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Petrol consumption and emissions from automobiles: Can policies make a difference?

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ABSTRACT: The use of fossil fuels in transportation has increasingly become an important topic as a result of growing concerns over global warming. Automobile petrol demand has been of particular interest to researchers and policy makers, given that the automobile is considered to be a major contributor to the enhanced greenhouse effect. This paper seeks to predict Australia's automobile petrol demand up to the year 2020 based on the best performing forecasting model selected out of eight models. In order to establish ways to reduce emissions for cars, we estimated the impact on CO_2 for several potential policy instruments, using TRESIS 1.4 (an integrated transport, land use and environmental strategy impact simulation program).

KEY WORDS: ***Petrol demand, passenger cars, forecasting models, greenhouse gas emissions, CO2, environmental policies, Tresis1.4***

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1. Introduction

The prediction of fuel consumption has been widely regarded as an important tool for energy planning, with the primary purposes often cited as to i) help policy makers develop appropriate pricing and taxation systems, ii) help decide future investments and decisions on oil reserves to improve energy security, and iii) allow for planning of future energy needs, as well as to identify national infrastructure and research and development requirements.

More recently, environmental concerns such as climate change and global warming have re-emphasized global fuel demand as a major theme, with a particular focus on the automobile. This is because one sixth of global greenhouse gas emissions are estimated to be produced from this sector (Potoglou and Kanaroglou, 2007). The recognition that economic development has been conditioned by its negative effects on the environment has resulted in recent global efforts to decrease the emissions of greenhouse gas emissions (primarily carbon dioxide or CO_2) in order to reduce anticipated atmospheric warming and other changes in global climate. In looking at car fuel demand, many studies have concentrated on petrol, given that cars represent one of the major consumers and petrol is the dominant fuel source for the current passenger car fleet (for studies that do not look solely at automobile petrol demand, see e.g., Birol and Guerer, 1993; Samimi, 1995).

This paper has two main purposes, namely academic and practical. In the transport and energy literature, petrol demand forecasting is an important topic with hundreds of studies having been undertaken in this area (see e.g., Banaszak *et al.* 1999; Murat and Ceylan, 2006). Researchers have used various types of modelling methods to estimate petrol demand. Whilst some studies have examined different approaches, these have typically only explored theoretical differences, usually without undertaking an empirical comparison of the practical usefulness in forecasting fuel demand (see e.g., Hunt *et al.*, 2003).

This paper addresses this gap in the literature by empirically comparing the effectiveness of different forecasting models on fuel demand forecasts. In doing so, we describe not only the theoretical elements of the various models, but also the set of practical considerations that define the appeal of specific models. We test the accuracy of each of the forecast models by measuring forecast errors from a hold out sample of data. In total, eight models are estimated, namely a linear trend model, a quadratic trend model, an exponential trend model, a single exponential smoothing model, a Holt's linear model, a Holt-Winters' model, a partial adjustment model (PAM), and an autoregressive integrated moving average (ARIMA**)** model. The empirical data used to test alternative model specifications is drawn from Australia.

Apart from its academic purpose, this paper also provides insight into practical applications. To date, a number of policy instruments have been introduced to reduce CO_2 such as carbon taxing, congestion charging, etc. The question is that which policy is capable of delivering a substantial abatement in CO_2 with a relatively low cost. We evaluate the impact of several potential tools on CO_2 by using TRESIS, an integrated transport, land use and environmental strategy impact simulation program so as to provide rationale to establish the suitable actions to reduce CO_2 from automobiles. TRESIS is applied to the Sydney metropolitan area.

The organisation of this paper is as follows. After introducing a profile of the Australian automobile fleet including its fuel consumption, greenhouse gas emissions, and some environmental policy instruments on automobile, eight forecasting models are briefly presented. This is followed by a brief introduction of TRESIS as the evaluation framework to assess the impact on CO_2 of several potential instruments including a carbon tax, a congestion charge and improved fuel efficiency. The next session presents forecasting results of eight models, followed by the scenarios analysis of those proposed policies to reduce car emissions. Conclusions are then drawn along with a discussion of the major findings as well as some key recommendations.

2. The automobile fleet in Australia

2.1 The automobile and its fuel consumption

In 2005, the total number of road transport vehicles in Australia was estimated to be over 13.9 million. Of these, approximately 80 percent were classified as passenger cars (ABS, 2006a). A significant characteristic of automobile usage in Australia is the high reliance on petrol, with 94 percent of automobiles using petrol as the primary source of combustion in Australia (ABS, 2007a). In 2005, approximately 28,967 million litres of road transport fuel was consumed. 64.6 percent (i.e., 18,712.7 million litres) was petrol, 30.0 percent diesel fuel (i.e., 8,690.1 million litres) with the remaining consumption representing other fuels (ABS, 2006b).

