TERM = str2double(get(hObject, 'String'));

% -----------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% -----------------------------------------------------------------------------------
% --- Executes on button press in pushbutton5, the "Continue Simulation" button. This
% will continue with the simulation.
function pushbutton5_Callback(hObject, eventdata, handles)
global TIMELINE_VECTOR FREQUENCY TIMEFRAME
TIMELINE_VECTOR = (1/FREQUENCY:1/FREQUENCY:TIMEFRAME);
close
GUI_3b

% --- Executes on button press in pushbutton6, the "Return to previous screen" button.
% This will close the window, clear all variables and go back to the initial GUI screen.
function pushbutton6_Callback(hObject, eventdata, handles)
close
clear all
Module_One_Start

% --- Executes on button press in pushbutton7, the "Cancel Simulation" button. This will
% close the window, end the simulation and clear all variables
function pushbutton7_Callback(hObject, eventdata, handles)
close
clear all
```

GUI_3a.m

```
function varargout = GUI_3a(varargin)
% This function contains the underlying code for the GUI_3a.fig GUI

% -----------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% -----------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_3a_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_3a_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% -----------------------------------------------------------------------------------
% SETTING UP THE GUI
% -----------------------------------------------------------------------------------
% --- Executes just before GUI_3a is made visible.
function GUI_3a_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
global WORLD_OIL_PRICE FREQUENCY TIMEFRAME

% Graphing the selected oil price path in the GUI
axes(handles.axes1)
TIMELINE_VECTOR = (1/FREQUENCY:1/FREQUENCY:TIMEFRAME);
plot(TIMELINE_VECTOR,WORLD_OIL_PRICE)
title('Oil Price Simulator Output')
xlabel('Years into future')
ylabel('Price of Oil ($USD)')
set(hObject, 'toolbar', 'figure')
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = GUI_3a_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% -----------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% -----------------------------------------------------------------------------------
```

```
% --- Executes on button press in pushbutton1, the "Continue Simulation" button. This
% will continue with the simulation.
function pushbutton1_Callback(hObject, eventdata, handles)
close
GUI_4

% --- Executes on button press in pushbutton4, the "Restart  Simulation" button.
% This will close the window, clear all variables and go back to the initial GUI screen.
function pushbutton4_Callback(hObject, eventdata, handles)
close
clear all
Module_One_Start

% --- Executes on button press in pushbutton6, the "Return to previous screen" button.
% This will close the window, clear all variables and go back to the initial GUI screen.
function pushbutton6_Callback(hObject, eventdata, handles)
close
clear all
GUI_1;

% --- Executes on button press in pushbutton7, the "Cancel Simulation" button. This will
% close the window, end the simulation and clear all variables

% If the user presses "Cancel  Simulation", the window is closed, the simulation is ended and the
variables are all deleted
function pushbutton2_Callback(hObject, eventdata, handles)
close
clear all
```

GUI_3b.m

```
function varargout = GUI_3b(varargin)
% This function contains the underlying code for the GUI_3b.fig GUI

% -------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% -------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_3b_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_3b_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% -------------------------------------------------------------------------------------
% SETTING UP THE GUI
% -------------------------------------------------------------------------------------
% --- Outputs from this function are returned to the command line.
function varargout = GUI_3b_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% --- Executes just before GUI_3b is made visible.
function GUI_3b_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;

% -------------------------------------------------------------------------------------
% OIL PRICE SIMULATOR
% -------------------------------------------------------------------------------------
% Runs, and graphs, a GBM oil price process. The GBM process produces a vector with an
% oil price for each period in the simulation.
global TIMEFRAME FREQUENCY TIMELINE_VECTOR WORLD_OIL_PRICE DRIFT_TERM...
       VOLATILITY_TERM

% Specifying the vector which will store an oil price for each period in the simulation
WORLD_OIL_PRICE = zeros(1,length(TIMELINE_VECTOR));

% Putting in the starting oil price, obtained from MED weekly price data. The starting
% price depends on the frequency; for annual observations, I use the average price for
% 2010; for quarterly observations, the average price for the fourth quarter of 2010;
% for monthly observations, the average price for December 2010.
if FREQUENCY == 1
    starting_price = 78.12;
elseif FREQUENCY == 4
    starting_price = 84.48;
else
    starting_price = 89.08;
end
```

```
WORLD_OIL_PRICE(1) = starting_price*exp((DRIFT_TERM - 0.5*VOLATILITY_TERM^2)*(1/FREQUENCY) +
VOLATILITY_TERM*random('normal',0,1)*sqrt(1/FREQUENCY));

for t = 2:length(TIMELINE_VECTOR)
    WORLD_OIL_PRICE(t) = WORLD_OIL_PRICE(t-1)*exp((DRIFT_TERM -
0.5*VOLATILITY_TERM^2)*(1/FREQUENCY) + VOLATILITY_TERM*random('normal',0,1)*sqrt(1/FREQUENCY));
end

% This is the code to plot the GBM modelling results in the GUI
axes(handles.axes1)
TIMELINE_VECTOR = (1/FREQUENCY:1/FREQUENCY:TIMEFRAME);
plot(TIMELINE_VECTOR,WORLD_OIL_PRICE)
title('Oil Price Simulator Output')
xlabel('Years into future')
ylabel('Price of Oil ($USD)')
set(hObject, 'toolbar', 'figure')
guidata(hObject, handles);


% --------------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% --------------------------------------------------------------------------------------
% If the user presses "Continue", the window is closed and the next part of the
% simulation is initialised.
function pushbutton1_Callback(hObject, eventdata, handles)
global RETAIL_FUEL_PRICES WORLD_OIL_PRICE
close
GUI_4;

% If the user presses "Cancel", the window is closed, the simulation is cancelled and
% all the variables are deleted.
function pushbutton2_Callback(hObject, eventdata, handles)
close
clear all

% If the user presses "Rerun Price Simulation", the GUI is restarted, causing the GBM
% simulation to run again, and the new results to be graphed onscreen.
function pushbutton3_Callback(hObject, eventdata, handles)
close
GUI_3b

% If the user presses "Return to Preferences", the model is returned to the
% very beginning and starts again
function pushbutton4_Callback(hObject, eventdata, handles)
close
clear all
Module_One_Start
```

GUI_4.m

```
function varargout = GUI_4(varargin)
% This function contains the underlying code for the GUI_4.fig GUI

% --------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% --------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_4_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_4_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% --------------------------------------------------------------------------------------
% SETTING UP THE GUI
% --------------------------------------------------------------------------------------
% --- Executes just before GUI_4 is made visible.
function GUI_4_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
global CO2_EMISSIONS_PRICE  FREQUENCY TIMEFRAME
CO2_EMISSIONS_PRICE = ones(1,FREQUENCY*TIMEFRAME);
set(handles.uipanel16,'SelectionChangeFcn',@uipanel16_SelectionChangeFcn);
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = GUI_4_OutputFcn(hObject, eventdata, handles)
```

```
varargout{1} = handles.output;

% ------------------------------------------------------------------------------------
% APPLYING CHANGES MADE BY THE USER
% ------------------------------------------------------------------------------------
function checkbox4_Callback(hObject, eventdata, handles)
global UNIVERSAL_RUC_SCHEME
UNIVERSAL_RUC_SCHEME = get(hObject, 'Value');

 % --- Executes when selected object is changed in uipanel16.
function uipanel16_SelectionChangeFcn(hObject, eventdata, handles)
handles = guidata(hObject);
global CO2_EMISSIONS_PRICE FREQUENCY TIMEFRAME
switch get(eventdata.NewValue,'Tag')
    case 'radiobutton24'
        CO2_EMISSIONS_PRICE = ones(1,FREQUENCY*TIMEFRAME);
    case 'radiobutton25'
        CO2_EMISSIONS_PRICE = zeros(1,FREQUENCY*TIMEFRAME);
end
guidata(hObject, handles);

% ------------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% ------------------------------------------------------------------------------------
% --- Executes on button press in pushbutton5, the "Continue" button. This continues on
% to the next part of the simulation.
function pushbutton5_Callback(hObject, eventdata, handles)
global CO2_EMISSIONS_PRICE EXPANDED_CO2_EMISSIONS_PRICE FREQUENCY TIMEFRAME...
       WORLD_OIL_PRICE RETAIL_FUEL_PRICES

if CO2_EMISSIONS_PRICE == zeros(1,FREQUENCY*TIMEFRAME);
    EXPANDED_CO2_EMISSIONS_PRICE = zeros(1, (FREQUENCY*TIMEFRAME) + (FREQUENCY*43) );
    % Passing on the CO2 price information, along with the oil price series developed
    %in GUI4, to the Retail_Fuel_Prices_Finder function
    RETAIL_FUEL_PRICES = Retail_Fuel_Prices_Finder(WORLD_OIL_PRICE, CO2_EMISSIONS_PRICE);
    close
    Module_Two_Start
else close
    GUI_5
end

% --- Executes on button press in pushbutton6, the "Cancel Simulation" button. This
% closes the simulation and deletes all variables.
function pushbutton6_Callback(hObject, eventdata, handles)
close
clear all
```

GUI_5.m

```
function varargout = GUI_5(varargin)
% This function contains the underlying code for the GUI_5.fig GUI

% ------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% ------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_5_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_5_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% ------------------------------------------------------------------------------------
% SETTING UP THE GUI
% ------------------------------------------------------------------------------------
% --- Executes just before GUI_5 is made visible.
function GUI_5_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
% Ensuring that when radiobuttons are changed, there will be a variable change
set(handles.uipanel1,'SelectionChangeFcn',@uipanel1_SelectionChangeFcn);
axes(handles.axes1)

% Graphs the IEA's Current_Policies_Scenario for CO2 pricing
load CO2_Price_Preset_Scenarios.mat

scenarios_timeline = (1:25);
plot(scenarios_timeline,Current_Policies_Scenario)
```

```
title('Current Policies Scenario')
xlabel('Years into future')
ylabel('CO2 Emissions Price ($NZD/ tonne)')
set(hObject, 'toolbar', 'figure')
guidata(hObject, handles);

% Ensuring that if the user clicks through to the next screen without changing the
% selected radio button, the IEA's "Current Policies Scenario" for CO2 prices is selected
CO2_PRICE_SCENARIO = 1;

% --- Outputs from this function are returned to the command line.
function varargout = GUI_5_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% ----------------------------------------------------------------------------------------
% APPLYING CHANGES MADE BY THE USER
% ----------------------------------------------------------------------------------------
% --- Executes when selected object is changed in uipanel1.
function uipanel1_SelectionChangeFcn(hObject, eventdata, handles)
handles = guidata(hObject);
load CO2_Price_Preset_Scenarios.mat
% Imports the scenario selected by the user as "selected_scenario"
global FREQUENCY TIMEFRAME CO2_PRICE_SCENARIO
switch get(eventdata.NewValue,'Tag')
    case 'radiobutton1'
        CO2_selected_scenario = Current_Policies_Scenario;
        CO2_selected_scenario_title = 'Current Policies Scenario';
        CO2_PRICE_SCENARIO = 1;
    case 'radiobutton2'
        CO2_selected_scenario = New_Policies_Scenario;
        CO2_selected_scenario_title = 'New Policies Scenario';
        CO2_PRICE_SCENARIO = 2;
    case 'radiobutton3'
        CO2_selected_scenario = Four_Fifty_Scenario;
        CO2_selected_scenario_title = '450 Scenario';
        CO2_PRICE_SCENARIO = 3;
    case 'radiobutton4'
        CO2_selected_scenario = NZD_25_Scenario;
        CO2_selected_scenario_title = 'NZD $25/ tonne';
        CO2_PRICE_SCENARIO = 4;
    case 'radiobutton5'
        CO2_selected_scenario = NZD_50_Scenario;
        CO2_selected_scenario_title = 'Reference (NZD $50/ tonne)';
        CO2_PRICE_SCENARIO = 5;
    case 'radiobutton6'
        CO2_selected_scenario = NZD_75_Scenario;
        CO2_selected_scenario_title = 'NZD $75/ tonne';
        CO2_PRICE_SCENARIO = 6;
    case 'radiobutton10'
        CO2_selected_scenario = NZD_100_Scenario;
        CO2_selected_scenario_title = 'NZD $100/ tonne';
        CO2_PRICE_SCENARIO = 7;
end
% Changing the graph to reflect the selected scenario
axes(handles.axes1)
CO2_scenarios_timeline = (1:25);
plot(CO2_scenarios_timeline,CO2_selected_scenario)
title(CO2_selected_scenario_title)
xlabel('Years into future')
ylabel('CO2 Emissions Price ($NZD/ tonne)')
guidata(hObject, handles);

% ----------------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% ----------------------------------------------------------------------------------------
% --- Executes on button press in pushbutton1, the "Continue Simulation" button. This
% will continue with the simulation.
function pushbutton1_Callback(hObject, eventdata, handles)
global TIMELINE_VECTOR FREQUENCY TIMEFRAME CO2_EMISSIONS_PRICE...
   CO2_PRICE_SCENARIO RETAIL_FUEL_PRICES WORLD_OIL_PRICE

TIMELINE_VECTOR = (1/FREQUENCY:1/FREQUENCY:TIMEFRAME);
CO2_EMISSIONS_PRICE = zeros(1,FREQUENCY*TIMEFRAME);

% Saving the selected scenario as the CO2_EMISSIONS_PRICE global variable.

% This is the process if one of the IEA scenarios is chosen. Note that I have converted
% the IEA's figures to New Zealand dollars using a flat exchange rate of
% $1 NZD = $0.70 USD. I also adopted a 2010 "base year" price of NZD $25/ tonne.
for t = 1:(FREQUENCY*TIMEFRAME)
    if CO2_PRICE_SCENARIO == 1
        CO2_EMISSIONS_PRICE(t) = min(64.29, (0.00071*((t-1)/FREQUENCY)^3 -...
            0.03929*((t-1)/FREQUENCY)^2 + 2.10714*((t-1)/FREQUENCY) + 25));
    elseif CO2_PRICE_SCENARIO == 2
        CO2_EMISSIONS_PRICE(t) = min(64.29, (0.00071*((t-1)/FREQUENCY)^3 -...
            0.03929*((t-1)/FREQUENCY)^2 + 2.10714*((t-1)/FREQUENCY) + 25));
    elseif CO2_PRICE_SCENARIO == 3
        if t<= (FREQUENCY*25)
```

```
            CO2_EMISSIONS_PRICE(t) = -0.00881*((t-1)/FREQUENCY)^3 +...
                0.53214*((t-1)/FREQUENCY)^2 - 1.94048*((t-1)/FREQUENCY) + 25;
        else CO2_EMISSIONS_PRICE(t) = 171.43;
        end
    end
end

% The MED's scenarios simply assume a flat CO2 price, in $NZD/ tonne:
for t = 1 : (FREQUENCY*TIMEFRAME)
    if CO2_PRICE_SCENARIO == 4
        CO2_EMISSIONS_PRICE(t) = 25;
    elseif CO2_PRICE_SCENARIO == 5
        CO2_EMISSIONS_PRICE(t) = 50;
    elseif CO2_PRICE_SCENARIO == 6
        CO2_EMISSIONS_PRICE(t) = 75;
    elseif CO2_PRICE_SCENARIO == 7
        CO2_EMISSIONS_PRICE(t) = 100;
    end
end

% Passing on the CO2 price information, along with the oil price series developed in
% GUI4, to the Retail_Fuel_Prices_Finder function
RETAIL_FUEL_PRICES = Retail_Fuel_Prices_Finder(WORLD_OIL_PRICE, CO2_EMISSIONS_PRICE);
close
Module_Two_Start;

% --- Executes on button press in pushbutton3, the "Cancel Simulation" button. This
% will close the window, end the simulation and clear all variables
function pushbutton3_Callback(hObject, eventdata, handles)
close
clear all
```

Retail_Fuel_Prices_Finder.m

```
function [retail_fuel_prices] = Retail_Fuel_Prices_Finder(world_oil_price, CO2_emissions_price)

