The rebound effect of the Australian proposed light vehicle fuel efficiency standards

Jiayu Wang(a), John Quiggin(b), Glyn Wittwer(c)

a. ITLS, The University of Sydney
b. School of Economics, The University of Queensland
c. CoPS, Victoria University

Abstract

Australia is planning to take action to tackle climate change via improvements in light vehicle fuel efficiency. The proposed light vehicle emissions standards are expected to reduce petroleum use as well as greenhouse gas emissions from passenger vehicles, sports utility vehicles and light commercial vehicles. Consumers of light vehicles, including private households and firms, will respond to this policy in a way that maximise their utility based on economic theory. On one hand, these economic agents will use less petrol, through directly purchasing more efficient new cars to react to the mandatory standard. On the other hand, the more efficient vehicle will provide an incentive for the consumers to use it more as the effective cost of driving decreases. Understanding these economic and behavioural responses to the policy is crucial for policymakers. This paper contributes to the empirical studies of the rebound effect by simulating the business-as-usual (BAU) and policy scenarios in a computable general equilibrium framework. The direct rebound effect of the Australian proposed light vehicle fuel efficiency standards are shown to range between 25 per cent and 30 per cent, measured by petroleum use. Each of these policy scenarios is shown to have a much larger economy-wide rebound effect, reaching up to 50 per cent measured by life-cycle greenhouse gas emissions. Although the stringent fuel efficiency standard generates more direct rebound effects measured in percentage than the lenient and medium standards, the stringent policy produces the most reduction in carbon emissions measured in physical units overall. This paper concludes by providing comprehensive understanding of the Australian proposed light vehicle fuel efficiency standards and offering policy recommendations based on the CGE simulation results.

Keywords

Energy efficiency
Fuel consumption
Rebound effect

Computable general equilibrium
Carbon dioxide emissions
Greenhouse emissions reduction

1. Introduction

The Australian Government has planned to set mandatory greenhouse gas emission targets for new light vehicles, based on Australia's strategy for CO_2 emissions reductions for passenger and light commercial vehicles (CCA, 2014). The government proposed to set a vehicle fleet average carbon intensity target for new vehicles sold in Australia that matches the international levels

Globally, fuel efficiency standards have become a favoured legislation option in many countries. For example, the USA established the Corporate Average Fuel Economy (CAFE) target for the new vehicle fleet in 1975. The CAFE program created by the US was first designed to tackle the oil price instability that had resulted from the 1970's oil embargo. A crucial development of the CAFE is an inclusion of the greenhouse gas (GHG)emission target set by the previous Obama Administrations (NHTSA, 2011).

The European Union has also made great strides in their legislation covering mandatory CO_2 emissions from new light-duty vehicles. The EU mandated passenger vehicles and light commercial vehicles emissions separately. The CO_2 emissions mandates resemble the US CAFE standards; the target measured by carbon dioxide emissions can be directly translated into goals measured by fuel economy. For example, following the formula provided by ICCT90 (2014a), the 2020 EU target for passenger vehicles 95 g/km translates to 3.8/km or 5.74 miles per gallon (mpg) of petrol, given the mix of the fuel type and the carbon content of each fuel type. However, the Australian car market lacks both a fuel efficiency standard and CO_2 emissions standards. This shortage might be one of the reasons why Australian vehicles are larger and less fuel-efficient.

However, there has been a debate on the effectiveness of fuel efficiency standards in the decades since the legislation of the US CAFE. For example, Karplus et al. (2013) identified that fuel efficiency standards could be at least six to fourteen times costlier than a gasoline tax in reaching a 20% decrease in overall gasoline use.