These figures can be further broken down into different vehicle types. In Australia, automobiles consumed 15,856 million litres of petrol or 85 percent of total road petrol consumption in 2005, and articulated and rigid trucks (two main types of freight vehicles) used 65 percent of road diesel during the same period (ABS, 2006b). If light commercial vehicles and non-freight carrying trucks were also considered, the diesel share of goods vehicles would be much higher than 65 percent. However, the diesel share of passenger cars was only 3.8 percent in 2006 (ABS, 2007a). These figures reveal that automobiles represent the major end users of petrol, and the consumption of road petrol is highly correlated with automobile usage.

Coupled with high petrol consumption, Australia has also exhibited strong growth in car ownership. From 2001 to 2005, the number of automobiles increased by 12.5 percent, with fuel consumption by road motor vehicles increasing by 3,019 million litres. Road traffic for the corresponding period increased from 206,383 to 31,972 million tonne-kilometres (ABS, 2006b). Whilst there exist many possible causes for this, the two key drivers of these increases are thought to be i) continuing growth in household incomes and ii) increases in population, given that Australian population increased by 1.2 million over the period 2001-05, and meanwhile the average individual income jumped by 24 percent according to the Australian Bureau of Statistics.

2.2 Greenhouse gas emissions from cars

Combustion of fuel is directly linked with emissions. In Australia, transport is the third largest greenhouse gas producer followed by stationary energy and agriculture. In 2005, 80.4 Mt CO_2-e (million tonnes of carbon dioxide equivalent) or 14 percent of national net emissions were produced by transport (Australian Greenhouse Office, 2007). As the largest transport source, automobiles contributed 43.7 Mt CO_2-e or 7.8 percent of national emissions in 2005. Emissions from automobiles increased by 25 percent between 1990 and 2005, which exhibited a faster growth than Australia's national emissions being two percent over the same period (Australian Greenhouse Office, 2007). This has to some extent assisted Australia to generate the highest greenhouse gas emissions per capita among the industrialised countries (Saddler *et al*., 2007).

One primary contributor to the significant increase in car emissions is the car ownership growth, given that the number of passenger cars increased by 16.5 percent between 2001 and 2007, and reached 11.46 million in 2007 (ABS, 2007a). The trend is continuing, even under the situation where nominal petrol prices jumped from over A$1.20 for a litre of petrol at the end of 2007, to over A$1.60 in June 2008. 70,539 new passenger vehicles[1] were sold in June 2008, increasing by 0.62 percent compared with the sales in June 2007 (ABS, 2008).

Despite such a radical increase in car numbers, average fuel efficiency of automobiles with petrol engines only changed from 11.3 to 11.2 litres per 100 kilometres over the period 2000-06 (ABS, 2001; ABS, 2007b). Given the rising car ownership and steady fuel efficiency in

[1] Sports utility vehicles are included in the category of passenger cars herein.

Australia, automobile petrol consumption increased by 13 percent or 1,972 million litres between 2000 and 2006 (ABS, 2001; ABS, 2007b). The continuing growth in car fuel consumption along with its emissions is expected to challenge Australia's Kyoto reduction target that is to keep at 108 percent of the 1990 greenhouse gas emissions level between 2008 and 2012 (Department of Climate Change, 2008).

2.3 Environmental policy instruments on passenger cars

There are two main categories of policy instruments aiming at reducing fuel consumption and emissions. These are i) technological advancement, and ii) pricing (or taxing) regimes. The improvement in fuel efficiency is a typical example of the former strategy. The first compulsory regulation on road vehicle fuel efficiency or fuel economy is the Corporate Average Fuel Economy (CAFE) standards introduced by the United States in response to the 1973 oil crisis (Bezdek and Wendling, 2005). Under this scheme, all new registered cars and light trucks must perform beyond the standards, which is currently set at 27.5 mpg (or 8.6 litres per 100 kilometres) for passenger cars (Zachariadis, 2006). The system works such that if a manufacturer fails to meet the CAFE standards, a penalty is applied. The CAFE standards have contributed to a sizable reduction in fuel consumption as well as emissions over the past three decades. In addition to America, other countries have also implemented vehicle fuel economy standards, such as Japan and the European Union. However, Australia has not yet embraced a compulsory rule to regulate car manufactures in terms of improvements in car fuel efficiency. In the absence of a regulation on fuel efficiency, as noted previously, the average car fuel efficiency only improved by less than one percent between 2000 and 2006.