% This stage of the simulation finds retail prices for petrol and diesel, given input
% vectors of oil prices and CO2 emissions prices. The process used to establish these
% prices, and the constants used, are derived from the MED (2011a), and the MED's
% weekly oil price monitoring data.

global UNIVERSAL_RUC_SCHEME

% ------------------------------------------------------------------------------------
% FACTORS OUTSIDE GOVERNMENT CONTROL
% ------------------------------------------------------------------------------------
% Gives the oil price in $NZD
NZD_oil_price = world_oil_price./0.70;

% Gives the importer cost, in $NZD per litre, for petrol and diesel.
petrol_importer_cost = NZD_oil_price*0.00763;
diesel_importer_cost = NZD_oil_price*0.00779;

% Assuming constant importer margins (based on 2010 averages), find the
% cost of a litre of petrol/ diesel, excluding taxes:
ex_tax_petrol_price = petrol_importer_cost + 0.174;
ex_tax_diesel_price = diesel_importer_cost + 0.194;

ex_tax_electricity_price = 0.20;

% ------------------------------------------------------------------------------------
% TAXES, WHICH THE GOVERNMENT CAN CONTROL WITHIN THIS MODEL
% ------------------------------------------------------------------------------------
% Determine the level of taxes and levies on each fuel:
diesel_taxes = 0.00375;
electricity_taxes = 0;

if UNIVERSAL_RUC_SCHEME
    petrol_taxes = 0;
else
    petrol_taxes = 0.59129;
end

% ------------------------------------------------------------------------------------
% EMISSIONS TRADING SCHEME
% ------------------------------------------------------------------------------------
% Constants: the CO2-equivalent emissions from a litre of fuel, measured in tonnes of
% CO2 equivalent. Figures from New Zealand Government (2008)

% Petrol figures weighted 80:20 in favour of 91 octane, as per observed consumption
% in 2010 MED (2011a, p. 60)
petrol_emissions_per_litre = 0.8 * (2.310*10^-3) + 0.2 * (2.367*10^-3);
diesel_emissions_per_litre = 2.670*10^-3;

% Figures are my estimate, based on MED (2011a)and MED (2011b)
electricity_emissions_per_kWh = 2*10^-4;
```

```
petrol_ETS_charge = CO2_emissions_price * petrol_emissions_per_litre;
diesel_ETS_charge = CO2_emissions_price * diesel_emissions_per_litre;
electricity_ETS_charge = CO2_emissions_price * electricity_emissions_per_kWh;

% -------------------------------------------------------------------------------------
% CONSTRUCTING RETAIL PRICES
% -------------------------------------------------------------------------------------
% Find the total ex-GST price of petrol and diesel.
ex_GST_petrol_price = ex_tax_petrol_price + petrol_taxes + petrol_ETS_charge;
ex_GST_diesel_price = ex_tax_diesel_price + diesel_taxes + diesel_ETS_charge;
ex_GST_electricity_price = ex_tax_electricity_price + electricity_taxes + electricity_ETS_charge;

% Adding in GST at 15%, find the retail petrol and diesel prices, in $NZD per litre.
retail_fuel_prices = zeros(3,size(world_oil_price,2));
retail_fuel_prices(1,:) = ex_GST_petrol_price.*1.15;
retail_fuel_prices(2,:) = ex_GST_diesel_price.*1.15;
retail_fuel_prices(3,:) = ex_GST_electricity_price.*1.15;

return
```

Module_Two_Start.m

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                              THE TRANSPORT SCENARIOS MODEL                           %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% MODULE TWO (CONTINUED): DETERMINING CHANGES IN THE VEHICLE FLEET, VKT, ENERGY USE,
% EMISSIONS...

global PLOT_ALL PER_CAPITA_GRAPHS SELECTED_GRAPHS NEW_PHEV_SUBSIDY NEW_BEV_SUBSIDY...
       BAN_USED_ADVANCED_VEHICLES BAN_USED_IMPORTS PHEVS_RUC_EXEMPT BEVS_RUC_EXEMPT...
       EFFICIENCY_SCENARIO NEW_CAR_EFFICIENCIES

PLOT_ALL = 1;            % Boolean (1 = plot all graphs offered)
PER_CAPITA_GRAPHS = 0;   % Boolean (1 = graphs 3 to 7 will be plotted on a
                         %           per capita basis if they are selected)

% The "SELECTED_GRAPHS" global variable is a 8x1 vector. Each element is set to "0" or
% "1", i.e. a boolean. A "1" means that the graph described below will be plotted.
SELECTED_GRAPHS =  [0;  % oil prices over time
                    0;  % petrol and diesel prices over time
                    0;  % vehicle fleet, by vehicle type, over time
                    0;  % VKT, by vehicle type, over time
                    0;  % consumption of petrol and diesel over time
                    0;  % consumption of electricity over time
                    0;  % CO2-equivalent emissions, by vehicle type, over time
                    0]; % The proportion of each vehicle type bought, over time

NEW_PHEV_SUBSIDY = 0;    % The subsidy applying to new PHEVs, in real (2010) dollars
NEW_BEV_SUBSIDY = 0;     % The subsidy applying to new PHEVs, in real (2010) dollars
BAN_USED_ADVANCED_VEHICLES = 0; % Boolean (1 = PHEV and BEV used imports are assumed
                         % to be banned or otherwise unavailable, and only NZ-new
                         % PHEVs and BEVs can be added to the fleet)
BAN_USED_IMPORTS = 0;    % Boolean (1 = used imports are banned, and only NZ-new
                         % vehicles can be added to the fleet)

% Note that "PHEVS_RUC_EXEMPT" has no effect unless the user has chosen to make the
% RUC scheme universal.
PHEVS_RUC_EXEMPT = 0;    % Boolean (1 = PHEVs are exempt from paying Road User Charges)
BEVS_RUC_EXEMPT = 0;     % Boolean (1 = BEVs are exempt from Road User Charges)

EFFICIENCY_SCENARIO = 0; % Different scenarios showing how fuel efficiency for "conventional" cars
will change
NEW_CAR_EFFICIENCIES = zeros(FREQUENCY*TIMEFRAME,7);

GUI_6;
```

GUI_6.m

```
function varargout = GUI_6(varargin)
% This function contains the underlying code for the GUI_6.fig GUI

% -------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% -------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_6_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_6_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
```

```
end

% ------------------------------------------------------------------------------------
% SETTING UP THE GUI
% ------------------------------------------------------------------------------------
% --- Executes just before GUI_6 is made visible.
function GUI_6_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
guidata(hObject, handles);

% --- Executes during object creation, after setting all properties.
function edit13_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes during object creation, after setting all properties.
function edit14_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Outputs from this function are returned to the command line.
function varargout = GUI_6_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% ------------------------------------------------------------------------------------
% APPLYING CHANGES MADE BY THE USER
% ------------------------------------------------------------------------------------
function edit13_Callback(hObject, eventdata, handles)
global NEW_PHEV_SUBSIDY
% Saving any subsidy that the user has chosen to apply to PHEVs
NEW_PHEV_SUBSIDY = str2double(get(hObject, 'String'));

function edit14_Callback(hObject, eventdata, handles)
global NEW_BEV_SUBSIDY
% Saving any subsidy that the user has chosen to apply to BEVs
NEW_BEV_SUBSIDY = str2double(get(hObject, 'String'));

function checkbox1_Callback(hObject, eventdata, handles)
global BAN_USED_IMPORTS
BAN_USED_IMPORTS = get(hObject, 'Value');

function checkbox3_Callback(hObject, eventdata, handles)
global PHEVS_RUC_EXEMPT
PHEVS_RUC_EXEMPT = get(hObject, 'Value');

function checkbox2_Callback(hObject, eventdata, handles)
global BEVS_RUC_EXEMPT
BEVS_RUC_EXEMPT = get(hObject, 'Value');

function checkbox6_Callback(hObject, eventdata, handles)
global BAN_USED_ADVANCED_VEHICLES
BAN_USED_ADVANCED_VEHICLES = get(hObject, 'Value')

% ------------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% ------------------------------------------------------------------------------------
% --- Executes on button press in pushbutton5, the "Continue" button. This continues on
% to the next part of the simulation.
function pushbutton5_Callback(hObject, eventdata, handles)
close
GUI_7

% --- Executes on button press in pushbutton6, the "Cancel Simulation" button. This
% closes the simulation and deletes all variables.
function pushbutton6_Callback(hObject, eventdata, handles)
close
clear all
```

GUI_7.m

```
function varargout = GUI_7(varargin)
% This function contains the underlying code for the GUI_7.fig GUI

% ------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% ------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_7_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_7_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end
```

```
if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% -------------------------------------------------------------------------------------
% SETTING UP THE GUI
% -------------------------------------------------------------------------------------
% --- Executes just before GUI_7 is made visible.
function GUI_7_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;

global POPULATION_PROJECTION TIMELINE_VECTOR FREQUENCY TIMEFRAME

% Ensuring that when radiobuttons are changed, there will be a variable change
set(handles.uipanel1,'SelectionChangeFcn',@uipanel1_SelectionChangeFcn);

Low_Population_Projection = zeros(1,FREQUENCY*TIMEFRAME);
Medium_Population_Projection = zeros(1,FREQUENCY*TIMEFRAME);
High_Population_Projection = zeros(1,FREQUENCY*TIMEFRAME);

for t = 1:FREQUENCY*TIMEFRAME
    Low_Population_Projection(t) = 4386000 + 31422*t/FREQUENCY - 437.8*(t/FREQUENCY)^2;
    Medium_Population_Projection(t) = 4388000 + 42400*t/FREQUENCY - 309.9*(t/FREQUENCY)^2;
    High_Population_Projection(t) = 4393000 + 52551*t/FREQUENCY - 144.2*(t/FREQUENCY)^2;
end

% Plotting SNZ's medium population projections
axes(handles.axes1)
scenarios_timeline = (TIMELINE_VECTOR);
plot(TIMELINE_VECTOR, Medium_Population_Projection)
title('SNZ Medium Population Projections')
xlabel('Years into future')
ylabel('Population')
set(hObject, 'toolbar', 'figure')
guidata(hObject, handles);

% Ensuring that if the user clicks through to the next screen without changing the
% selected radio button, the IEA's "Current Policies Scenario" is selected
POPULATION_PROJECTION = 2;

% --- Outputs from this function are returned to the command line.
function varargout = GUI_7_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% -------------------------------------------------------------------------------------
% APPLYING CHANGES MADE BY THE USER
% -------------------------------------------------------------------------------------
% --- Executes when selected object is changed in uipanel1.
function uipanel1_SelectionChangeFcn(hObject, eventdata, handles)
handles = guidata(hObject);

global POPULATION_PROJECTION TIMELINE_VECTOR FREQUENCY TIMEFRAME

Low_Population_Projection = zeros(1,FREQUENCY*TIMEFRAME);
Medium_Population_Projection = zeros(1,FREQUENCY*TIMEFRAME);
High_Population_Projection = zeros(1,FREQUENCY*TIMEFRAME);

for t = 1:FREQUENCY*TIMEFRAME
    Low_Population_Projection(t) = 4386000 + 31422*t/FREQUENCY - 437.8*(t/FREQUENCY)^2;
    Medium_Population_Projection(t) = 4388000 + 42400*t/FREQUENCY - 309.9*(t/FREQUENCY)^2;
    High_Population_Projection(t) = 4393000 + 52551*t/FREQUENCY - 144.2*(t/FREQUENCY)^2;
end

% Imports the projection selected by the user as "selected_projection"
switch get(eventdata.NewValue,'Tag')
    case 'radiobutton2'
        selected_projection = Low_Population_Projection;
        selected_projection_title = 'SNZ Low Population Projections';
        POPULATION_PROJECTION = 1;
    case 'radiobutton1'
        selected_projection = Medium_Population_Projection;
        selected_projection_title = 'SNZ Medium Population Projections';
        POPULATION_PROJECTION = 2;
    case 'radiobutton3'
        selected_projection = High_Population_Projection;
        selected_projection_title = 'SNZ High Population Projections';
        POPULATION_PROJECTION = 3;
end
% Changing the graph to reflect the selected scenario
axes(handles.axes1)
plot(TIMELINE_VECTOR,selected_projection)
title(selected_projection_title)
guidata(hObject, handles);

% -------------------------------------------------------------------------------------
```

```
% BUTTONS TO EXIT THE GUI
% --------------------------------------------------------------------------------------
% --- Executes on button press in pushbutton1, the "Continue Simulation" button. This
% continues with the simulation.
function pushbutton1_Callback(hObject, eventdata, handles)
close
GUI_8;

% --- Executes on button press in pushbutton2, the "Return to previous screen" button.
% This will close the window and go back to the previous GUI screen.
function pushbutton2_Callback(hObject, eventdata, handles)
global POPULATION_PROJECTION
POPULATION_PROJECTION = 2;
close
GUI_6;

% --- Executes on button press in pushbutton3, the "Cancel Simulation" button. This will
% close the window, end the simulation and clear all variables
function pushbutton3_Callback(hObject, eventdata, handles)
close
clear all
```