While energy efficiency mandates have become one of the most popular policy instruments around the world in climate change, according to many economists, this policy may encourage consumption of energy-goods and services, thus offsetting the desired energy conservation. This phenomenon has been termed the "rebound effect" by economists Greene, 1992, Sorrell and Dimitropoulos, 2007. Consider for a moment the case of the fuel efficiency improvement of a passenger vehicle. Suppose also that this technological improvement is costless and exogenous. First, the fuel requirement per kilometre driven is reduced, and if the motorist travels the same distance as before, the direct reduction in fuel use is the product of the fuel efficiency progress and the total distance travelled. This direct effect of a fuel efficiency improvement is termed the “mechanical effect” in this thesis. Secondly, as fuel use per kilometre decreases, so does the fuel cost per kilometre. Following the law of demand, which states that as the price of a good or service (distance travelled by a private motor vehicle) decreases, demand for it will increase, if the good or service is normal, *ceteris paribus*, the distance travelled by the vehicle will increase. The difference between the fuel use for the new distance travelled in the new car and the fuel use for the old distance travelled in the new car is termed the “behavioural effect”. The rebound effect is the ratio of the behavioural effect to the mechanical effect, usually expressed as a percentage. When the rebound effect is large, the energy conservation becomes small. If the rebound effect is 100 per cent, for instance, the expected energy savings are completely offset by the behavioural effect. If the rebound effect is larger than 100 per cent, more energy is required to meet the growth in demand, a phenomenon termed “backfire” by rebound researchers Gillingham et al., 2015, Turner, 2013.

Knowledge of the computable general equilibrium (CGE) modelling approach is essential for understanding the rebound effect of energy efficiency policies. The direct rebound effect results from an increase in energy services or goods, after an improvement in the energy efficiency in producing these services or goods (Sorrell and Dimitropoulos, 2008). The economy-wide rebound effect, however, results from an increase in all goods and services after an improvement in energy efficiency in producing a single energy service or good. While a partial equilibrium technique could be exploited to estimate the direct rebound effect, it provides limited insight into the economy-wide adjustments of an energy efficiency improvement. CGE models, however, are capable of capturing the adjustment changes in prices, consumption and production that are led by the energy efficiency improvement. In fact, CGE models are widely used in the exploration of impacts of energy and environmental policy on energy consumption, CO_2 emissions, and economic welfare at a regional, national or global level Adams et al., 2015, McDougall and Golub, 2007, Paltsev et al., 2005. However, investigation into the rebound effect in the CGE area is limited, and the results of these attempts are inconclusive.

Although some research has been carried out on the economy-wide rebound effect in the CGE area, there is still very little distinction between the rebound effects from different economic agents. So far, most studies have investigated energy efficiency improvement on the industrial level. For example, Hanley et al. (2009) imposed a 5 per cent improvement in the efficiency of energy use across all industrial sectors and found a rebound of over 100 per cent in a dynamic CGE model of the Scottish economy. Koesler et al. (2016) studied a costless 10 per cent increase in energy efficiency in all eight production sectors and showed an economy-wide rebound effect of around 50 per cent in the German economy.

Surprisingly, the rebound effects of energy efficiency improvements at the household level have not been closely examined. In addition, the economy-wide rebound effect of a specific energy efficiency policy has not been investigated by CGE modellers and rebound researchers. The goal of this work, therefore, is to study the rebound effects of a specific energy efficiency policy at the household and industrial levels. The policy of interests in this study is the Australian proposed light vehicle efficiency standards (CCA, 2014). The proposed light vehicle emissions standards have two aims: (1) reducing automotive fuel use and (2) reducing greenhouse gas emissions. Therefore, we incorporate a satellite account of the embodied CO_2 emissions of the life-cycle assessment to provide a rebound effect measured in the unit of CO_2-equivalent.

We use the ORANI-G, a disaggregated CGE model for the Australian economy to examine the economy-wide rebound effect of the mandatory standards on light vehicle sales. The baseline equilibrium is obtained from the 2012–2013 input–output table published by the Australian Bureau of Statistics (ABS, 2015a). To evaluate the proposed mandatory standards, we first design the benchmark, or the business-as-usual scenario, for 2020. In the benchmark, fuel efficiency improves exogenously and rises in cost without policy intervention. This improvement in fuel efficiency is estimated via a VAR model by Wang (2018), where the author took a time series analysis approach and consider the consumer preference on the vehicle compositional change. We then conduct a policy simulation, in which the fuel efficiency target is obtained from CCA's report (2014a). With regard to additional costs of vehicles as well as regulation costs, the findings from CCA's report show net consumer benefits and trivial regulation costs. We take the findings from CCA, thereby imposing no cost in the policy scenario. By comparing the results of the policy simulation with those in the benchmark, we deduce the economy-wide rebound effect of the light vehicle emissions standards.