With respect to environmentally related taxes levied on cars[2], Australia has i) excise taxes on fuel (e.g., A$0.38 per litre on unleaded petrol; A$0.40 per litre on diesel, etc.), ii) registration fees, and iii) stamp duties. These charges can be classified into two categories: fuel related taxes (i.e., excise taxes) and car related taxes such as luxury car tax, registration fees and stamp duties. However, these policies have a common disadvantage. That is a lack of direct connection with emission abatement, unlike a carbon tax.

A carbon tax is a tax imposed on energy sources releasing carbon dioxide (e.g., petrol, diesel, etc.) to reduce CO_2 emitted into the atmosphere, through its pricing effect on fuel consumptions and energy selection (Zhang and Baranzini, 2004). It has been found by some studies that a carbon tax is more cost-effective than a fuel tax and car related taxes (see e.g., Baranzini *et al.*, 2000; Johansson and Schipper, 1997). The first carbon charging scheme was introduced by Finland in January 1990. Since then, Sweden, Denmark, the Netherlands, Norway and Italy also introduced carbon taxes in the 1990s. Most of those countries have achieved significant emission abatements after implementing carbon taxes. For example, Denmark's total CO_2 emissions decreased by 5.7 percent from 1990 to 2005, and Finland achieved a 14.6 percent decrease between 2004 and 2005 (EEA, 2007).

Besides emissions, another issue related to growing car traffic is congestion. A congestion charge is a strategy to reduce congestion as well as emissions, by charging more during certain times (e.g., peak hours) for the use of roads (Litman, 2007). One type of congestion pricing is the charging for the marginal congestion cost (Nash and Sansom, 2001). It is a distance-based road pricing to discourage the usage of private cars and consequently relieve congestion, as well as reduce emissions. Another type of pricing system is cordon charging. With a cordon toll, drivers have to pay for entering or leaving the charging zone (normally the central city area) during the designated time periods of the day (Santos, 2004).

Singapore implemented a cordon toll scheme in 1975, followed by Bergen in 1986, Oslo in 1990 and Trondheim in 1991 (Santos and Fraser, 2006). More recently, London introduced its cordon toll scheme in 2003, and Stockholm started the full-scale charging trial in 2006

[2] These are sourced from the OECD's Environmentally Related Tax Rate Database at http://www2.oecd.org/ecoinst/queries/selcountry.asp?q=81&qry=Taxbases-Tax%20Rates

(Armelius and Hultkrantz, 2006), and implemented its congestion tax in 2007 (The Swedish Road Administration, 2007). A distance-based congestion charge is going to be introduced in the Netherlands from 2011. Again, to date, nowhere in Australian has the decision been made to implement a congestion charge, even though the environmental effectiveness of a congestion charge could be significant. For example, in the London charging zone, the traffic volume during 2006 decreased by 21 percent compared with the year of 2002, and CO_2 reduced by 16 percent (Transport for London, 2007).

3. Data for forecasting

Quarterly time series data is used for forecasting in this study, including total road petrol consumption (TPC), real gross domestic product (GDP), and real petrol price (RPP) for Australia over the period 1977q1 (the first quarter of 1977) to 2006q4 (the fourth quarter of 2006). The consumer price index (CPI) and petrol price index (PPI) are adjusted to 1998q1 as the base. Total road petrol consumption is measured in megalitres (millions of litres), obtained from three sources: the Department of Primary Industries, Bureau of Transport and Communications Economics (BTCE), and the Department of Industry, Tourism and Resources. The Australian Bureau of Statistics (ABS) and BTCE are the main sources for gross domestic product data. Real GDP is seasonally adjusted to 1998 as the base, measured in million dollars. Nominal retail petrol price (NRPP) in cents is obtained from BTCE and ABS, and real petrol price (RPP) is calculated by adjusting for petrol price index.

The data is divided into two parts. The first dates from 1977q1 to 2005q1 which we use for model and estimation purposes. The remaining data, from 2005q2 to 2006q4 is used as a hold out sample to examine the forecasting effectiveness of different forecasting approaches estimated on the first segment of data.

4. Forecasting models for Australian petrol demand

Approaches for econometric modelling and forecasting may be divided into four categories: (i) models used to estimate relationships between explanatory and dependent variables over periods of time, incorporating underlying economic processes; (ii) models that depict relationships between the past and current values, and forecast future events on the basis of historical outcomes only; (iii) cross sectional methods that analyse relationships between various variables at a point in time for different units; and (iv) approaches that consider relationships between dependent and independent variables for different units over time (Verbeek, 2004). The four types of econometric models require different data types, with the first two methods requiring time series data (i.e., observations on a single event over multiple time periods) with the third method requiring one off cross-sectional data, and the last requiring panel data incorporating the two dimensions of time series and cross-sectional data simultaneously.