GUI_8.m

```
function varargout = GUI_8(varargin)
% This function contains the underlying code for the GUI_8.fig GUI

% --------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% --------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_8_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_8_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% --------------------------------------------------------------------------------------
% SETTING UP THE GUI
% --------------------------------------------------------------------------------------
% --- Executes just before GUI_8 is made visible.
function GUI_8_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;

global ICEV_EFFICIENCY_SCENARIO FREQUENCY

% Ensuring that when radiobuttons are changed, there will be a variable change
set(handles.uipanel1,'SelectionChangeFcn',@uipanel1_SelectionChangeFcn);
% Plotting the "20% improvement by 2030" scenario
axes(handles.axes1)
scenarios_timeline = (0:1/FREQUENCY:20);
fuel_efficiency = (10:-0.1/FREQUENCY:8);
plot(scenarios_timeline,fuel_efficiency)
title('20% improvement by 2030 scenario')
xlabel('Years into future')
ylabel('New Medium Petrol Car Fuel Efficiency (L/ 100 km)')
set(hObject, 'toolbar', 'figure')
guidata(hObject, handles);

% Ensuring that if the user clicks through to the next screen without changing the
% selected radio button, the IEA's "Current Policies Scenario" is selected
ICEV_EFFICIENCY_SCENARIO = 1;

% --- Outputs from this function are returned to the command line.
function varargout = GUI_8_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% --------------------------------------------------------------------------------------
% APPLYING CHANGES MADE BY THE USER
% --------------------------------------------------------------------------------------
% --- Executes when selected object is changed in uipanel1.
function uipanel1_SelectionChangeFcn(hObject, eventdata, handles)
handles = guidata(hObject);

% Stores the fuel efficiency scenario chosen by the user as "selected_scenario"
global FREQUENCY ICEV_EFFICIENCY_SCENARIO
switch get(eventdata.NewValue,'Tag')
    case 'radiobutton1'
```

```
        selected_scenario = (10:-0.1/FREQUENCY:8);
        selected_scenario_title = '20% improvement by 2030 scenario';
        scenarios_timeline = (0:1/FREQUENCY:20);
        ICEV_EFFICIENCY_SCENARIO = 1;
    case 'radiobutton2'
        selected_scenario = (10:-0.15/FREQUENCY:7);
        selected_scenario_title = '30% improvement by 2030 scenario';
        scenarios_timeline = (0:1/FREQUENCY:20);
        ICEV_EFFICIENCY_SCENARIO = 2;
    case 'radiobutton3'
        selected_scenario = (10:-0.2/FREQUENCY:6);
        selected_scenario_title = '40% improvement by 2030 scenario';
        scenarios_timeline = (0:1/FREQUENCY:20);
        ICEV_EFFICIENCY_SCENARIO = 3;
    case 'radiobutton4'
        selected_scenario = (10:-0.05/FREQUENCY:8);
        selected_scenario_title = '20% improvement by 2050 scenario';
        scenarios_timeline = (0:1/FREQUENCY:40);
        ICEV_EFFICIENCY_SCENARIO = 4;
    case 'radiobutton5'
        selected_scenario = (10:-0.075/FREQUENCY:7);
        selected_scenario_title = '30% improvement by 2050 scenario';
        scenarios_timeline = (0:1/FREQUENCY:40);
        ICEV_EFFICIENCY_SCENARIO = 5;
    case 'radiobutton6'
        selected_scenario = (10:-0.1/FREQUENCY:6);
        selected_scenario_title = '40% improvement by 2050 scenario';
        scenarios_timeline = (0:1/FREQUENCY:40);
        ICEV_EFFICIENCY_SCENARIO = 6;
end
% Changing the graph to reflect the selected scenario
axes(handles.axes1)
plot(scenarios_timeline,selected_scenario)
title(selected_scenario_title)
xlabel('Years into future')
ylabel('New Medium Petrol Car Fuel Efficiency (L/ 100 km)')
guidata(hObject, handles);

% -----------------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% -----------------------------------------------------------------------------------------
% --- Executes on button press in pushbutton1, the "Continue Simulation" button. This
% finalises the fuel efficiency scenario, and then continues with the simulation.
function pushbutton1_Callback(hObject, eventdata, handles)
global ICEV_EFFICIENCY_SCENARIO NEW_CAR_EFFICIENCIES FREQUENCY TIMEFRAME
initial_efficiencies = [7.5 10.0 12.5 7.0 9.5 3.0 0.0];
NEW_CAR_EFFICIENCIES = zeros(FREQUENCY*TIMEFRAME,7);

if ICEV_EFFICIENCY_SCENARIO == 1
    if TIMEFRAME <= 20
        for t = 1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.2*t/(FREQUENCY*20));
        end
    else for t = 1:FREQUENCY*20
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.2*t/(FREQUENCY*20));
        end
        for t = FREQUENCY*20+1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = NEW_CAR_EFFICIENCIES(FREQUENCY*20,:);
        end
    end
end

if ICEV_EFFICIENCY_SCENARIO == 2
    if TIMEFRAME <= 20
        for t = 1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.3*t/(FREQUENCY*20));
        end
    else for t = 1:FREQUENCY*20
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.3*t/(FREQUENCY*20));
        end
        for t = FREQUENCY*20+1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = NEW_CAR_EFFICIENCIES(FREQUENCY*20,:);
        end
    end
end

if ICEV_EFFICIENCY_SCENARIO == 3
    if TIMEFRAME <= 20
        for t = 1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.4*t/(FREQUENCY*20));
        end
    else for t = 1:FREQUENCY*20
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.4*t/(FREQUENCY*20));
        end
        for t = FREQUENCY*20+1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = NEW_CAR_EFFICIENCIES(FREQUENCY*20,:);
        end
    end
```

```
end

if ICEV_EFFICIENCY_SCENARIO == 4
    if TIMEFRAME <= 40
        for t = 1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.2*t/(FREQUENCY*40));
        end
    else for t = 1:FREQUENCY*40
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.2*t/(FREQUENCY*40));
        end
        for t = FREQUENCY*40+1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = NEW_CAR_EFFICIENCIES(FREQUENCY*40,:);
        end
    end
end

if ICEV_EFFICIENCY_SCENARIO == 5
    if TIMEFRAME <= 40
        for t = 1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.3*t/(FREQUENCY*40));
        end
    else for t = 1:FREQUENCY*40
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.3*t/(FREQUENCY*40));
        end
        for t = FREQUENCY*40+1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = NEW_CAR_EFFICIENCIES(FREQUENCY*40,:);
        end
    end
end

if ICEV_EFFICIENCY_SCENARIO == 6
    if TIMEFRAME <= 40
        for t = 1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.4*t/(FREQUENCY*40));
        end
    else for t = 1:FREQUENCY*40
            NEW_CAR_EFFICIENCIES(t,:) = initial_efficiencies*(1-0.4*t/(FREQUENCY*40));
        end
        for t = FREQUENCY*40+1 : FREQUENCY*TIMEFRAME
            NEW_CAR_EFFICIENCIES(t,:) = NEW_CAR_EFFICIENCIES(FREQUENCY*40,:);
        end
    end
end

close
GUI_9;

% --- Executes on button press in pushbutton2, the "Return to previous screen" button.
% This will close the window, clear ICEV_EFFICIENCY_SCENARIO and go back to the GUI_7 screen.
function pushbutton2_Callback(hObject, eventdata, handles)

global ICEV_EFFICIENCY_SCENARIO
close
ICEV_EFFICIENCY_SCENARIO = 0;
GUI_7

% --- Executes on button press in pushbutton3, the "Cancel Simulation" button. This will
% close the window, end the simulation and clear all variables
function pushbutton3_Callback(hObject, eventdata, handles)
close
clear all
```

GUI_9.m

```
function varargout = GUI_9(varargin)
% This function contains the underlying code for the GUI_9.fig GUI

% ------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% ------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_9_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_9_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% ------------------------------------------------------------------------------------
```

```
% SETTING UP THE GUI
% ---------------------------------------------------------------------------------------
% --- Executes just before GUI_9 is made visible.
function GUI_9_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;

global BATTERY_COST_SCENARIO FREQUENCY

% Ensuring that when radiobuttons are changed, there will be a variable change
set(handles.uipanel1,'SelectionChangeFcn',@uipanel1_SelectionChangeFcn);
% Plotting the DOE (2010) scenario for BEV battery costs
axes(handles.axes1)
scenarios_timeline = (1/FREQUENCY:1/FREQUENCY:20);

BEV_battery_cost = zeros(1,20*FREQUENCY);

for time = 1:20*FREQUENCY
    BEV_battery_cost(time) = 32294.01*(time/FREQUENCY)^-0.75;
end

semilogy(scenarios_timeline,BEV_battery_cost)
title('DOE (2010) battery cost scenario')
xlabel('Years into future')
ylabel('BEV Battery Cost ($USD)')
set(hObject, 'toolbar', 'figure')
guidata(hObject, handles);

% Ensuring that if the user clicks through to the next screen without changing the
% selected radio button, the DOE (2010) scenario is selected
BATTERY_COST_SCENARIO = 2;

% --- Outputs from this function are returned to the command line.
function varargout = GUI_9_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% ---------------------------------------------------------------------------------------
% APPLYING CHANGES MADE BY THE USER
% ---------------------------------------------------------------------------------------
% --- Executes when selected object is changed in uipanel1.
function uipanel1_SelectionChangeFcn(hObject, eventdata, handles)
handles = guidata(hObject);

% Stores the fuel efficiency scenario chosen by the user as "BATTERY_COST_SCENARIO"
global FREQUENCY BATTERY_COST_SCENARIO

BEV_battery_cost = zeros(1,20*FREQUENCY);

switch get(eventdata.NewValue,'Tag')
    case 'radiobutton2'
        for time = 1:20*FREQUENCY
            BEV_battery_cost(time) = 25000*(time/FREQUENCY)^-0.904;
        end

        selected_scenario_title = '$50/ kWh by 2030 scenario';

        scenarios_timeline = (1/FREQUENCY:1/FREQUENCY:20);
        BATTERY_COST_SCENARIO = 1;

    case 'radiobutton1'
        for time = 1:20*FREQUENCY
            BEV_battery_cost(time) = 32294.01*(time/FREQUENCY)^-0.75;
        end

        selected_scenario_title = 'DOE (2010) scenario: $100/ kWh by 2030';
        scenarios_timeline = (1/FREQUENCY:1/FREQUENCY:20);
        BATTERY_COST_SCENARIO = 2;

    case 'radiobutton3'
        for time = 1:20*FREQUENCY
            BEV_battery_cost(time) = 25000*(time/FREQUENCY)^-0.306;
        end

        selected_scenario_title = '$300/ kWh by 2030 scenario';

        scenarios_timeline = (1/FREQUENCY:1/FREQUENCY:20);
        BATTERY_COST_SCENARIO = 3;

    case 'radiobutton5'
        for time = 1:40*FREQUENCY
            BEV_battery_cost(time) = 25000*(time/FREQUENCY)^-0.734;
        end

        selected_scenario_title = '$50/ kWh by 2050 scenario';

        scenarios_timeline = (1/FREQUENCY:1/FREQUENCY:40);
        BATTERY_COST_SCENARIO = 4;

    case 'radiobutton4'
```

```
        for time = 1:40*FREQUENCY
            BEV_battery_cost(time) = 25000*(time/FREQUENCY)^-0.546;
        end

        selected_scenario_title = '$100/ kWh by 2050 scenario';

        scenarios_timeline = (1/FREQUENCY:1/FREQUENCY:40);
        BATTERY_COST_SCENARIO = 5;

    case 'radiobutton6'
        for time = 1:40*FREQUENCY
            BEV_battery_cost(time) = 25000*(time/FREQUENCY)^-0.248;
        end

        selected_scenario_title = '$300/ kWh by 2050 scenario';

        scenarios_timeline = (1/FREQUENCY:1/FREQUENCY:40);
        BATTERY_COST_SCENARIO = 6;

end
% Changing the graph to reflect the selected scenario
axes(handles.axes1)
semilogy(scenarios_timeline,BEV_battery_cost)
title(selected_scenario_title)
guidata(hObject, handles);

% ------------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% ------------------------------------------------------------------------------------
% --- Executes on button press in pushbutton1, the "Continue Simulation" button. This
% finalises the fuel efficiency scenario, and then continues with the simulation.
function pushbutton1_Callback(hObject, eventdata, handles)

close
GUI_10;

% --- Executes on button press in pushbutton2, the "Return to previous screen" button.
% This will close the window, clear EFFICIENCY_SCENARIO and go back to the GUI_7 screen.
function pushbutton2_Callback(hObject, eventdata, handles)

global BATTERY_COST_SCENARIO
close
BATTERY_COST_SCENARIO = 0;
GUI_8

% --- Executes on button press in pushbutton3, the "Cancel Simulation" button. This will
% close the window, end the simulation and clear all variables
function pushbutton3_Callback(hObject, eventdata, handles)
close
clear all
```

GUI_10.m

```
function varargout = GUI_10(varargin)
% This function contains the underlying code for the GUI_10.fig GUI

% ------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% ------------------------------------------------------------------------------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_10_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_10_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% ------------------------------------------------------------------------------------
% SETTING UP THE GUI
% ------------------------------------------------------------------------------------
% --- Executes just before GUI_10 is made visible.
function GUI_10_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
% Setup required for if the user elects to only select some of the plots for outputting
set(handles.uipanel1,'SelectionChangeFcn',@uipanel1_SelectionChangeFcn);
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = GUI_10_OutputFcn(hObject, eventdata, handles)
```

```
varargout{1} = handles.output;

% -------------------------------------------------------------------------------------
% DETERMINES WHICH GRAPHS TO PLOT, IF THE USER HAS NOT DECIDED TO "PLOT ALL"
% -------------------------------------------------------------------------------------
% --- Executes on button press in checkbox1.
function checkbox1_Callback(hObject, eventdata, handles)
global SELECTED_GRAPHS
SELECTED_GRAPHS(1) = get(hObject, 'Value');

% --- Executes on button press in checkbox2.
function checkbox2_Callback(hObject, eventdata, handles)
global SELECTED_GRAPHS
SELECTED_GRAPHS(2) = get(hObject, 'Value');

% --- Executes on button press in checkbox3.
function checkbox3_Callback(hObject, eventdata, handles)
global SELECTED_GRAPHS
SELECTED_GRAPHS(3) = get(hObject, 'Value');

% --- Executes on button press in checkbox4.
function checkbox4_Callback(hObject, eventdata, handles)
global SELECTED_GRAPHS
SELECTED_GRAPHS(4) = get(hObject, 'Value');

% --- Executes on button press in checkbox5.
function checkbox5_Callback(hObject, eventdata, handles)
global SELECTED_GRAPHS
SELECTED_GRAPHS(5) = get(hObject, 'Value');

% --- Executes on button press in checkbox6.
function checkbox6_Callback(hObject, eventdata, handles)
global SELECTED_GRAPHS
SELECTED_GRAPHS(6) = get(hObject, 'Value');

% --- Executes on button press in checkbox7.
function checkbox7_Callback(hObject, eventdata, handles)
global SELECTED_GRAPHS
SELECTED_GRAPHS(7) = get(hObject, 'Value');

% --- Executes on button press in checkbox12.
function checkbox12_Callback(hObject, eventdata, handles)
global PER_CAPITA_GRAPHS
PER_CAPITA_GRAPHS = get(hObject, 'Value');

% --- Executes on button press in checkbox13.
function checkbox13_Callback(hObject, eventdata, handles)
global SELECTED_GRAPHS
SELECTED_GRAPHS(8) = get(hObject, 'Value');

% --- Executes when selected object is changed in uipanel1.
function uipanel1_SelectionChangeFcn(hObject, eventdata, handles)
handles = guidata(hObject);
global PLOT_ALL
% Enabling or disabling the check boxes depending on whether "Plot All" is selected
switch get(eventdata.NewValue,'Tag')
    case 'radiobutton1'
      set(handles.checkbox1,'Enable','on');
      set(handles.checkbox2,'Enable','on');
      set(handles.checkbox3,'Enable','on');
      set(handles.checkbox4,'Enable','on');
      set(handles.checkbox5,'Enable','on');
      set(handles.checkbox6,'Enable','on');
      set(handles.checkbox7,'Enable','on');
      set(handles.checkbox13,'Enable','on');
      PLOT_ALL = 0;
    case 'radiobutton2'
      set(handles.checkbox1,'Enable','off');
      set(handles.checkbox2,'Enable','off');
      set(handles.checkbox3,'Enable','off');
      set(handles.checkbox4,'Enable','off');
      set(handles.checkbox5,'Enable','off');
      set(handles.checkbox6,'Enable','off');
      set(handles.checkbox7,'Enable','off');
      set(handles.checkbox7,'Enable','off');
      PLOT_ALL = 1;
end
guidata(hObject, handles);

% -------------------------------------------------------------------------------------
% BUTTONS TO EXIT THE GUI
% -------------------------------------------------------------------------------------
% --- Executes on button press in pushbutton1, the "Continue" button. This will continue
% with the simulation.
function pushbutton1_Callback(hObject, eventdata, handles)
    close
    Module_Two_Continued;
```

```
% --- Executes on button press in pushbutton2, the "Cancel Simulation" button. This will
% close the window, end the simulation and clear all variables
function pushbutton2_Callback(hObject, eventdata, handles)
close
clear all
```

Module_Two_Continued.m

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                              THE TRANSPORT SCENARIOS MODEL                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% MODULE TWO (CONTINUED): DETERMINING CHANGES IN THE VEHICLE FLEET, VKT, ENERGY USE,
% EMISSIONS...

global PLOT_ALL SELECTED_GRAPHS PER_CAPITA_GRAPHS TIMEFRAME FREQUENCY...
    RETAIL_FUEL_PRICES WORLD_OIL_PRICE DESCRIPTION_STRING...
    DATA_MATRIX DATA1 DATA2 DATA3 DATA4 DATA5 DATA6 DATA7 DATA8 Y_AXIS_LABEL TITLE_LABEL...
    PLOT_INDICATOR LEGEND_LABEL POPULATION_PROJECTION

% ---------------------------------------------------------------------------------------
% ESTABLISHING THE POPULATION PROJECTIONS THAT WILL BE USED IN THE MODEL
% ---------------------------------------------------------------------------------------
% These are formulaic representations of SNZ's 2009-base national population projections
% and are available at:
%    http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/
%    NationalPopulationProjections_HOTP09base-61.aspx
population = zeros(1,(FREQUENCY*TIMEFRAME));

if POPULATION_PROJECTION == 1
    for t=1:(FREQUENCY*TIMEFRAME)
        population(t) = 4386000 + 31422*t/FREQUENCY - 437.8*(t/FREQUENCY)^2;
    end
elseif POPULATION_PROJECTION == 2
    for t=1:(FREQUENCY*TIMEFRAME)
        population(t) = 4388000 + 42400*t/FREQUENCY - 309.9*(t/FREQUENCY)^2;
    end
else for t=1:(FREQUENCY*TIMEFRAME)
        population(t) = 4393000 + 52551*t/FREQUENCY - 144.2*(t/FREQUENCY)^2;
    end
end