This study is organised as follows. Section 2 provides a detailed literature review of the CGE modelling of the rebound effect, with a focus on the modelling approaches. Section 3 presents the theoretical structure of the ORANI-G model, which is used for simulating the Australian proposed light vehicle emissions standards, and the implementation of the policy simulation in the ORANI-G model. Section 4 provides the simulation results and identifies the economy-wide rebound effect of the proposed policy. A life-cycle assessment of embodied carbon dioxide emissions approach is adopted, to estimate the indirect and the economy-wide rebound effect. Section 5 concludes the study.

2. Literature Review of the CGE modelling on the rebound effect

Computable general equilibrium (CGE) modelling is an important technique that policymakers, economics, and climate scientists use to understand the economy-wide effect of an energy or climate policy. CGE models provide a complete picture of the economic activity, as well as the environmental impacts, such as greenhouse gas emissions. The CGE approach is well known for investigating the effects of a variation in taxes, tariffs and commodity prices on macroeconomic indicators, such as industrial output, labour market, etc. (Dixon et al., 1997). While most of these applications have targeted the economic activity of one country or multi-region, there is now a trend towards applying the CGE model for exploring both the economic and environmental impacts of climate and environmental policies (Chen et al., 2016). However, by taking an environmental viewpoint, CGE modelling requires additional accounts for measuring the impact of a policy on the environment, such as a satellite greenhouse gas emissions account. The model also needs to be modified to incorporate the environmental impacts associated with human-related activities.

The MIT Economic Projection and Policy Analysis (EPPA) model is an excellent example of how the model can be constructed and applied to project the global CO2 emissions under different scenarios (Chen et al., 2016). The Global Trade Analysis Project Energy (GTAP-E) is another outstanding case that illustrates the disaggregated energy sector and substitutability between energy and other primary factors (McDougall and Golub, 2007). The Victoria University Regional Model (VURM) is a well-established multi-sectoral dynamic CGE model of the Australian economy that has been used in projections of the GHG mitigation policies (Adams et al., 2015).

In this study, we develop a different approach toward modelling the environmental policies by linking their environmental impacts to the economic activities of the Australian economy. One of the most important features of the new approach is that it incorporates the life-cycle embodied carbon emissions to the household consumption of each commodity. Thus, the new model provides a platform to analyse the impact of the climate policy with new dataset on the embodied carbon intensity estimated by the life-cycle assessment at the final demander's level, i.e. the representative household.

The main objective of this research is to explain how the CGE model is developed and applied to analyse the Australian proposed light vehicle emissions standards. First, we describe the theoretical framework of ORANI-G, the CGE model developed by Dixon et al. (1997) and updated by Horridge (2003), in terms of model structure and data, as well as key assumptions. Second, we explore the key literature on the price elasticity of petrol to calibrate the corresponding elasticity parameter with the most convincing estimates in the model. Third, we change the household utility function to reflect how the technological change improves the household utility without shifts in taste. For example, the household benefits from the autonomous energy efficiency improvement (AEEI) of light vehicles, which captures non-price driven changes in fuel use over time without a decision to shift to more fuel-efficient vehicles. The technological improvement embedded in the car or other energy appliances enables the household to take advantage of the technological progress that allows the consumer to retain the same utility, with less energy consumption and with less expenditure on energy in the long run. Last, with the satellite account on the life-cycle CO_2 emissions from the household, this new approach gives a complete picture of the effectiveness of the demand-side management (DSM).