In this study, time series data are collected to predict petrol demand in Australia. As such, we limit ourselves to only the first two types of econometric models. Among first category of econometric models, the partial adjustment model (PAM) remains one of the most commonly used models (see e.g., Birol and Guerer, 1993; Al-faris, 1997; Banaszak *et al.*, 1999). For estimating short- and long-run elasticities, the PAM is the most appropriate dynamic model at the individual country level (Sterner *et al.*, 1992). Given the focus herein on petrol demand for a single country (i.e., Australia), the PAM is used for the empirical analysis. The autoregressive integrated moving average (ARIMA**)** model is an example of a model belonging to the second category. In addition to the above two econometric models, other simpler methods are available for use in demand forecasting. These simpler statistical approaches typically provide a straightforward means of directly calculating forecasts. Six simple models are also employed for forecasting, including the linear trend model, the quadratic trend model, the exponential trend model, exponential smoothing, Holt's linear method and Holt-Winters' method, Interestingly, these simpler methods are often forsaken within the literature with a tendency towards the use of more econometrically advanced methods.

In order to identify which method(s) provides the best forecast, with minimal forecasting error, we define and measure forecasting error using the mean absolute deviation (MAD) technique as defined in Equation (1).

$$MAD = \frac{\sum_{t=1}^{n} \left| y_t - f_t \right|}{n} \quad (1)$$

where y_t is the actual observation in time period *t* and f_t is the forecast in time period *t*. According to Levine *et al*. (2005), the mean absolute deviation (MAD) is an effective measure of the average of the absolute differences between the actual observations and the predicted values of a time series. If a forecasting model fits the actual data in a given time series accurately, the MAD will be small.

5. TRESIS: An integrated simulation program

The second part of this paper is used to establish the best strategy to contribute to CO_2 reductions. This is beyond the ability of the above "business-as-usual" forecasting models. As such, we employ another model that uses simulation to address this issue. The relationship among land use, transportation and the environment is critical to growth management, which has led to significant changes in planning and evaluation models (Waddell, 2002).TRESIS (Transportation and Environment Strategy Impact Simulator) is an integrated model recently developed to estimate the impact of transport, land use and environmental instruments from a variety of perspectives such as economic, social, environmental, etc. (Hensher, 2008). TRESIS 1.4 is specifically designed for the Sydney metropolitan with base year of 1998 and has a wide range of performance indicators as outputs. Compared with other integrated simulation models, TRESIS 1.4 offers the following advantages.

- Most models (e.g., UrbanSim) focus on the relationship between land use and transportation. TRESIS 1.4 has the integration among land use, transportation and the environment.

- TRESIS 1.4 is of a variety of performance indicators (e.g., economic, environmental, social equity, etc.), which allows for the systematic evaluation on different policies or different combinations of instruments. By analysing the trade-offs among several key indicators, the most suitable strategy can be suggested in terms of cost effectiveness.

- TRESIS 1.4 is capable of delivering long-term scenario analysis (until 2025).

Given those merits of TRESIS 1.4, we use TRESIS 1.4 as the framework to evaluate those policy instruments introduced in the second section (i.e., improvements in car fuel efficiency, carbon taxing and congestion charging) in the Australian context, and further suggest the appropriate way to reducing car emissions.

In TRESIS 1.4, each instrument is evaluated by a number of indicators. As we are particularly interested in the environmental impact of different policies, total annual carbon dioxide (TCO_2) is selected as a key indicator. Also from a transport planning perspective, total annual passenger vehicle kilometres (TVKM) and modal share (shown as the growth in patronage) are also important to identify the changes in traffic and travel behaviours. Besides its effect on environment, the corresponding cost of an environmental policy should also be considered, such as total annual auto VKM operating cost (VehOpCost). Government revenue is also included for the economic analysis.

6. An evaluation of forecasting results

All models reported here were estimated using Statistical Package for the Social Sciences (SPSS 15.0) and Statistical Analysis System (SAS 9.1). We now outline the results of the eight forecasting models3. After estimating forecasts from those eight models, we calculate MADs to determine the forecasting ability of the different models, given in Table 1. The examination of the results produces some interesting conclusions. Firstly, all models provide reasonably accurate forecasts, with the MAD estimates in percentages varying from 3.63 percent to 6.09 percent. The short-run forecasting accuracy is between 93.91 percent and 96.37 percent. Secondly, the quadratic trend model produces the best forecasts, with a MAD value of 170.14 and a forecasting error of 3.63 percent. Thirdly, simpler models (particularly the trend-fitting models) tend to outperform the more sophisticated models such as the ARIMA model. Fourthly, the results show that forecasting accuracy tends to decrease, as the forecasting horizon increases. Fifth, most estimated forecasts are larger than the real value of the observations as most forecast errors are negative. Finally, the demand for road petrol in Australia shows an increasing trend over time, which the forecasts show are likely to continue into the future.