% ---------------------------------------------------------------------------------------
% MOVING TO THE MOST IMPORTANT PART OF THE SIMULATION - THE VEHICLE FLEET FUNCTION
% ---------------------------------------------------------------------------------------
% The Vehicle_Fleet_Function keeps track of the number of vehicles in the fleet over the
% simulation timeframe, along with the distance they travel.
[vehicle_fleet_tracker,VKT_tracker,proportions_tracker, fuel_demand_tracker, emissions_tracker]
         = Vehicle_Fleet_Function(population);

% ---------------------------------------------------------------------------------------
% ADJUSTING GRAPHS DEPENDING ON WHETHER THEY ARE "PER CAPITA" OR FOR THE OVERALL COUNTRY
% ---------------------------------------------------------------------------------------
if PER_CAPITA_GRAPHS
    for type = 1:7
        vehicle_fleet_tracker(:,type) = vehicle_fleet_tracker(:,type) ./ population(:);
        VKT_tracker(:,type) = VKT_tracker(:,type) ./ population(:);
        emissions_tracker(:,type) = emissions_tracker(:,type) ./ population(:);
    end

    for t=1:(FREQUENCY*TIMEFRAME)
        fuel_demand_tracker(1,t) = fuel_demand_tracker(1,t) ./ population(t);
        fuel_demand_tracker(2,t) = fuel_demand_tracker(2,t) ./ population(t);
        fuel_demand_tracker(3,t) = fuel_demand_tracker(3,t) ./ population(t);
    end
else
    % Converting litres to megalitres and kWh to GWh
    fuel_demand_tracker = fuel_demand_tracker ./ 1000000;
    % Converting "kilometres travelled" to "millions of kilometres travelled"
    VKT_tracker = VKT_tracker ./ 1000000;
end

% ---------------------------------------------------------------------------------------
% SETTING UP THE GRAPHS
% ---------------------------------------------------------------------------------------
% If the user has selected "plot all", all graphs are selected
if (PLOT_ALL)
    SELECTED_GRAPHS(:) = 1;
end

% These data arrays hold the variables that will be plotted on the y axis of the graphs
DATA1 = transpose(WORLD_OIL_PRICE);
DATA2 = [transpose(RETAIL_FUEL_PRICES(1,:)) transpose(RETAIL_FUEL_PRICES(2,:))];
DATA3 = vehicle_fleet_tracker;
DATA4 = VKT_tracker;
DATA5 = [transpose(fuel_demand_tracker(1,:)) transpose(fuel_demand_tracker(2,:))];
DATA6 = transpose(fuel_demand_tracker(3,:));
DATA7 = emissions_tracker;
DATA8 = proportions_tracker;
```

```
% ----------------------------------------------------------------------------------------
% PLOTTING THE GRAPHS WHICH THE USER HAS SELECTED
% ----------------------------------------------------------------------------------------
if SELECTED_GRAPHS(1) == 1
    DESCRIPTION_STRING = 'The plot shows the projected world price of oil (in $USD/ barrel)';
    DATA_MATRIX = DATA1;
    Y_AXIS_LABEL = 'Oil Price ($USD)';
    TITLE_LABEL = 'World Oil Prices';
    LEGEND_LABEL = {'World Oil Price'};
    PLOT_INDICATOR = 1;
    GUI_Output
end

if SELECTED_GRAPHS(2) == 1
    DESCRIPTION_STRING = 'The plot shows projected retail prices for petrol and diesel (in $NZD/
    litre)';
    DATA_MATRIX = DATA2;
    Y_AXIS_LABEL = 'Retail Prices for Petrol/ Diesel ($NZD/ litre)';
    TITLE_LABEL = 'Retail Prices for Petrol and Diesel';
    LEGEND_LABEL = {'Retail Petrol Price','Retail Diesel Price'};
    PLOT_INDICATOR = 2;
    GUI_Output
end

if SELECTED_GRAPHS(3) == 1
    DESCRIPTION_STRING = 'The plot shows the projected number of vehicles in the fleet, broken
    down by vehicle type';
    DATA_MATRIX = DATA3;
    Y_AXIS_LABEL = 'Vehicle Fleet';
    TITLE_LABEL = 'Estimated Vehicle Fleet';
    LEGEND_LABEL = {'Small Petrol Cars','Medium Petrol Cars','Large Petrol Cars',...
        'Small Diesel Cars','Large Diesel Cars','PHEV Cars','BEV Cars'};
    PLOT_INDICATOR = 3;
    GUI_Output;
end

if SELECTED_GRAPHS(4) == 1
    DESCRIPTION_STRING = 'This plot shows projected vehicle kilometres travelled (VKT), broken
    down by vehicle type';
    DATA_MATRIX = DATA4;
    if PER_CAPITA_GRAPHS
        Y_AXIS_LABEL = 'VKT (kilometres per period)';
    else Y_AXIS_LABEL = 'VKT (millions of kilometres per period)';
    end
    TITLE_LABEL = 'Vehicle Kilometres Travelled by Vehicle Type';
    LEGEND_LABEL = {'Small Petrol Cars','Medium Petrol Cars','Large Petrol Cars',...
        'Small Diesel Cars','Large Diesel Cars','PHEV Cars','BEV Cars'};
    PLOT_INDICATOR = 4;
    GUI_Output;
end

if SELECTED_GRAPHS(5) == 1
    DESCRIPTION_STRING = 'The plot shows projected consumption of petrol and diesel';
    DATA_MATRIX = DATA5;
    if PER_CAPITA_GRAPHS
        Y_AXIS_LABEL = 'Consumption (litres per period)';
    else Y_AXIS_LABEL = 'Consumption (millions of litres per period)';
    end
    TITLE_LABEL = 'Petrol and Diesel Consumption';
    LEGEND_LABEL = {'Petrol Consumption','Diesel Consumption'};
    PLOT_INDICATOR = 5;
    GUI_Output;
end

if SELECTED_GRAPHS(6) == 1
    DESCRIPTION_STRING = 'This plot shows projected consumption of electricity by PHEVs and BEVs';
    DATA_MATRIX = DATA6;
    if PER_CAPITA_GRAPHS
        Y_AXIS_LABEL = 'Electricity Consumption by PHEVs and BEVs (kWh per period)';
    else Y_AXIS_LABEL = 'Electricity Consumption by PHEVs and BEVs (GWh per period)';
    end
    TITLE_LABEL = 'Electricity Consumption';
    LEGEND_LABEL = {'Electricity Consumption'};
    PLOT_INDICATOR = 6;
    GUI_Output;
end

if SELECTED_GRAPHS(7) == 1
    DESCRIPTION_STRING = 'This plot shows projected CO2-equivalent emissions, broken down by
    vehicle type';
    DATA_MATRIX = DATA7;
    Y_AXIS_LABEL = 'CO2-Equivalent Emissions (tonnes CO2-e per period)';
    TITLE_LABEL = 'CO2-Equivalent Emissions';
    LEGEND_LABEL = {'Small Petrol Cars','Medium Petrol Cars','Large Petrol Cars',...
        'Small Diesel Cars','Large Diesel Cars','PHEV Cars','BEV Cars'};
    PLOT_INDICATOR = 7;
    GUI_Output;
```

```
end

if SELECTED_GRAPHS(8) == 1
    DESCRIPTION_STRING = 'This plot shows the proportion of each type of car entering the fleet
    each period';
    DATA_MATRIX = DATA8;
    Y_AXIS_LABEL = 'Proportion';
    TITLE_LABEL = 'Proportion of Vehicle Sales';
    LEGEND_LABEL = {'New Small Petrol Cars','New Medium Petrol Cars','New Large Petrol Cars',...
        'New Small Diesel Cars','New Large Diesel Cars','New PHEV Cars','New BEV Cars','Used Small
Petrol Cars','Used Medium Petrol Cars','Used Large Petrol Cars',...
        'Used Small Diesel Cars','Used Large Diesel Cars','Used PHEV Cars','Used BEV Cars'};
    PLOT_INDICATOR = 8;
    GUI_Output;
end

% ------------------------------------------------------------------------------------
% END OF MODEL
% ------------------------------------------------------------------------------------
```

Vehicle_Fleet_Function.m

```
% This is a very important function. It does the following:
% 1) Initialises the vehicle fleet, using MOT data
% 2) At the start of each period, increments the age of each vehicle in the fleet by one
% 3) At the end of each period, estimates which old vehicles get scrapped.
% 4) At the end of each period, estimates the total number of new vehicles, and calls
%    the "New_Vehicle_Proportions" function to determine how many of each type is added.

function [vehicle_fleet_tracker,VKT_tracker,proportions_tracker, fuel_demand_tracker,
emissions_tracker] = Vehicle_Fleet_Function(population)

global FREQUENCY TIMEFRAME RETAIL_FUEL_PRICES NEW_CAR_EFFICIENCIES

% ------------------------------------------------------------------------------------
% INPUTTING THE NUMBER, AGE AND TYPE OF VEHICLES IN THE FLEET AS AT 31 DECEMBER 2010
% ------------------------------------------------------------------------------------
% Loads the MOT_Fleet_Data.mat file. This file contains information on the number, type
% and age (in years) of vehicles in the fleet as at 31st December 2010. This information
% is adjusted for the simulation frequency and saved as the "initial_vehicle_fleet"
% array (later on, this gets updated each period to reflect changes in the fleet).
initial_vehicle_fleet = zeros(FREQUENCY*(TIMEFRAME+43),7);
load MOT_Fleet_Data.mat

for i=1:(43*FREQUENCY)
    initial_vehicle_fleet(i,:) = MOT_fleet_data((floor((i-1)/FREQUENCY+1)),:)./FREQUENCY;
end

% Finds the number of cars per capita, which is assumed to remain constant over the
% simulation timeframe. It is determined by dividing the total number of cars in the
% fleet (as at 31st December 2010) by NZ's estimated population (as at 30th June 2010).
vehicles_per_capita = sum(sum(initial_vehicle_fleet))/4388000;

% ------------------------------------------------------------------------------------
% CREATING ARRAYS TO STORE FUEL EFFICIENCY INFORMATION FOR VEHICLES IN THE FLEET
% ------------------------------------------------------------------------------------
% These arrays store information on the fuel efficiency of cars in the fleet, for
% each vehicle type and age.
expanded_efficiencies = zeros(FREQUENCY*(TIMEFRAME+43),7);

% Here we input information on the fuel efficiency of the initial fleet as at 31st
% December 2010. Fuel efficiency up to this point is assumed to be fixed for each
% vehicle type.
for a = 1:43*FREQUENCY
    expanded_efficiencies(a,1) = 7.5;
    expanded_efficiencies(a,2) = 10.0;
    expanded_efficiencies(a,3) = 12.5;
    expanded_efficiencies(a,4) = 7.0;
    expanded_efficiencies(a,5) = 9.5;
    expanded_efficiencies(a,6) = 3.0;
end

% ------------------------------------------------------------------------------------
% SETTING UP THE MAIN "FOR" LOOP, WHICH UPDATES THE FLEET EACH PERIOD
% ------------------------------------------------------------------------------------
% The "initial_", "surviving_" and "final_" vehicle fleet arrays store information on
% the total number of vehicles (broken down by age and type) which are in the fleet in a
% particular period. The values in these arrays are overwritten in the following period.

% Here, note the following:
% 1) Vehicles in the "initial" fleet are those which are in the fleet at the beginning
%    of the period.
% 2) Vehicles in the "surviving" fleet are those from the initial fleet which are not
%    scrapped during the period, i.e. they survive until the end of the period.
% 3) Vehicles in the "final" fleet are those which are in the fleet at the end of the
%    period - including surviving vehicles, and vehicles added to the fleet during the
%    period.
surviving_vehicle_fleet = zeros(FREQUENCY*(TIMEFRAME+43),7);
```

```
final_vehicle_fleet = zeros(FREQUENCY*(TIMEFRAME+43),7);

% The "vehicle_fleet_tracker" array stores information on the total number of vehicles
% of each type (i.e. not broken down by age) which are in the fleet at the end of each
% period.
vehicle_fleet_tracker = zeros(FREQUENCY*TIMEFRAME,7);

% These arrays keep track of fuel demand (for petrol, diesel and electricity),
% emissions (by vehicle type) and VKT (ditto) over the simulation timeframe.
fuel_demand_tracker = zeros(3,FREQUENCY*TIMEFRAME);
emissions_tracker = zeros(FREQUENCY*TIMEFRAME,7);
VKT_tracker = zeros((FREQUENCY*TIMEFRAME),7);

% Loads the MOT_Scrappage_Data.mat file. This file contains the "scrappage_data"
% variable, which shows the proportion of the vehicle fleet (broken down
% by age) that will be scrapped each period.
scrappage_by_type = zeros(FREQUENCY*(TIMEFRAME+43),7);
load MOT_Scrappage_Data.mat

if FREQUENCY == 1
    for a = 1:(TIMEFRAME+43)*FREQUENCY
        scrappage_by_type(a,:) = scrappage_data(min(a,43*FREQUENCY),1);
    end
elseif FREQUENCY == 4
    for a = 1:(TIMEFRAME+43)*FREQUENCY
        scrappage_by_type(a,:) = scrappage_data(min(a,43*FREQUENCY),2);
    end
else
    for a = 1:(TIMEFRAME+43)*FREQUENCY
        scrappage_by_type(a,:) = scrappage_data(min(a,43*FREQUENCY),3);
    end
end

% Calling the New_Vehicle_Proportions function, which finds the proportion of each
% vehicle type that is purchased for each period in the simulation.
[proportions_tracker, electrical_efficiencies] = New_Vehicle_Proportions();

% -------------------------------------------------------------------------------------
% THE MAIN "FOR" LOOP, WHICH UPDATES THE FLEET EACH PERIOD
% -------------------------------------------------------------------------------------
for time = 1:(FREQUENCY*TIMEFRAME)

    % Increases the age of each vehicle which is in the fleet at the start of the period
    for j = (FREQUENCY*(TIMEFRAME+43):-1:2)
        initial_vehicle_fleet(j,:) = initial_vehicle_fleet(j-1,:);
    end
    initial_vehicle_fleet(1,:) = 0;

    % Finds the number of cars from the initial fleet which will survive the period
    surviving_vehicle_fleet = initial_vehicle_fleet - (initial_vehicle_fleet .*
scrappage_by_type);

    % Finds the actual number of vehicles entering the fleet this period
    number_entering_vehicles = (population(time)*vehicles_per_capita)-
sum(sum(surviving_vehicle_fleet));

    % Categorises the vehicles entering the fleet into the seven types, and as being "NZ new" or
"used imports"
    NZ_new_vehicles_by_type = zeros(FREQUENCY*(TIMEFRAME+43),7);
    used_import_vehicles_by_type = zeros(FREQUENCY*(TIMEFRAME+43),7);

    for k = 1:7
        NZ_new_vehicles_by_type(1,k) = proportions_tracker(time,k) * number_entering_vehicles;
        used_import_vehicles_by_type(1+8*FREQUENCY,k) = proportions_tracker(time,k+7) *
number_entering_vehicles;
    end

    % -------------------------------------------------------------------------------------
    % DETERMINING VKT FOR EACH VEHICLE AGE AND TYPE
    % -------------------------------------------------------------------------------------
    % The next stage is to establish VKT for the period. The MOT (2011) gives average VKT
    % per vehicle, based on the total number of vehicles which are in the fleet for at least
    % part of the period. Therefore, the data includes those which are scrapped, and those
    % which enter, during the period. The "effective" fleet below includes the vehicles
    % which are in the fleet at the start of the period - including some which will then be
    % scrapped. It also includes vehicles which are added to the fleet during the period -
    % but these are assumed to enter halfway through the period, and therefore only travel
    % half as far as other vehicles of the same age.
    effective_vehicle_fleet_for_VKT = initial_vehicle_fleet + NZ_new_vehicles_by_type/2 ...
        + used_import_vehicles_by_type/2;