CGE models are ideal for analysing the impacts of the energy efficiency improvements and energy policies, because this modelling approach could capture the serial adjustments in the production and final consumption of all goods. As the energy efficiency improves in a certain sector, the effect could further flow into the whole economy. The partial equilibrium model, however, does not take into account the interactions between sectors and agents in the economy and is, therefore, inadequate for offering a systematic solution for analysing the energy efficiency change.

CGE models are well-established tools for energy and climate policy analysis, but applying this tool to the investigation of the economy rebound effect is limited. Within the current CGE studies in rebound effect, approach, results and implications vary significantly.

3. The Theoretical framework of ORANI-G

ORANI-G is a traditional Johansen model that contains numerous cost-minimising producers and a single utility maximising household for the Australian economy. The reason this type of model is called computable and general is because it will "postulate neo-classical production functions and price-responsive demand functions, linked around an input–output matrix in a Walrasian general equilibrium model that endogenously determines quantities and prices". In essence, the CGE model is nonlinear; however, to avoid the computational difficulties in solving a large non-linear system, Johansen (1960) first proposed the linearised solution for approximation. With the progress in the computation, the error from the linearisation could be minimised by using a multi-step Euler procedure.

3.1. The household and other final demanders

Like most of the CGE models, ORANI-G presents domestic household consumption using a representative household. This representative household behaves in a way characterised by a utility maximisation problem. The utility maximisation problem states that the household allocates its budget over all commodity goods, either produced domestically or imported from other countries, to maximise its utility. The utility function, in particular, follows the Stoney–Geary form, or the Klein–Rubin form, which is a shifted Cobb–Douglas utility function.

In fact, the consequences of a fuel efficiency improvement in a Stoney–Geary utility framework are the same as a fuel efficiency improvement in a Cobb–Douglas utility function. A fuel efficiency improvement, in a Stoney–Geary utility function, changes the “productivity” of fuel use in the household, including the subsistent level and supernumerary level of fuel use. For the subsistent level of fuel use, the fuel efficiency improvement will reduce the basic requirement for fuel, for the household could travel the same distance with less amount of automotive fuel than before. In other words, the productivity of the subsistent fuel use increases. Besides, the productivity of the supernumerary fuel use also increases, because the fuel efficiency improvement does not distinguish how much fuel is used for basic demand purposes from luxury purposes; the overall fuel use productivity of the household then increases.

There are several other final demanders in ORANI-G, including the government and the rest of the world. Like private households, government also consumes both domestically produced goods and imported goods. Government expenditure is treated to move together with the real aggregate expenditure of the representative household. This specification of government expenditure implies that all goods demanded by the government changes by the same proportion as the change in real household expenditure. When there is a price change, the government does not respond to it as a private consumer because the government does not maximise its utility. Here, it simply expands or shrinks, depending on the behaviour of the representative household in the economy. The overseas demand for Australian-produced goods and services are aggregated as export demand, including each country of the rest of the world, excluding Australia itself. It is noteworthy that the ORANI-G takes a small open economy theory in modelling trading. That is to say, when the price of Australia’s products falls, the demand for these product will increase sharply because Australia is a relatively small economy and the products can be absorbed easily by the rest of the world. On the other hand, because of its small influence on the world price, when the price of goods produced in Australia increases, the export demand will fall sharply. This is why the calibrated elasticities for export goods are valued between −2 to −10.