6.1 Optimal forecasts

The quadratic trend model[4] is identified as the best-forecasting model. Thus, it is used to estimate quarterly petrol demand from 2007 to 2020. The seasonal forecasts for several time spans are given in Table 2. The estimated forecasts show that annual road petrol demand is expected to reach 22,436.49 megalitres by 2020 which is 22.2 percent more than consumption in 2000 (i.e., 18,360.6 megalitres)[5]. The passenger car sector has been the major road petrol consumer in Australia and its petrol share remained unchanged for almost a decade, according to a series of ABS Survey of Motor Vehicle Use. Approximately 85 percent of Australian road petrol was consumed by automobiles in 2006 (ABS, 2007b). Assuming that this share figure keeps constant at 85 percent until 2020, 19,071.02 megalitres of petrol would be consumed by automobiles by 2020, which is approximately 18 percent higher than automobile petrol consumed in 2000, given that 88 percent of total road petrol was consumed by automobiles in 2000.

[3] For the detailed estimation and analysis for those eight models, please see another paper (Li, Rose and Hensher, 2008)

[4] An quadratic trend form is given in this equation: $y_t = \beta_0 + \beta_1 x_t + \beta_2 x_t^2 + \varepsilon_t$, where The independent variable (x) is the time period code, starting from "0".

[5] Our data series goes up to 2006. The big spike in petrol prices occurred in 2008, with average prices increasing from $Aud1.20 to $Aud1.60 in the first half of 2008. This is likely to deflate the forecasts, although we suspect that this will be a small adjustment given the relatively small amount of aggregate disposable income spent on car use (in contrast to car ownership). We also expect that manufacturers will respond by delivering more fuel efficient cars to the market, like they did in the 1970's after the price increases. The big influence on demand growth will remain population growth.

Table 2: MADs of different forecasting models

Year/Quarter	Real values	Linear Trend			Quadratic Trend			Exponential Trend			Single Exponential Smoothing		
		Forecasts	Errors	Error%	Forecasts	Errors	Error%	Forecasts	Errors	Error%	Forecasts	Errors	Error%
05Q2	4790.63	4901.86	-111.23	-2.32%	4899.60	-109.23	-2.27%	4902.30	-111.67	-2.33%	4958.81	-168.18	-3.51%
05Q3	4633.43	4913.77	-280.34	-6.05%	**4911.39**	-278.22	-6.00%	4915.87	-282.43	-6.10%	4958.81	-325.38	-7.02%
05Q4	4891.58	4925.68	-34.10	-0.70%	**4923.18**	-31.86	-0.65%	4929.47	-37.89	-0.77%	4958.81	-67.23	-1.37%
06Q1	4726.00	4937.58	-211.59	-4.48%	4934.96	-209.24	-4.42%	4943.11	-217.11	-4.59%	4958.81	-232.82	-4.93%
06Q2	4596.84	4949.49	-352.64	-7.67%	4946.74	-350.18	-7.61%	4956.78	-359.94	-7.83%	4958.81	-361.97	-7.87%
06Q3	4791.90	4961.39	-169.49	-3.54%	4958.52	-166.91	-3.48%	4970.50	-178.60	-3.73%	4958.81	-166.91	-3.48%
06Q4	4923.30	4973.30	-50.00	-1.02%	4970.30	-47.29	-0.95%	4984.25	-60.95	-1.24%	4958.81	-35.51	-0.72%
		MAD =	172.77	3.68%	**MAD =**	**170.14**	**3.63%**	MAD =	178.37	3.80%	MAD =	194.00	4.13%
Year/Quarter	**Real values**	**Holt's Linear Method**			**Holt-Winters' Method**			**ARIMA**			**Partial Adjustment Model**		
		Forecasts	Errors	Error%	Forecasts	Errors	Error%	Forecasts	Errors	Error%	Forecasts	Errors	Error%
05Q2	4790.63	4978.34	-187.71	-3.92%	4900.09	-109.46	-2.28%	**4809.25**	-18.62	-0.39%	4978.62	-187.99	-3.92%
05Q3	4633.43	4991.47	-358.03	-7.73%	5042.89	-409.46	-8.84%	5037.24	-403.81	-8.72%	4969.71	-336.28	-7.26%
05Q4	4891.58	5004.59	-113.01	-2.31%	5209.74	-318.16	-6.50%	5219.94	-328.36	-6.71%	4958.98	-67.40	-1.3%
06Q1	4726.00	5017.71	-291.72	-6.17%	4918.55	-192.56	-4.07%	**4880.98**	-154.99	-3.28%	5021.88	-295.88	-6.26%
06Q2	4596.84	5030.83	-433.99	-9.44%	4950.29	-353.45	-7.69%	**4869.63**	-272.79	-5.93%	4882.88	-286.04	-6.22%
06Q3	4791.90	5043.95	-252.05	-5.26%	5094.43	-302.53	-6.31%	5098.52	-306.62	-6.40%	**4875.47**	-83.57	-1.71%
06Q4	4923.30	5057.08	-133.78	-2.72%	5262.84	-339.54	-6.90%	5282.66	-359.36	-7.30%	**4890.75**	32.55	0.066%
		MAD=	252.90	5.36%	MAD=	289.31	6.09%	MAD=	263.51	5.53%	MAD=	184.24	3.92%