    % Using fuel prices and elasticities, determine the percentage change to VKT for each
    % vehicle type (independent of age) in each period
    relevant_fuel_prices = zeros(3,1);
    relevant_fuel_prices(:) = RETAIL_FUEL_PRICES(:,time);
    VKT_price_response_factors_by_type = VKT_Price_Response(relevant_fuel_prices);

    VKT_by_age_and_type = zeros(FREQUENCY*(TIMEFRAME+43),7);
```

```
    adjusted_VKT_by_age_and_type = zeros(FREQUENCY*(TIMEFRAME+43),7);

    % Loads the MOT_Travel_Data.mat file. This file contains the "MOT_travel_data"
    % variable, which shows how the average distance that vehicles (broken down
    % by age) travelled in 2010.
    load MOT_Travel_Data.mat

    if FREQUENCY == 1
        for type=1:7
            for j = 1: FREQUENCY*(TIMEFRAME+43)
                VKT_by_age_and_type(j,type) = effective_vehicle_fleet_for_VKT(j,type)...
                    .*MOT_travel_data(min(j,43*FREQUENCY),1);
            end
        end
    elseif FREQUENCY == 4
        for type=1:7
            for j = 1: FREQUENCY*(TIMEFRAME+43)
                VKT_by_age_and_type(j,type) = effective_vehicle_fleet_for_VKT(j,type)...
                    .*MOT_travel_data(min(j,43*FREQUENCY),2);
            end
        end
    else
        for type=1:7
            for j = 1: FREQUENCY*(TIMEFRAME+43)
                VKT_by_age_and_type(j,type) = effective_vehicle_fleet_for_VKT(j,type)...
                    .*MOT_travel_data(min(j,43*FREQUENCY),3);
            end
        end
    end

    % Here, VKT is adjusted based on fuel prices and the elasticity of the vehicles
    for age = 1 : FREQUENCY*(TIMEFRAME+43)
        adjusted_VKT_by_age_and_type(age,:) = VKT_by_age_and_type(age,:)...
            .* VKT_price_response_factors_by_type(1,:);
    end

    VKT_tracker(time,:) = sum(adjusted_VKT_by_age_and_type,1);

    % ---------------------------------------------------------------------------------------
    % DETERMINING FUEL DEMAND AND EMISSIONS, BASED ON DISTANCE TRAVELLED AND FUEL EFFICIENCY
    % ---------------------------------------------------------------------------------------
    % Car ages have been increased earlier, and here we shift the fuel efficiency figures
    % down one row so that they continue to line up with cars of the appropriate age
    for j = (FREQUENCY*(TIMEFRAME+43):-1:2)
        expanded_efficiencies(j,:) = expanded_efficiencies(j-1,:);
    end

    % Puts in the fuel efficiencies for NEW cars entering this period...
    expanded_efficiencies(1,:) = NEW_CAR_EFFICIENCIES(time,:);

    [Q_D_fuels, emissions_by_type] = Fuel_Demand_And_Emissions_Function...
        (adjusted_VKT_by_age_and_type,expanded_efficiencies,electrical_efficiencies);

    fuel_demand_tracker(:,time) =  Q_D_fuels(:);
    emissions_tracker(time,:) = emissions_by_type(:);

    % Adds in the different types of new vehicle entering the fleet this period
    final_vehicle_fleet = surviving_vehicle_fleet + NZ_new_vehicles_by_type...
        + used_import_vehicles_by_type;

    vehicle_fleet_tracker(time,:) = sum(final_vehicle_fleet);

    % The final fleet is now saved to the initial fleet for the next period
    initial_vehicle_fleet = final_vehicle_fleet;
end

return
```

New_Vehicle_Proportions.m

```
% Each period, vehicles are added to the vehicle fleet. For these new vehicles,
% this function determines the proportion of each vehicle type that will be chosen,
% e.g. 10% BEV, 15% PHEV, 75% the other types...

function [proportions, electrical_efficiencies] = New_Vehicle_Proportions()

global TIMEFRAME FREQUENCY TIMELINE_VECTOR DISCOUNT_RATE RETAIL_FUEL_PRICES...
       NEW_PHEV_SUBSIDY NEW_BEV_SUBSIDY BAN_USED_IMPORTS BAN_USED_ADVANCED_VEHICLES...
       PHEVS_RUC_EXEMPT BEVS_RUC_EXEMPT UNIVERSAL_RUC_SCHEME NEW_CAR_EFFICIENCIES
BATTERY_COST_SCENARIO

% ---------------------------------------------------------------------------------------
% VEHICLE ATTRIBUTES
% ---------------------------------------------------------------------------------------
% The electrical efficiency of PHEVs and BEVs is assumed to remain constant over time.
electrical_efficiencies = [0 0 0 0 0 12 20 0 0 0 0 0 12 20];

% ICEV fuel efficiencies change over time. The "fuel_efficiencies" vector represents
```

```
% their starting values. Note that this vector is only ever used for used imports, and
% only in the first eight years. The efficiency of new cars, and used cars after eight
% years, is given in the NEW_CAR_EFFICIENCIES global variable.
initial_efficiencies = [7.5, 10, 12.5, 7, 9.5, 3, 0, 7.5, 10, 12.5, 7, 9.5, 3, 0];

% The values for the capex coefficient (alpha), and the opex coefficient (beta), are
% derived from my regressions on 2002-2010 car registration data.
alpha = -0.000013;
beta = -0.015788;

% PHEV and BEV purchase prices change over time, and may be adjusted for subsidies.
capex = [26639, 44300, 89571, 48300, 93571, 0, 0, 10668, 13425, 17436, 17425, 21436, 0, 0];

gamma = [-0.023, 0.619, 1.681, -0.965, -0.917, 0, 0, 0.614, 1.108, 0.650, -2.318, -0.448, 0, 0];
gamma(6) = gamma(2);
gamma(7) = gamma(4);
gamma(13) = gamma(9);
gamma(14) = gamma(8);

% ---------------------------------------------------------------------------------------
% PUTTING IN PHEV AND BEV BATTERY PRICES
% ---------------------------------------------------------------------------------------
% Note that battery costs are flat beyond 2030 or 2050, depending on the choice of
% scenario.
BEV_battery_cost = zeros(FREQUENCY*TIMEFRAME,1);
PHEV_battery_cost = zeros(FREQUENCY*TIMEFRAME,1);

if BATTERY_COST_SCENARIO == 1
    for time = 1 : FREQUENCY*TIMEFRAME
        BEV_battery_cost(time,:) = max(1666.667, 25000*(time/FREQUENCY)^-0.904) / 0.70;
    end
elseif BATTERY_COST_SCENARIO == 2
    for time = 1 : FREQUENCY*TIMEFRAME
        BEV_battery_cost(time,:) = max(3333.333, 25000*(time/FREQUENCY)^-0.673) / 0.70;
    end
elseif BATTERY_COST_SCENARIO == 3
    for time = 1 : FREQUENCY*TIMEFRAME
        BEV_battery_cost(time,:) = max(6666.667, 25000*(time/FREQUENCY)^-0.441) / 0.70;
    end
elseif BATTERY_COST_SCENARIO == 4
    for time = 1 : FREQUENCY*TIMEFRAME
        BEV_battery_cost(time,:) = max(1666.667, 25000*(time/FREQUENCY)^-0.734) / 0.70;
    end
elseif BATTERY_COST_SCENARIO == 5
    for time = 1 : FREQUENCY*TIMEFRAME
        BEV_battery_cost(time,:) = max(3333.333, 25000*(time/FREQUENCY)^-0.546) / 0.70;
    end
else for time = 1 : FREQUENCY*TIMEFRAME
        BEV_battery_cost(time,:) = max(6666.667, 25000*(time/FREQUENCY)^-0.358) / 0.70;
    end
end

% PHEV batteries are assumed to cost 40% as much as BEV batteries.
PHEV_battery_cost(:) = 0.4*BEV_battery_cost(:);

% ---------------------------------------------------------------------------------------
% SETTING UP THE "FOR" LOOP WITH PARTS THAT DON'T CHANGE EACH PERIOD
% ---------------------------------------------------------------------------------------
% The "proportions" array will store the proportion of each vehicle type that gets added
% to the fleet, for each period in the simulation
proportions = zeros(FREQUENCY*TIMEFRAME,14);

% ---------------------------------------------------------------------------------------
% THE MAIN "FOR" LOOP: FINDS "MARKET SHARE" OF SALES FOR EACH VEHICLE TYPE, AND FOR EACH
% PERIOD IN THE SIMULATION
% ---------------------------------------------------------------------------------------
% Looping through and developing an array holding the composition (proportions) of each
% type of vehicle in the new purchases for that time period
for period = 1 :(FREQUENCY*TIMEFRAME)
    opex100 = zeros(1,14);

    % Used PHEVs and BEVs are assumed to be imported with brand-new batteries
    capex(1,6) = capex(1,2) + PHEV_battery_cost(time) - NEW_PHEV_SUBSIDY + 3000/0.70;
    capex(1,7) = capex(1,2) + BEV_battery_cost(time) - NEW_BEV_SUBSIDY - 3000/0.70;
    capex(1,13) = capex(1,9) + PHEV_battery_cost(time) + 3000/0.70;
    capex(1,14) = capex(1,9) + BEV_battery_cost(time) - 3000/0.70;

    % ---------------------------------------------------------------------------------
    % ROAD USER CHARGES
    % ---------------------------------------------------------------------------------
    % Currently, only diesel vehicles and BEVs pay Road User Charges. If the scheme is
    % made universal, all vehicles must pay (except those exempted below). The
    % "road_user_charges" variable shows the cost (in $NZD) of paying RUCs for 100 km of
    % travel, for each vehicle type.
    road_user_charges = zeros(1,14);
    if UNIVERSAL_RUC_SCHEME
        road_user_charges(:) = 4.431;
    else
```

```
        road_user_charges = [0, 0, 0, 4.431, 4.431, 0, 4.431, 0, 0, 0, 4.431, 4.431, 0, 4.431];
    end

    if PHEVS_RUC_EXEMPT
        road_user_charges(6) = 0;
        road_user_charges(13) = 0;
    end

    if BEVS_RUC_EXEMPT
        road_user_charges(7) = 0;
        road_user_charges(14) = 0;
    end

    % ---------------------------------------------------------------------------------
    % CONSUMERS LOOK AHEAD 43 YEARS FROM WHEN THEY BUY A CAR...
    % ---------------------------------------------------------------------------------
    % The "opex100" is the opex cost per 100 km that consumers face for each
    % vehicle type
    for type = 1:3
        opex100(type) = NEW_CAR_EFFICIENCIES(period,type) * RETAIL_FUEL_PRICES(1,period)...
            + road_user_charges(type);
    end
    for type = 4:5
        opex100(type) = NEW_CAR_EFFICIENCIES(period,type) * RETAIL_FUEL_PRICES(2,period)...
            + road_user_charges(type);
    end
    for type = 6:7
        opex100(type) = NEW_CAR_EFFICIENCIES(period,type) * RETAIL_FUEL_PRICES(1,period)...
            + electrical_efficiencies(type) * RETAIL_FUEL_PRICES(3,period) +
road_user_charges(type);
    end

    if (period <= 8*FREQUENCY)
        for type = 8:10
            opex100(type) = initial_efficiencies(type) * RETAIL_FUEL_PRICES(1,period)...
                + road_user_charges(type);
        end
        for type = 11:12
            opex100(type) = initial_efficiencies(type) * RETAIL_FUEL_PRICES(2,period)...
                + road_user_charges(type);
        end
        for type = 13:14
            opex100(type) = initial_efficiencies(type) * RETAIL_FUEL_PRICES(1,period)...
                + electrical_efficiencies(type) * RETAIL_FUEL_PRICES(3,period) +
road_user_charges(type);
        end
    else
        for type = 8:10
            opex100(type) = NEW_CAR_EFFICIENCIES(period-8*FREQUENCY,type-7)...
                * RETAIL_FUEL_PRICES(1,period) + road_user_charges(type);
        end
        for type = 11:12
            opex100(type) = NEW_CAR_EFFICIENCIES(period-8*FREQUENCY,type-7)...
                * RETAIL_FUEL_PRICES(2,period) + road_user_charges(type);
        end
        for type = 13:14
            opex100(type) = NEW_CAR_EFFICIENCIES(period-8*FREQUENCY,type-7)...
                * RETAIL_FUEL_PRICES(1,period) + electrical_efficiencies(type)...
                * RETAIL_FUEL_PRICES(3,period) + road_user_charges(type);
        end
    end

    % ---------------------------------------------------------------------------------
    % FINDING THE PROPORTION OF CARS BOUGHT IN EACH PERIOD
    % ---------------------------------------------------------------------------------
    % If the user has decided to ban used imports, only new cars will be purchased.
    % Otherwise, we will tend to have a non-zero proportion of each car type bought
    if BAN_USED_IMPORTS
        for type = 1:7
            proportions(period,type) = exp(alpha*capex(1,type) + beta*opex100(type) +
gamma(type));
        end
    else
        for type = 1:14
            proportions(period,type) = exp(alpha*capex(1,type) + beta*opex100(type) +
gamma(type));
        end
    end

    % New PHEVs and BEVs are assumed to become available in 2013.
    if period<= (FREQUENCY*2)
        proportions(period,6) = 0;
        proportions(period,7) = 0;
    end

    % Used PHEVs and BEVs are assumed to become available in 2021, unless the user has
    % elected to "ban" the import of these vehicles
    if BAN_USED_ADVANCED_VEHICLES == 1
```

```
        proportions(:,13) = 0;
        proportions(:,14) = 0;
    elseif period <= (FREQUENCY*10)
        proportions(period,13) = 0;
        proportions(period,14) = 0;
    end

    % This finalises the proportion of each type of car that is bought in
    % this period, using the multinomial logit specification
    proportions(period,:) = proportions(period,:)./sum(proportions(period,:));
end

return
```

Fuel_Demand_And_Emissions_Function.m

```
function [Q_D_fuels, emissions_by_type] = Fuel_Demand_And_Emissions_Function...
    (adjusted_VKT_by_age_and_type,expanded_efficiencies,electrical_efficiencies)
% This function finds the quantity demanded for petrol and diesel (in L) and electricity
% (in kWh) for a single period.

global TIMEFRAME FREQUENCY

% ---------------------------------------------------------------------------------------
% DETERMINING FUEL CONSUMPTION FOR EACH VEHICLE TYPE
% ---------------------------------------------------------------------------------------
Q_D_petrol_by_age_and_type = zeros(FREQUENCY*(TIMEFRAME+43),7);
Q_D_diesel_by_age_and_type = zeros(FREQUENCY*(TIMEFRAME+43),7);
Q_D_electricity_by_age_and_type = zeros(FREQUENCY*(TIMEFRAME+43),7);

for type = 1:3
    Q_D_petrol_by_age_and_type(:,type) = adjusted_VKT_by_age_and_type(:,type)...
        .*expanded_efficiencies(:,type)/100;
end

for type = 4:5
    Q_D_diesel_by_age_and_type(:,type) = adjusted_VKT_by_age_and_type(:,type)...
        .*expanded_efficiencies(:,type)/100;
end

% Petrol demand from plug-in hybrids
Q_D_petrol_by_age_and_type(:,6) = adjusted_VKT_by_age_and_type(:,6)...
    .*expanded_efficiencies(:,6)/100;

for type = 6:7
    Q_D_electricity_by_age_and_type(:,type) = adjusted_VKT_by_age_and_type(:,type)...
        .*electrical_efficiencies(type)/100;
end