3.2. Industry production function

Each industrial sector follows a two-step production decision process in ORANI-G. The first step for each sector is to choose the amount of primary factors and intermediate inputs to use. Primary factors and intermediate inputs are weakly separable in many CGE models, as is the case here. At this stage, the sector only makes a decision on the aggregate demand for all the primary factors. However, for the intermediate inputs, it determines the demand for each commodity at the aggregated level it uses for production, omitting the primary factors. At this stage, the production function is assumed to be of the Leontief form, implying that there is no substitution between primary factors and any of the intermediate goods, and between any of the intermediate goods. The second step involves different procedures for the primary factors and intermediate goods. For primary factors, the sector chooses how much capital, labour and land to use to achieve the aggregated level of primary factors set in the first step. Land is usually a fixed variable. In the short term, it is conventional to treat labour employment as adjustable, while capital stocks are fixed. On the contrary, in the long term, it is often assumed that full employment is achieved, so capital stocks are adjustable while employment is fixed. The aggregation of land, labour and capital follows a CES function, implying that substitutability is allowed between these factors. Since weak separability is assumed between intermediate goods and primary goods, there could be a different decision procedure for the intermediate goods in the second step of the production function. As for the intermediate goods, the second step involves a process that is similar to the second step of a household consumption choice. The industrial sector, at this stage, decides how much to spend on domestic and imported goods.

3.3. Zero pure profits conditions

In a traditional CGE model, firms are assumed not to make a profit in a fully competitive market. The price they charge is exactly the same as the cost they bear in production. Zero pure profits conditions also apply to all other activities in addition to production, such as importing and exporting. Therefore, the basic value – cost of production value – of each domestically produced commodity is the same for all economic agents, including producers, consumers, government and for export. However, agent prices (the price of the goods received by each agent) differ because they comprise the basic value plus all kinds of taxes and marginal costs, such as transportation on delivering this goods to the agent. The taxes and additional costs are the price linkages between agent prices and basic values.

3.4. Market clearing conditions

Market clearing conditions are essential in a CGE model, which states that demand and supply are equal in all markets in Australia. First, for domestically produced goods, the demand from various sources, including private households, government purchases, investment, intermediate input use by firms, and export demand should be equal to the supply of the goods produced in Australia. For primary factors, the supply of labour, capital, and land should equal the demand for labour, capital and land. Labour, in ORANI-G, can move across industries with ease, while capital, on the other hand, is fixed in each industry. The reason to assume non-shiftability on capital is to model the fixed capital stocks in each of the highly specialised industrial sectors. As for land, ORANI-G only considers the agricultural land used in each industry. Therefore, a limited number of industrial sectors rely on land to produce goods. Like capital, land is a sluggish primary factor, which is non-shiftable across industries.

4. Data Input

Two types of data are important for analysing policies using a CGE approach. First, an input–output table is essential for providing the baseline equilibrium for the economy. From the input–output table, the coefficients of the matrix that simulates the policy shock can be obtained. Besides, the input–output data provide the miscellaneous indexes, such as GDP and terms of trade. The Centre of Policy Studies (CoPS) at Victoria University converted the Australian Input–Outputdata for 2012–2013, published by the Australian Bureau of Statistics (ABS, 2015b), into a database that is applicable for CGE analysis in a ORANI-G model. The aggregated version we used here has 25 commodities, which equals the number of industries.

Equally important data on behaviours of economic agents are required for CGE analysis. These behavioural data include the Armington elasticity – the elasticity of substitution between domestic and imported goods – for domestic producers and the representative household, the elasticity of substitution between capital, labour and land for each industry, the price elasticity of demand and the income elasticity of demand for the representative household, and the price elasticity for export, among others. The values of these elasticity parameters are sourced from various studies. For example, the elasticities relating to household behaviour are estimated by Powell (1992), and the Armington elasticity of substitution between domestically produced goods and imported goods are taken from the estimates by Menon (1993).

In this study, we also linked the existing data file to a carbon emission intensity account, estimated by a life-cycle assessment (LCA) by Dey (2008). Table 1 shows the carbon intensity of each commodity good and the mapping from the commodities in the carbon intensity account to the ORANI-G commodities.

Table 1. Mapping of the carbon intensity account to the ORANI-G commodities.