Table 2: Quarterly petrol demand forecasts (Megalitres) 2007-20

	2007	2010	2015	2020
Q1	4982.08	5123.23	5357.84	5591.62
Q2	4993.85	5134.98	5369.54	5603.29
Q3	5005.62	5146.73	5381.25	5614.96
Q4	5017.39	5158.47	5392.96	5626.62
Annual	19998.94	20563.41	21501.58	22436.49

The continuing growth in petrol consumption is expected to produce more emissions and hence challenge the environment in terms of climate change, global warming, etc. The result estimated from the partial adjustment model of this study shows that income is the primary factor influencing road petrol demand[6]. It is critical to find ways to reducing greenhouse gas emissions without having a detrimental impact on the economy. These above forecasting models are all developed under the "business-as-usual" scenario, and are not capable of conducting "what-if" scenarios analysis of potential changes or interventions. In order to discover the ability to reduce emissions, TRESIS 1.4 is used to estimate the impact on CO_2 of several instruments such as improvements in fuel economy, a carbon tax and a congestion charge.

7. Policy scenarios

TRESIS is applied to the Sydney metropolitan area with the chosen policy instruments implemented in 2011 up to 2018, including a 50c/kg (50 cents per kilogram) carbon tax, a 5c/km (5 cents per kilometre) congestion charge for the entire Sydney metropolitan area (or a variable user charge) from 7am to 6pm every day, and a five percent improvements in car fuel efficiency per annum. Table 3 contains the estimated results of all chosen policy instruments.

A 50c/kg carbon tax would lead to a 5.57 percent reduction in total annual vehicle kilometres, along with a 5.9 percent decrease in total CO_2 emissions from cars. The total car operating cost would rise by 33 percent. This policy is expected to discourage car use and meanwhile stimulate public patronage; for example, car travel would be reduced by 3.72 percent for driving alone, whilst rain travel would increase by 27.88 percent. More government revenue is expected to generate through this policy. The TRESIS result also supports the finding of the partial adjustment model in this study. That is, petrol demand is price inelastic. In TRESIS, one litre of petrol is assumed to contain 0.635775 kg *Carbon* (Hensher, 2008). A 50c/kg carbon tax is equivalent to a 31.79c increase for a litre of fuel. Given the current petrol price being A$ 1.60 a litre, a 50c/kg carbon increases the petrol price by 20 percent, and would decrease fuel consumption by 5.9 percent. This implies a price elasticity of -0.294.

We also examine the effect of a 5c/km variable user charge. This policy would deliver a smaller reduction in CO_2 being 2.95 percent compared with a 50c/kg carbon tax; however the car operating cars would be reduced by 2.95 percent. This reduction is mainly contributed by the significant switch from private cars toward public transport (e.g., a 33.56 growth for train). Government would gain a 64.71 percent increase in revenue.

[6] We estimated short-run price and income elasticities being -0.216 and 0.267 respectively, and -0.294 and 0.363 for the long run

Table 3: Policy scenarios of selected instruments in 2018

(Policy enacted from 2011)

Indicators	**50c/kg Carbon tax**	**5c/km Variable user charge metro area 7am – 6pm**	**Fuel efficiency improvement by 5% annually**
TCO_2 (kg)	-5.9%	-2.95%	-22.57%
Tenergy (litres)	-5.9%	-2.95%	-22.57%
TVKM (km)	-5.57%	-2.92%	5.02%
VehOpCost	33.0%	-2.95%	-22.88%
Total Government revenue ($)	*30.53%*	*65.02%*	*-13.17%*
Commuter Mode growth			
TDA	-3.72%	-4.77%	1.88%
TRS	-3.34%	-5.26%	1.71%
TTrain	27.88%	33.56%	-13.87%
TBus	19.77%	33.06%	-10.36%
TLight Rail	8.15%	2.23%	-4.65%
TBwy	46.38%	64.71%	-21.3%

- Tenergy: total fuel consumption. The reduction in CO_2 is through lower fuel consumption.
- Commuter Mode growth: These percentages are growth in patronage (with and without the policy).