% ---------------------------------------------------------------------------------------
% DETERMINING TOTAL PETROL, DIESEL AND ELECTRICITY CONSUMPTION
% ---------------------------------------------------------------------------------------
% "Q_D_fuels" contains the total consumption of each fuel in this period, and is
% obtained by summing consumption over each vehicle age and type.
Q_D_fuels = zeros(3,1);
Q_D_fuels = [sum(sum(Q_D_petrol_by_age_and_type));
            sum(sum(Q_D_diesel_by_age_and_type));
            sum(sum(Q_D_electricity_by_age_and_type))];

% ---------------------------------------------------------------------------------------
% DETERMINING EMISSIONS BY VEHICLE TYPE
% ---------------------------------------------------------------------------------------
emissions_by_type = zeros(1,7);

% Showing the CO2-equivalent emissions from a litre of fuel, measured in tonnes of
% CO2-equivalent. Figures from New Zealand Government (2008). Petrol emissions are
% weighted 80:20 in favour of 91 octane, as per observed consumption  in 2010
% (MED, 2011, p. 60)
petrol_emissions_per_litre = 0.8 * (2.310*10^-3) + 0.2 * (2.367*10^-3);
diesel_emissions_per_litre = 2.670*10^-3;

% I have estimated electricity emissions, based on MED (2011a) and MED (2011b)
electricity_emissions_per_kWh = 2*10^-4;

Q_D_petrol_by_type = sum(Q_D_petrol_by_age_and_type,1);
Q_D_diesel_by_type = sum(Q_D_diesel_by_age_and_type,1);
Q_D_electricity_by_type = sum(Q_D_electricity_by_age_and_type,1);

for type = 1:3
    emissions_by_type(1,type) = Q_D_petrol_by_type(type) * petrol_emissions_per_litre;
end

for type = 4:5
    emissions_by_type(1,type) = Q_D_diesel_by_type(type) * diesel_emissions_per_litre;
end

for type = 6
    emissions_by_type(1,type) = Q_D_petrol_by_type(type) * petrol_emissions_per_litre...
```

```
        + Q_D_electricity_by_type(type) * electricity_emissions_per_kWh;
end

for type = 7
    emissions_by_type(1,type) = Q_D_electricity_by_type(type) * electricity_emissions_per_kWh;
end

return
```

VKT_Price_Response.m

```
function [VKT_price_response_factors_by_type] = VKT_Price_Response(relevant_fuel_prices)
% "Relevant" fuel prices might be current prices, or - for consumers deciding on which
% car to buy - an expected future price for a particular future period.
% This function uses the "relevant" fuel prices, plus initial prices and vehicle-specific
% elasticities, to determine the effect on VKT for each vehicle type.
% Note that elasticities don't depend on the vehicles' ages. Also note that
% VKT_price_response_factor equals one if prices are the same as they were in 2010,
% is greater than one if prices are lower, and less than one if prices are higher.

global UNIVERSAL_RUC_SCHEME

% -------------------------------------------------------------------------------------
% ADJUSTING VKT FOR ELASTICITY
% -------------------------------------------------------------------------------------

% Fuel elasticities for each car type. Diesel cars are assumed to be less elastic unless
% the RUC scheme is made universal, since in the current situation a doubling in diesel
% cost won't double their total running cost

if UNIVERSAL_RUC_SCHEME == 0
    elasticity_by_type = [0.12 0.12 0.12 0.10 0.10 0.06 0];
else elasticity_by_type = [0.10 0.10 0.10 0.10 0.10 0.06 0];
end

price_ratio = ones(3,size(relevant_fuel_prices,2));

% Prices are compared to 2010 prices, from MED (2011). Petrol prices are weighted
% 80:20 in favour of the 91 octane price
for i = 1:size(relevant_fuel_prices,2)
    if UNIVERSAL_RUC_SCHEME == 0
        price_ratio(1,i) = relevant_fuel_prices(1,i) ./ 1.7851;
    else price_ratio(1,i) = relevant_fuel_prices(1,i) ./ 1.1938;
    end
    price_ratio(2,i) = relevant_fuel_prices(2,i) ./ 1.1736;
    price_ratio(3,i) = relevant_fuel_prices(3,i) ./ 0.25;
end

VKT_price_response_factors_by_type = ones(size(relevant_fuel_prices,2),7);
VKT_price_response_factors_by_type(:,1) = 1 - elasticity_by_type(1) * log(price_ratio(1,:)) /
0.69314718;
VKT_price_response_factors_by_type(:,2) = 1 - elasticity_by_type(2) * log(price_ratio(1,:)) /
0.69314718;
VKT_price_response_factors_by_type(:,3) = 1 - elasticity_by_type(3) * log(price_ratio(1,:)) /
0.69314718;
VKT_price_response_factors_by_type(:,4) = 1 - elasticity_by_type(4) * log(price_ratio(2,:)) /
0.69314718;
VKT_price_response_factors_by_type(:,5) = 1 - elasticity_by_type(5) * log(price_ratio(2,:)) /
0.69314718;
VKT_price_response_factors_by_type(:,6) = 1 - elasticity_by_type(6) * log((price_ratio(1,:) +
price_ratio(3,:))/2) / 0.69314718;
VKT_price_response_factors_by_type(:,7) = 1 - elasticity_by_type(7) * log(price_ratio(3,:)) /
0.69314718;

return
```

GUI_Output.m

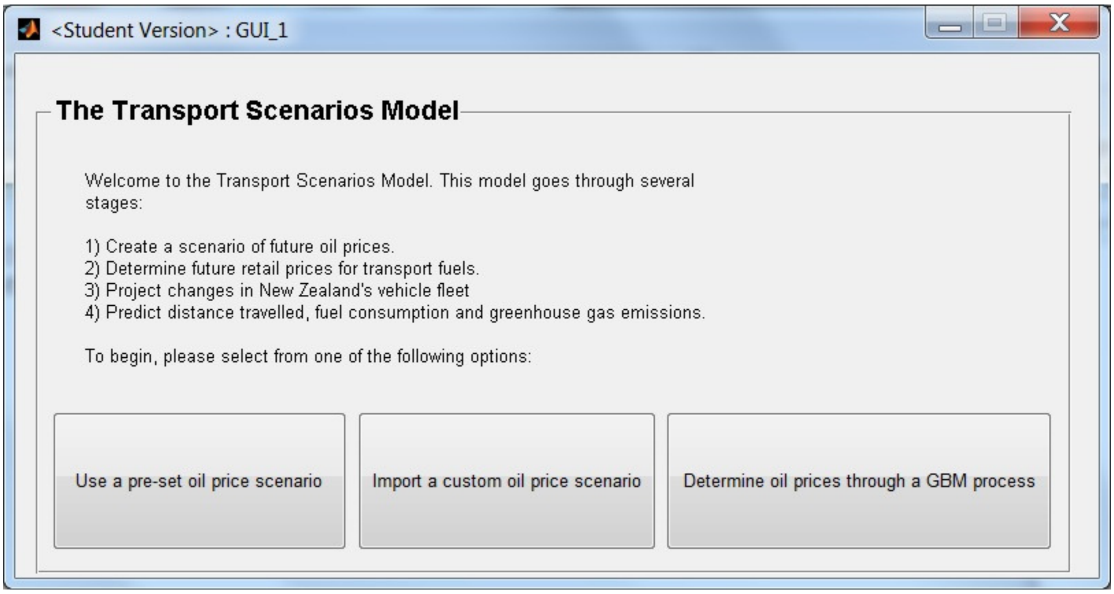
```
function varargout = GUI_Output(varargin)
% This function contains the underlying code for the GUI_Output.fig GUI

% -------------------------------------------------------------------------------------
% AUTOMATICALLY GENERATED INITIALISATION CODE - DO NOT EDIT
% -------------------------------------------------------------------------------------
gui_Singleton = 0;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_Output_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_Output_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
```

```
    gui_mainfcn(gui_State, varargin{:});
end

% ----------------------------------------------------------------------------------------
% SETTING UP THE GUI
% ----------------------------------------------------------------------------------------
% --- Executes just before GUI_Output is made visible.
function GUI_Output_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
global DESCRIPTION_STRING DATA_MATRIX Y_AXIS_LABEL TITLE_LABEL LEGEND_LABEL...
       PLOT_INDICATOR TIMELINE_VECTOR FREQUENCY
% Description of plot
set(handles.text1,'String',DESCRIPTION_STRING);
% Initialising tables
set(handles.uitable1,'ColumnName',{'Year','Variable'})
% Hidden variable indicator
set(handles.text3,'String',PLOT_INDICATOR);
% Plotting required data
colour = {'b-','g-','r-','c-','m-','y-','k-','b.--','g.--','r.--','c.--','m.--','y.--','k.--'};
axes(handles.axes1)

if ((PLOT_INDICATOR == 1)  || (PLOT_INDICATOR == 2))
    for i=1:size(DATA_MATRIX,2)
        plot(transpose(TIMELINE_VECTOR),DATA_MATRIX(:,i),char(colour(i)))
        hold on
    end
else
    area(TIMELINE_VECTOR, DATA_MATRIX)
end

hold off
title(TITLE_LABEL)
xlabel('Year')
ylabel(Y_AXIS_LABEL)
legend(LEGEND_LABEL)
set(hObject, 'toolbar', 'figure')
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = GUI_Output_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

% ----------------------------------------------------------------------------------------
% EXECUTES WHEN THE USER PRESSES "Show Table" - BRINGS UP TABULATED DATA AND LABELS
% ----------------------------------------------------------------------------------------
function pushbutton1_Callback(hObject, eventdata, handles)
handles.output = hObject;
global PLOT_INDICATOR TIMELINE_VECTOR DATA1 DATA2 DATA3 DATA4 DATA5 DATA6 DATA7 DATA8

uitable(handles.uitable1);
if str2double(get(handles.text3,'String'))==1
    set(handles.uitable1, 'Data', [transpose(TIMELINE_VECTOR) DATA1])
    set(handles.uitable1,'ColumnName',{'Year','World Oil Price ($USD/ barrel)'})
elseif str2double(get(handles.text3,'String'))==2
    set(handles.uitable1, 'Data', [transpose(TIMELINE_VECTOR) DATA2])
    set(handles.uitable1,'ColumnName',{'Year','Petrol Price ($/ L)',...
        'Diesel Price ($/ L)','Electricity Price ($/ kWh)'})
elseif str2double(get(handles.text3,'String'))==3
    set(handles.uitable1, 'Data', [transpose(TIMELINE_VECTOR) DATA3])
    set(handles.uitable1,'ColumnName',{'Year','Small Petrol Cars',...
        'Medium Petrol Cars', 'Large Petrol Cars','Small Diesel Cars',...
        'Large Diesel Cars','PHEVs', 'BEVs'})
elseif str2double(get(handles.text3,'String'))==4
    set(handles.uitable1, 'Data', [transpose(TIMELINE_VECTOR) DATA4])
    set(handles.uitable1,'ColumnName',{'Year','Small Petrol Cars',...
        'Medium Petrol Cars', 'Large Petrol Cars','Small Diesel Cars',...
        'Large Diesel Cars','PHEVs', 'BEVs'})
elseif str2double(get(handles.text3,'String'))==5
    set(handles.uitable1, 'Data', [transpose(TIMELINE_VECTOR) DATA5])
    set(handles.uitable1,'ColumnName',{'Year','Petrol Demand','Diesel Demand'})
elseif str2double(get(handles.text3,'String'))==6
    set(handles.uitable1, 'Data', [transpose(TIMELINE_VECTOR) DATA6])
    set(handles.uitable1,'ColumnName',{'Year','Electricity Demand'})
elseif str2double(get(handles.text3,'String'))==7
    set(handles.uitable1, 'Data', [transpose(TIMELINE_VECTOR) DATA7])
    set(handles.uitable1,'ColumnName',{'Year','Small Petrol Cars',...
        'Medium Petrol Cars', 'Large Petrol Cars','Small Diesel Cars',...
        'Large Diesel Cars','PHEVs', 'BEVs'})
else
    set(handles.uitable1, 'Data', [transpose(TIMELINE_VECTOR) DATA8])
    set(handles.uitable1,'ColumnName',{'Year','New Small Petrol Cars',...
        'New Medium Petrol Cars', 'New Large Petrol Cars','New Small Diesel Cars',...
        'New Large Diesel Cars','New PHEVs', 'New BEVs','Used Small Petrol Cars',...
        'Used Medium Petrol Cars', 'Used Large Petrol Cars','Used Small Diesel Cars',...
        'Used Large Diesel Cars','Used PHEVs', 'Used BEVs'})
    ylim([0 5])
end
set(handles.uitable1, 'Enable', 'on')
```

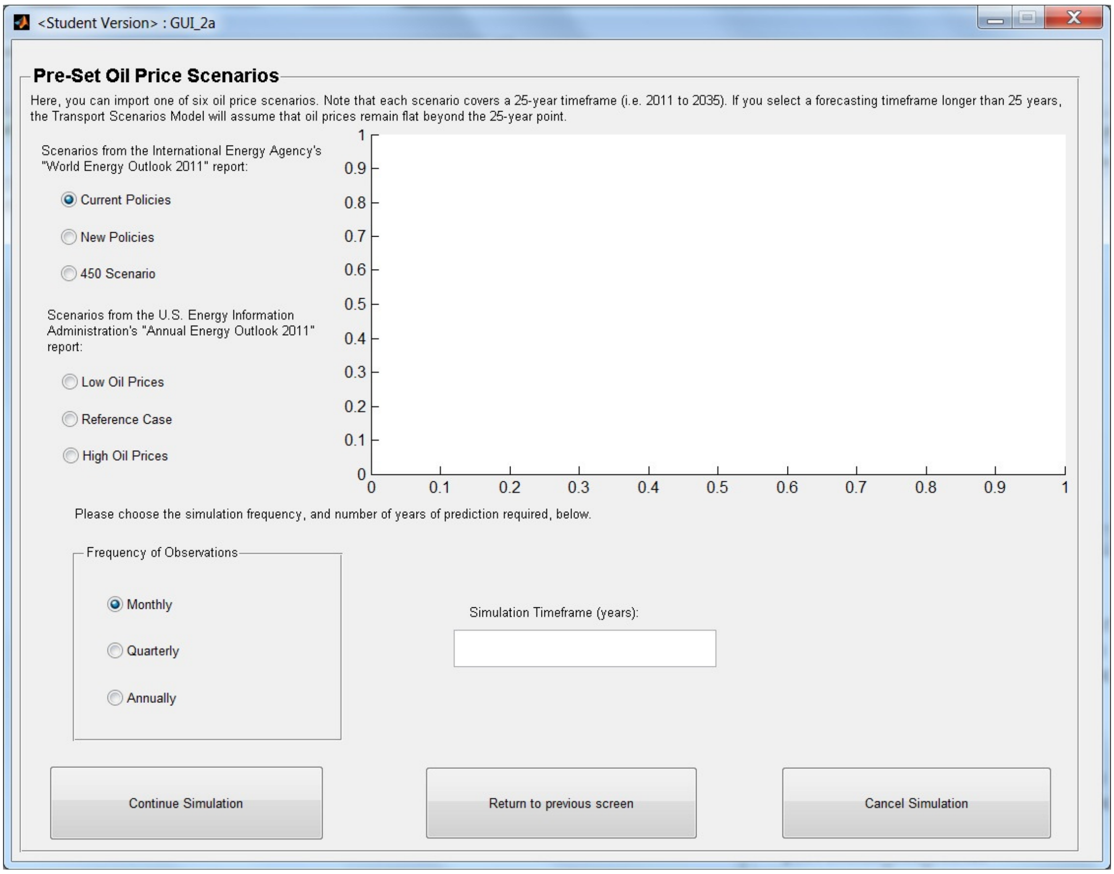
```
guidata(hObject, handles)