Detailed commodity group	Life cycle Greenhouse gas intensity (kg CO_2-e/$)	ORANI sector/ commodity
Domestic fuel and power	1.333	Electricity
Bakery products	0.403	FoodDrinks
Condiments	0.444	FoodDrinks
Dairy products	1.162	Livestock
Fish	0.507	CropsForFish
Fruit and nuts	0.391	FoodDrinks
Meals out	0.394	FoodDrinks
Meat	1.709	Livestock
Non-alcoholic beverages	0.281	FoodDrinks
Vegetables	0.398	FoodDrinks

Detailed commodity group	Life cycle Greenhouse gas intensity (kg CO_2-e/$)	ORANI sector/ commodity
Alcohol	0.301	FoodDrinks
Clothing	0.308	TCFs
Clothing services	0.138	TCFs
Footwear	0.299	TCFs
Appliances	0.738	OthManufact
Blankets, linen and furniture	0.349	OthManufact
Furniture and flooring	0.304	Construction
Glass and tableware	0.614	OthManufact
Tools	0.239	OthManufact
Household services	0.205	OtherService
Health fees	0.261	HealthCommun
Health insurance	0.017	HealthCommun
Freight	0.753	RoadFreight
Vehicle fuel	2.600	PetrolDiesel
Motor vehicle purchase	0.289	RoadPassngr
Motor vehicle parts and accessories	0.289	RoadPassngr
Public transport	0.540	OthTransport
Vehicle charges	0.152	MVPOthTrnEq
Vehicle registration and insurance	0.016	MVPOthTrnEq
Holidays	0.850	HotelsCafes
Pets	0.356	OtherService
Recreational goods	0.406	OtherService
Recreational services	0.127	OtherService
Personal care	0.221	Education
Miscellaneous goods	0.312	BusinessSrv
Miscellaneous services	0.157	BusinessSrv

5. Application and results

5.1. The business-as-usual scenario

To forecast a business-as-usual (BAU) scenario for 2025 as a benchmark, we use inputs from the VAR model (Wang, 2018) as well as from other external sources.

First, we use the technology trend for industries and for households in fuel use. Second, we use the projections for macroeconomic variables such as GDP and population from the Reserve Bank of Australia (Reifschneider and Tulip, 2017) and the World Bank. Without a policy standard on fuel efficiency, the fuel efficiency will increase by 32% by 2025, compared to base year 2012. This result is taken directly from the estimate in the VAR model, which considers the compositional changes of vehicle sales as well as autonomous fuel efficiency improvement over time.

For the household sector, we treat the light vehicle efficiency improvement as a sufficiency consumption choice module. This treatment on the household sector is in line with the traditional treatment of household consumption choice in research on indirect rebound effects Chitnis et al., 2013, Chitnis et al., 2014, Murray, 2013. In the sufficiency module, the household is assumed to allocate the entire fuel savings on all commodities. Therefore, the direct rebound effect could be tiny, whereas indirect rebounds could be large.

In the 2025 benchmark scenario, as well as in all the other policy scenarios, all simulations share the same macroeconomic and demographic changes. As shown in the following table, in the first CGE simulation, the macroeconomic picture shows that GDP grows by around 29.4 per cent by 2025 compared to 2012 (around 2 per cent per annum). There is normal growth in exports, about 31.8 per cent between 2012 and 2025, or around 2 per cent per annum. Private consumption and government expenditure grow at the same rate, about 29.0 per cent in this period. Investment grows at a lower rate, 24.2 per cent and import increases at a normal pace at 22.6 per cent in this period.

As for energy and carbon emissions, for this study on economy-wide rebound effect emissions from both the use of petroleum and from all other sectors are important. As reported by the Survey of Motor Vehicle Use (ABS, 2013), total registered light vehicles in Australia consumed 24 billion litres of fuel. According to the National Transport Commission, 55 per cent of light vehicles are used by private consumers, and the remainder by industries and the government. In the ORANI-G model, the petroleum refining industry is the industry that produces automotive fuels. As shown in Table 3, the inputs for this industry include many intermediate inputs and primary factors. Mining products account for 70 per cent of the overall inputs, followed by capital stocks, reaching nearly 15 per cent of the production costs. In this model, the output of the petroleum refining industry is automotive fuels only, which are used by industries, private households, government and for export. As for industries, construction (22 per cent), mining (17 per cent) and road freight (11 per cent) industries use the most fuel. These industries, however, use heavy vehicles, such as articulated trucks and light rigid trucks, whose efficiency would not be directly affected by the light vehicle standards. On the contrary, light vehicles are widely used in service industries, such as trade, hotel and cafes, road passenger transport, business and services, and government administration. In these sectors, which use light vehicles to provide final services and goods, fuel efficiency improves 20 per cent as the autonomous technological change.