TDA:	Modal growth for car drive alone
TRS:	Modal growth for ride share
Ttrain:	Modal growth for train travel
Tbus:	Modal growth for bus travel
TLrl:	Modal growth for light rail travel
Tbwy:	Modal growth for busway use

The scenario of improved car fuel efficiency is also presented herein. Unlike the above two policies with the effect of increasing public patronage, a five-percent improvement in car fuel efficiency per annum would cause more use of private cars. Meanwhile, car operating costs would decrease by 22.88 percent. Thus, total vehicle kilometres are expected to increase by 5.02 percent due to the rising car use and lower motoring cost. However, this strategy would directly result in a 22.57 percent decrease in CO_2 by 2018 though the saving in fuel. Government revenue is expected to decrease mainly because of less fuel excise.

From the environmental perspective, the policy scenarios assessed herein suggest that improved fuel efficiency is the most effective policy in terms of reducing CO_2, given that a five-percent annual improvement in passenger car fuel efficiency would lead to a 22.57 percent reduction in CO_2 in 2018. However, as we discussed before, this policy would stimulate private car use and hence may cause another problem that is congestion.

Given that the major limitation of improved fuel efficiency is to increase car travel, a pricing scheme should also be levied on car use. Thus, a mix of improved car fuel efficiency and a charge on cars is suggested in stead of a single approach. Both a carbon tax and a variable user charge are of the ability of reducing car use. However, we herein chose the carbon tax as the pricing tool. The reason for this is explained as follows.

A variable user charge is a distance-based charge. That is, the driving distance is the only parameter to this charging system. If this type of congestion charging[7] were implemented, drivers pay the same fee for an equivalent distance regardless of the mode of cars, small, medium or luxury. However, a carbon tax is levied on the quality of carbon emitted from the consumption of fuels with the carbon component. In another world, carbon taxation is directly linked with the amount of fossil fuels consumed, which is determined by driving distance and average fuel consumption per kilometre. Unlike a variable user charge, a carbon tax takes both distance and fuel efficiency into accounts. Thus, if a carbon tax were implemented, a person driving a car with higher fuel consumption per kilometre should pay more for an equivalent distance.

Both a carbon tax and a variable user charge have a positive impact on public transport patronage growth. However, theoretically, a carbon tax is also able to increase the share of more fuel-efficient cars, given that less charge would be applied to cars with better fuel economy under a carbon tax. TRESIS 1.4 is not only cable of capturing the mode switch between private cars and public transport, but also the shift among ten types of traditional-fuel cars classified as micro, small, large, luxury, etc. Generally, the size of a car is correlated its fuel consumption. That is, a larger-size car tends to consume more petrol. For example, in Australia, the average fuel consumption per 100 kilometres for a micro (or subcompact) petrol car is 7.1 litres, 8.9 litres for a small (or compact) car, 10.6 litres for a medium-size car, etc[8].

A 50c/kg carbon tax would increase the micro car and small-size car by 3.03 percent and 2.08 percent respectively, whilst other classes of cars are all expected to decrease, with the biggest looser being the four-wheel drive vehicle[9] decreasing by 1.84 percent. However, a 5c/km variable charge would only deliver a 0.23 percent increase in micro cars and a 0.18 percent reduction in small-size cars. These two taxing regimes have different impact on motoring cost, which can be viewed through fuel prices[10]. In part due to the lack of ability to encourage cars with better fuel efficiency but also linked to its higher cost on fuel, more people are expected to switch to public transport under this variable user charging scheme. Using the bus as an example, TRESIS 1.4 reveals that a 5c/km variable user charge would increase bus patronage by 33 percent which is larger than the impact of the proposed carbon tax being a approximately 20 percent growth (see Table 3).

We present the results of two different combinations. If the mix of a five-percent fuel economy improvement and a 5c/km variable user charge were implemented, public transport patronage would have a sizeable increase as we explained before, for example a 15.32 growth in train travel and a 14.77 growth in bus travel. The considerable growth in public transport demand would be a challenge to the current public transport system in Sydney, given that it is already running at its nearly full capacity (Open Road, 2008). Without a substantial investment in improving public transport infrastructure to accommodate rising patronage, this combined strategy would incur a risk that is overcrowding in bus and train, and consequently driving people back to cars. Therefore, although this mix would deliver a 25.39 percent reduction in CO_2 by 2018, it is not a feasible strategy for Sydney unless the public transport system is improved in terms of capacity, frequency, etc.

Another combination of the same car fuel efficiency improvement and a 50c/kg carbon tax would have a similar impact on CO_2 being a 26.29 percent decrease by 2018. Moreover, this mix would to some extent reduce car use being approximately 0.37 percent. If we break down

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[7] Another type of congestion charging is a cordon toll; it is not distance based, but charging zone based (see e.g., the London congestion charge).