% ------------------------------------------------------------------------------------
% EXITING THE GUI
% ------------------------------------------------------------------------------------
% Executes when the user presses "Close Window". This closes the GUI but doesn't delete
% any variables.
function pushbutton2_Callback(hObject, eventdata, handles)
close
```

APPENDIX B: GUI SCREENS IN THE TRANSPORT SCENARIOS MODEL

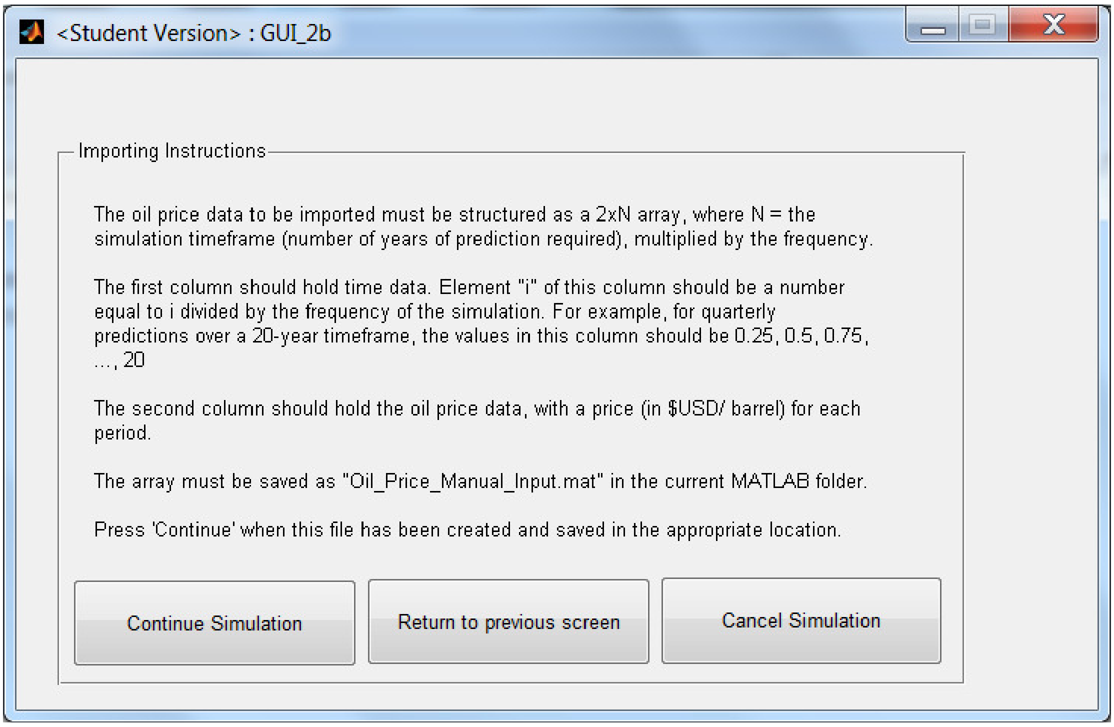
GUI Screen 1



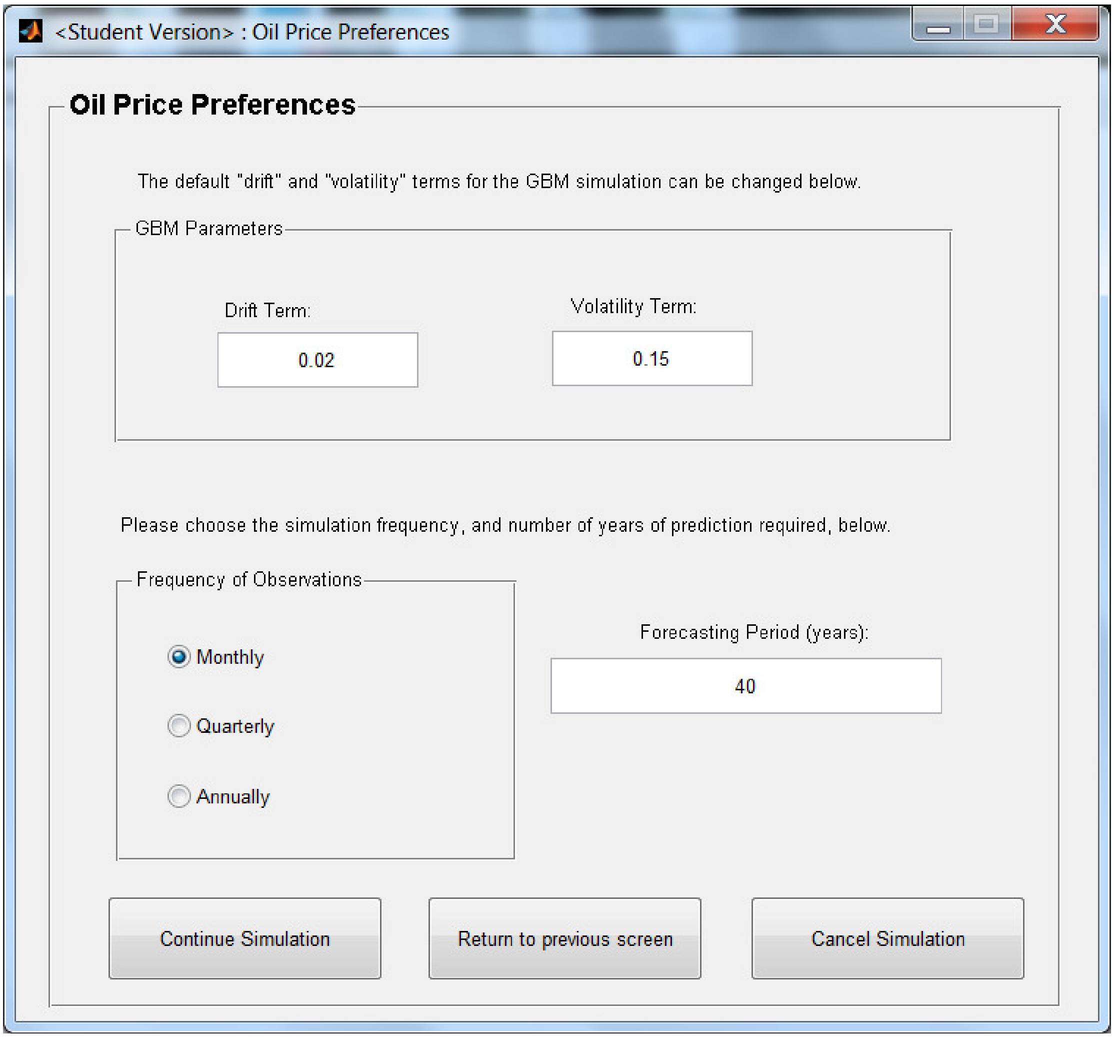
GUI Screen 2a



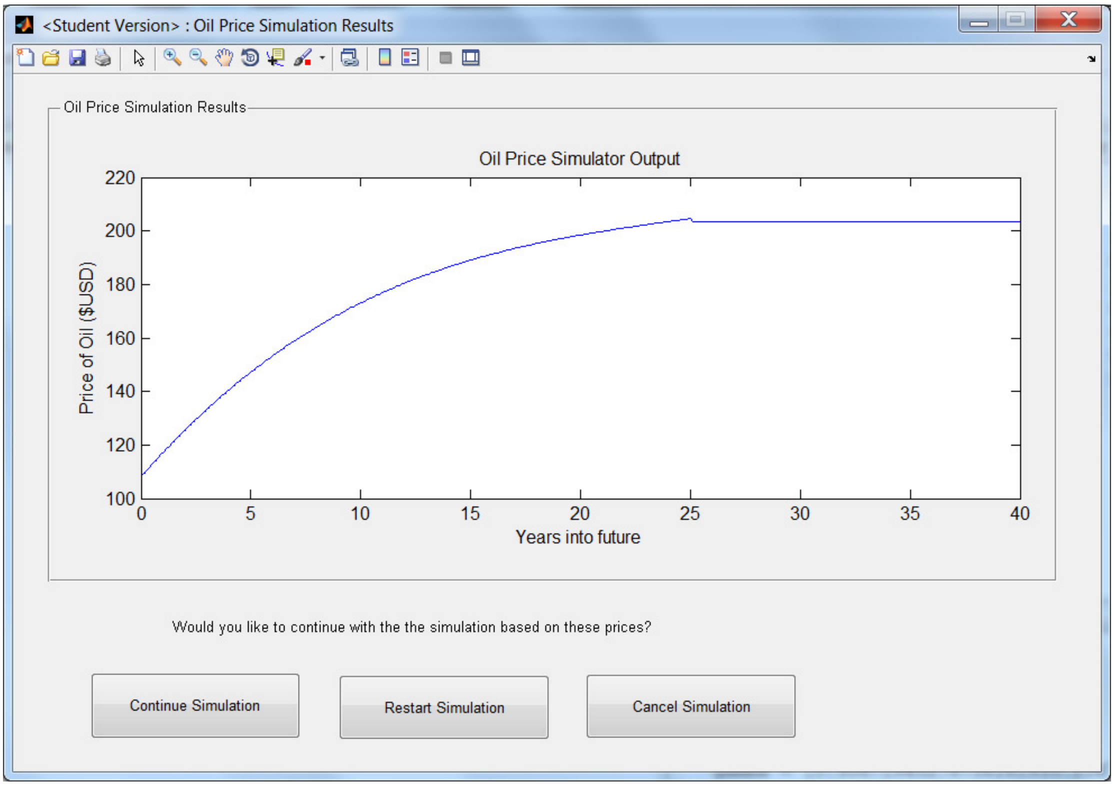