[8] These fuel consumption figures are obtained from an ongoing study – Regional TRESIS for the State of New South Wales, Australia.

[9] Its average fuel efficiency is 14.8 litres of petrol per 100 kilometres in Australia.

[10] A 50c/kg carbon tax is equivalent to a 31.79c increase in petrol price per litre. Given the average car fuel efficiency of 11 litres per 100 kilometres, a 5c/km variable user charge adds on an extra cost of 45.45 cents per litre on fuel

car travel into different classes, cars with high fuel consumption would be decreased (e.g., a 1.1 percent decrease for four-wheel drive), whilst cars with better fuel economy would be stimulated (e.g., a 0.18 percent increase for the micro car).More importantly, the mix of improved fuel efficiency and a carbon tax would not impose a dramatic pressure on the current Sydney's public transport system (e.g., a 3.29 percent increase in train patronage and a 2.29 percent increase in bus patronage). Hence, this strategy is preferred compared with the previous mix in which a variable user charge is considered. Therefore, we suggest the combined strategy of improvements in car fuel efficiency and a carbon tax to contribute to reducing emissions from cars and meanwhile avoiding traffic congestion.

8. Conclusions

This paper employed eight models to predict future Australian automobile petrol demand. Different models were estimated allowing for a comparison of forecasts to establish which model is most likely to produce the more accurate forecasts. To evaluate forecast performance, a hold out sample was employed to test the effectiveness of corresponding forecasts. Based on the best-forecasting model (i.e., the quadratic trend model, with a MAD value of 170.14 and a mean absolute error of 3.63 percent in a short run), the annual demand for road transport petrol in Australia is expected to increase by approximately 22.2 percent from 2000 to 2020, with automobile petrol demand forecast to increase by about 18 percent over the same period, and reach 19,071.02 megalitres in 2020.

Through the partial adjustment model, we estimated short- and long-run elasticities for Australian road petrol demand. The short-run price and income elasticities are -0.216 and 0.267 respectively, and -0.294 and 0.363 for the long run. By applying these estimates in forecasting, the MAD value for the PAM is 184.24 or a mean absolute percentage error of 3.92 percent. This suggests that the responsiveness of petrol demand to price and income changes was well captured in this model. These estimates also support the common findings of many other studies that i) petrol demand is price inelastic, and ii) income has a more significant impact on consumption than petrol prices.

Rising petrol consumption is directly linked with more emissions from automobiles. This could be a threat to Australia's emissions abatement target that is at 108 percent of the 1990 emissions level over the period 2008-12. Using Sydney as an example, we investigated the ability of several policy instruments (i.e., improved car fuel efficiency, a carbon tax and a variable user charge) to reduce CO_2, as well as their economic and traffic impacts. The results of TRESIS 1.4 have shown that improved car fuel efficiency would contribute to the most substantial reduction in CO_2 among those three environmental instruments. The opportunity gap for increasingly fuel-efficient vehicles in Australia is shown that the Federal Government is planning to allocate A$ 35 million to build a new car model in Melbourne – the hybrid Camry car by Toyota (The Australian, 2008). Compared with conventional vehicles, the hybrid car uses less fuel and hence produces less CO_2. For example, the average fuel consumption per 100 kilometres for Prius (a hybrid car produced by Toyota) is 4.4 litres of petrol, while the average Australia's passenger car fuel efficiency is 11.2 litres of petrol per 100 kilometres in 2006.

Although improved fuel efficiency is capable of reducing fuel consumption and CO_2, it would stimulate car use and consequently cause congestion. Therefore, instead of a single policy, we suggest a mix of improved car fuel efficiency and a carbon tax. The reason for not choosing a variable user charge is that it would lead to a sizeable growth in public transport demand which is not a feasible approach to countries or cities without additional capacity, such as Sydney. Thus, a carbon tax is a better choice as the pricing tool on car use, given that it has a smaller impact on patronage growth. As an example, the combined strategy of a five-percent annual fuel economy improvement and a 50c/kg carbon tax would deliver a 26.3 percent decrease in CO_2 by 2018; meanwhile, private car usage would be slightly decreased, without a sizable increase in public transport demand. Thus, the target of reducing emissions from cars could be fulfilled without the side effects including traffic congestion and overcrowding in public transport. This strategy is also expected to encourage more fuel-efficient cars to support sustainable development.

Finally, we conclude that automobile petrol demand will continually attract the attention of academics and governments throughout the world into the future. This is because this topic remains a major theme related to reducing the reliance of automobile fossil fuel (particularly petrol) usage.

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