GUI Screen 2b



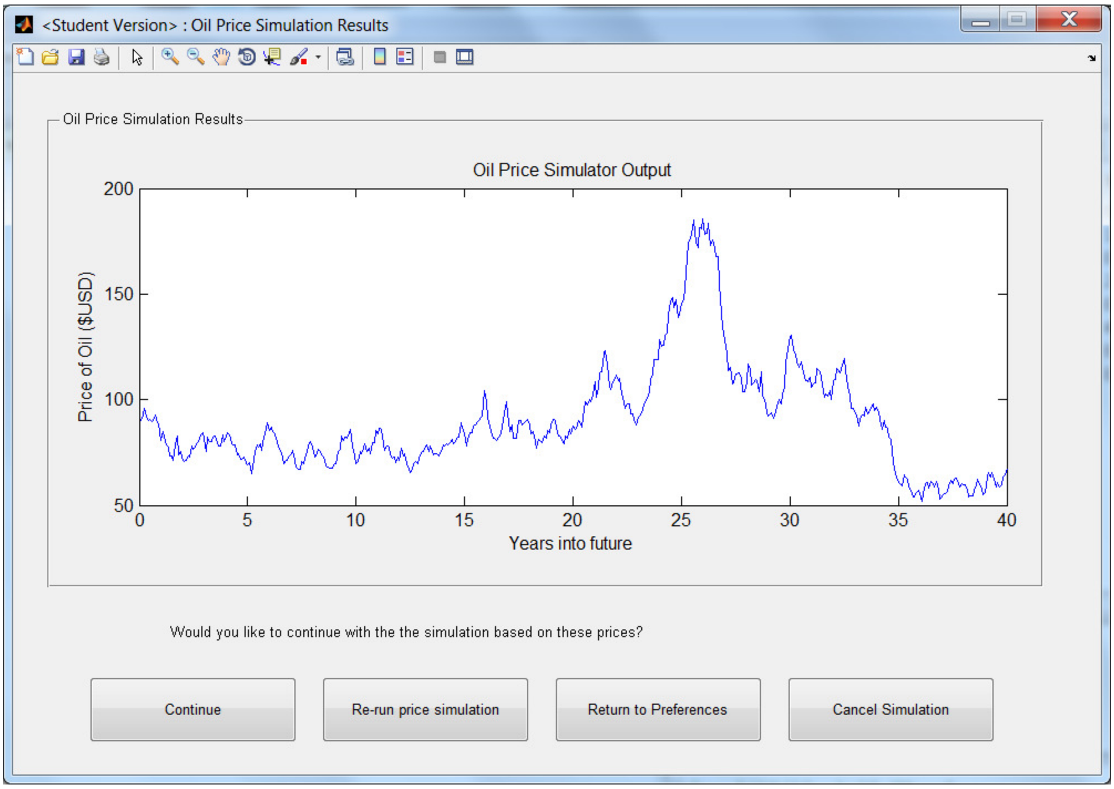
GUI Screen 2c



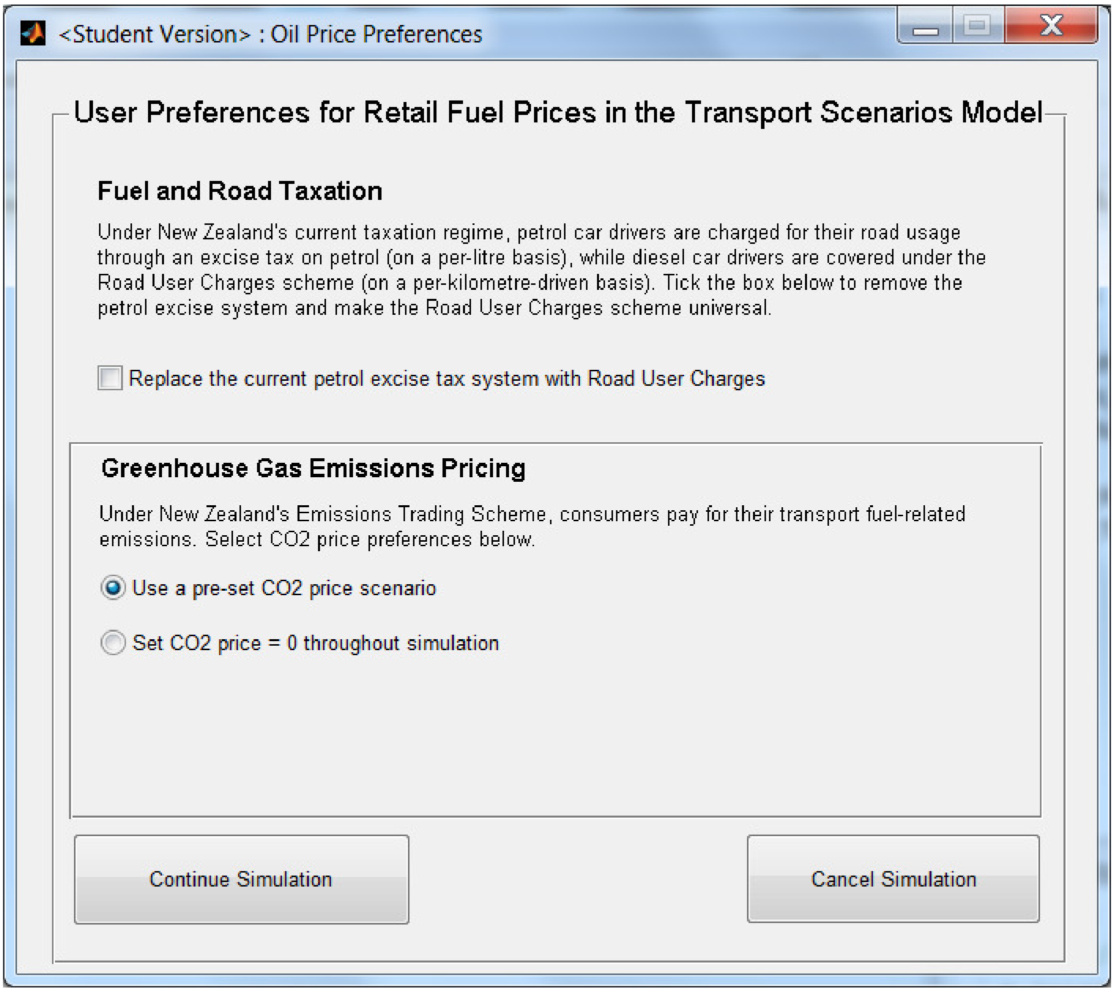
GUI Screen 3a



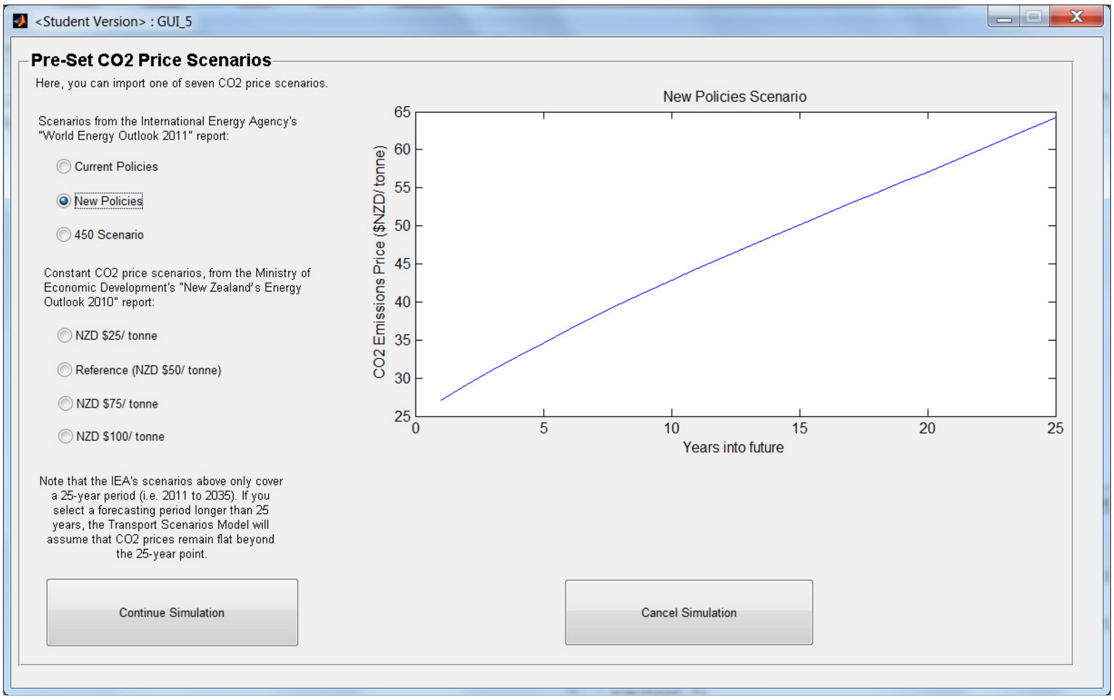
GUI Screen 3b



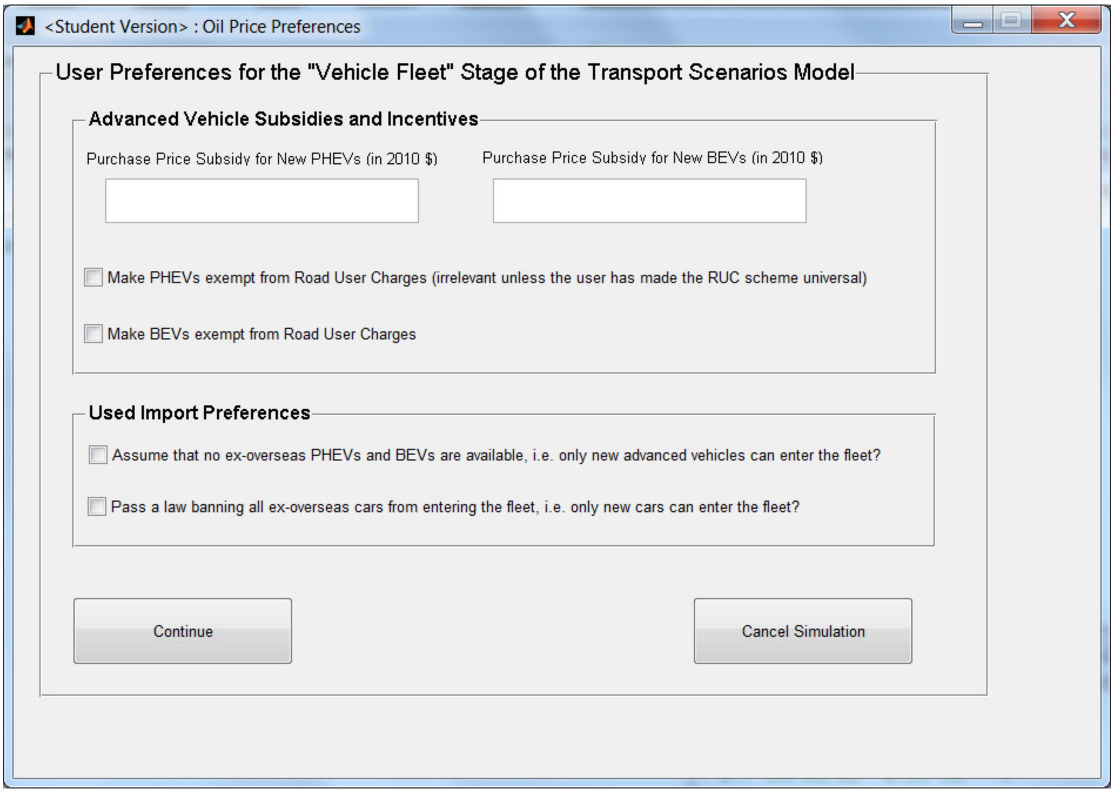
GUI Screen 4



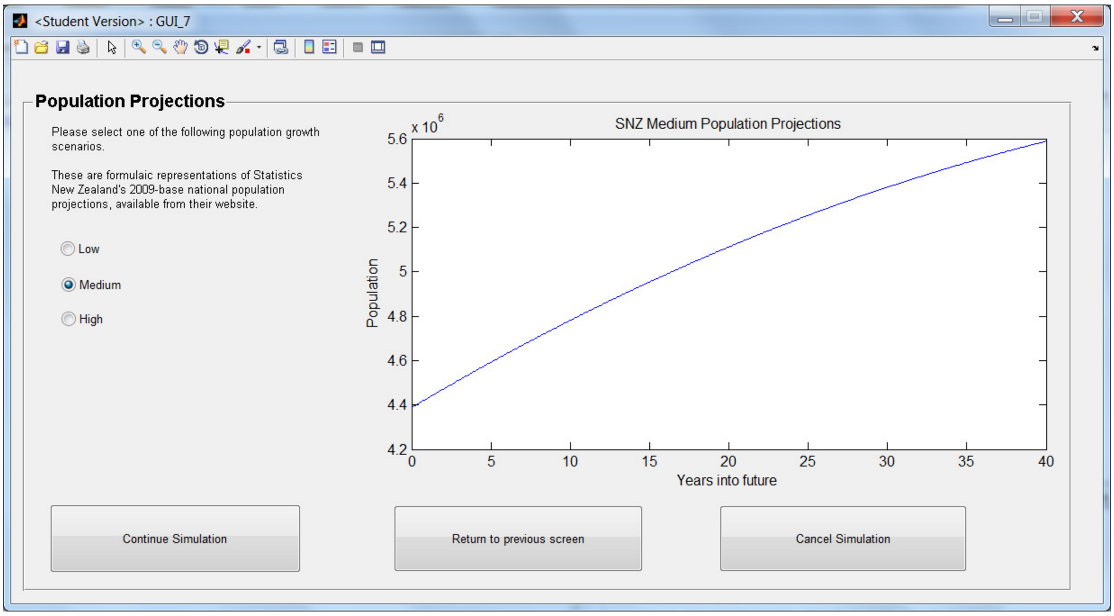
GUI Screen 5



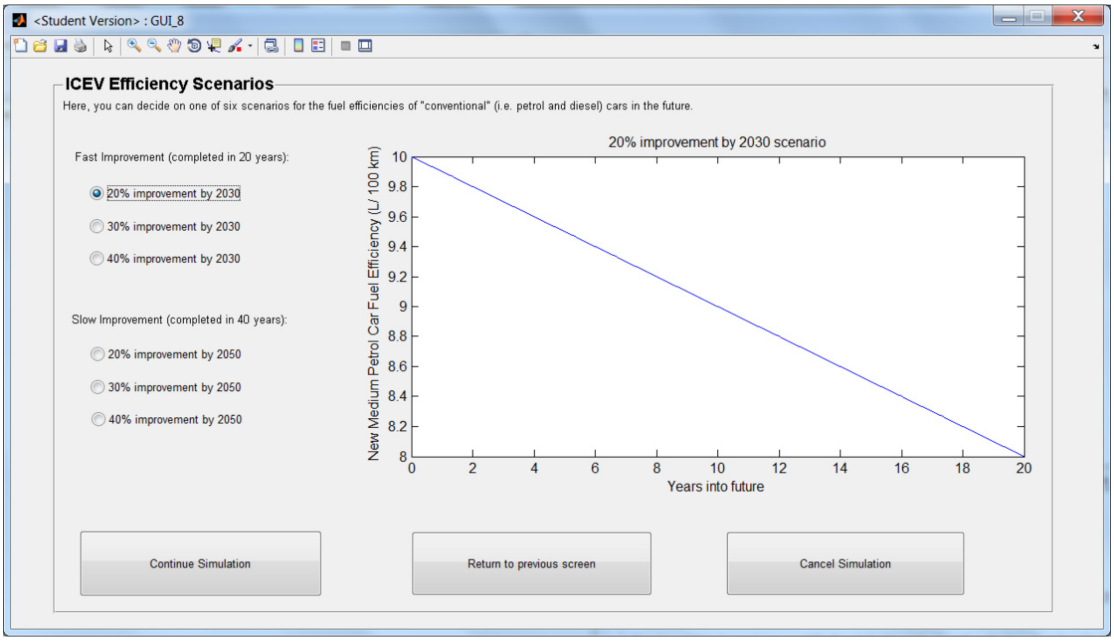
GUI Screen 6



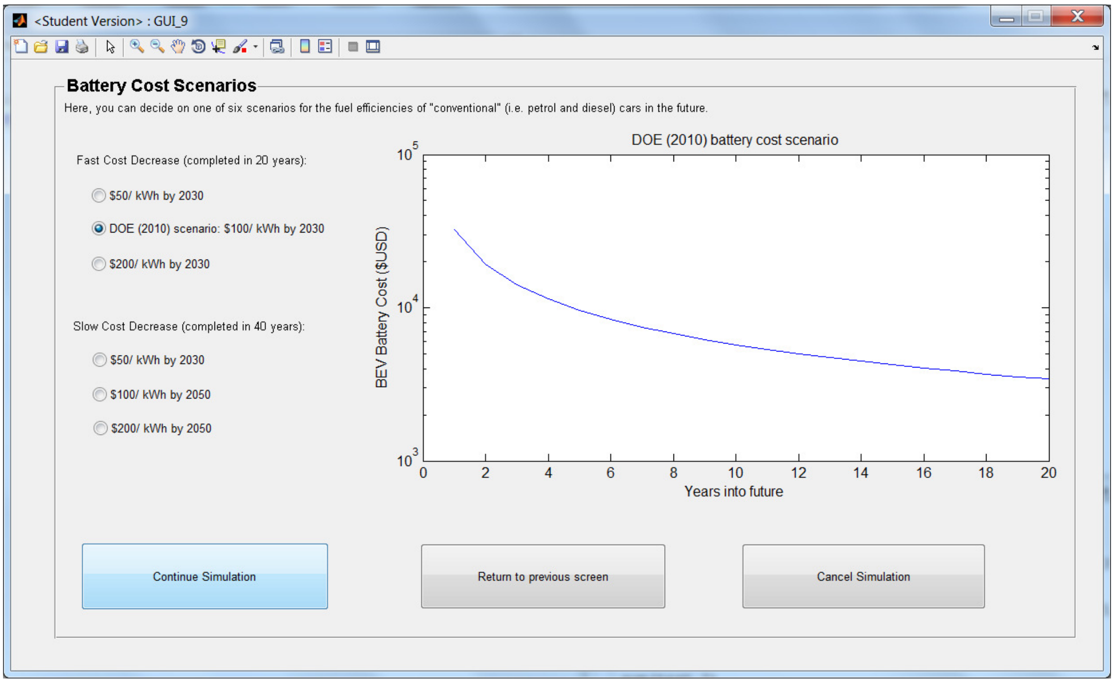
GUI Screen 7



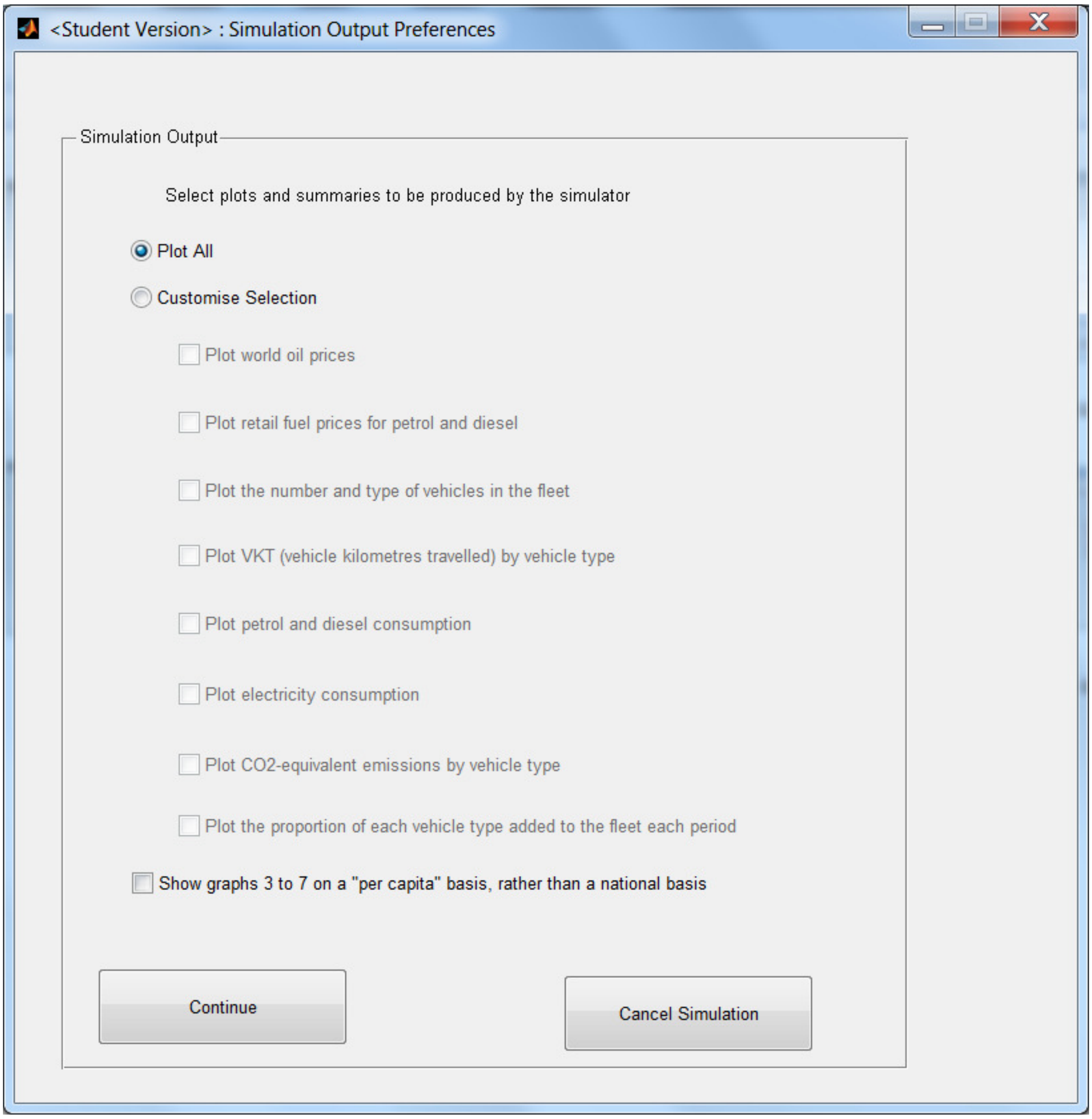
GUI Screen 8



GUI Screen 9



GUI Screen 10



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