For the petroleum refining industry, the BAU scenario sees a slight decrease in petrol prices and minor changes in petrol production. As shown in Table 4, the price index for domestically produced petroleum products decreases by 4.06 per cent between 2012 and 2025, whereas the price index for GDP decreases more than 10 per cent in the 2025 BAU scenario. The petroleum production decreases by 3 per cent, whereas GDP increases by over 29 per cent between 2012 and 2025. This implies that the share of petroleum industry in GDP is lower than in 2012.

Table 2. Macroeconomic indicators of simulation results including the business-as-usual scenario for model year 2025, lenient policy standard (2025 PA), medium policy standard (2025 PB) and stringent policy standard (2025 PC).

	2012–13	2025 BAU	2025 PA	2025 PB	2025 PC
Private consumption ($b, 2012 prices)	840	1084	1085	1085	1086
Public consumption ($b, 2012 prices)	270	348	349	349	349
Investment ($b, 2012 prices)	430	534	532	532	532
Exports ($b, 2012 prices)	290	382	381	381	380
Imports ($b, 2012 prices)	310	380	379	379	379
GDP ($b, 2012 prices)	1520	1968	1968	1969	1969

Table 3. Petroleum refining industry inputs use in 2012–2013 in Australia.

Commodity	Inputs to petrol production	Percentage
1 Livestock	1	0%
2 CropsForFish	3	0%
3 Mining	10,428	70%
4 FoodDrinks	18	0%
5 TCFs	10	0%
6 WoodPaperPrd	24	0%
7 PetrolDiesel	251	2%
8 OthPetPrds	122	1%
9 OthManufact	165	1%
10 Metals	52	0%
11 MVPOthTrnEq	1	0%
12 OthTranEqp	0	0%
13 ElecGasWater	85	1%
14 Construction	27	0%

Commodity	Inputs to petrol production	Percentage
15 Trade	37	0%
16 HotelsCafes	43	0%
17 RoadFreight	11	0%
18 RoadPassngr	1	0%
19 OthTransport	142	1%
20 BusinessSrv	466	3%
21 OwnerDwellng	0	0%
22 GovAdminDfnc	12	0%
23 Education	6	0%
24 HealthCommun	0	0%
25 OtherService	110	1%
Capital	2,035	14%
Labour	883	6%
Land	58	0%

Table 4. The petroleum refining industry: Inputs and outputs in 2012 AUD.

	2012 $m	2025 BAU	2025 PA	2025 PB	2025 PC
Petroleum refining industry inputs:					
Crude oil	10,427	10,441	10,028	9,698	9,366
Other intermediates	1589	1482	1424	1377	1331
labour	882	772	741	717	693
capital	2035	1782	1711	1655	1598
Land	57	57	43	41	38
Tax	766	713	696	672	650
Total Inputs	15,756	15,247	14,643	14,160	1,3676
Petroleum refining industry outputs:					
Petrol and diesel	15,756	15247	14,643	14,160	1,3676
Total output	15,756	15247	14,643	14,160	1,3676
Reference variable:					
GDP	1,519,936	1,967,709	1,968,248	1,968,552	1,968,856
Price index for domestic motor fuels	1	0.9594	0.9594	0.9594	0.9594
Price index for GDP	1	0.8975	0.8985	0.8993	0.9001
Refined petroleum industry, % GDP	1.04%	0.77%	0.74%	0.72%	0.69%

As shown in Table 5, all industry (except the petroleum industry) expands significantly with the macroeconomic growth in the 2025 BAU scenario, compared to base year 2012–13. This is because the fuel efficiency improvement in the BAU scenario is about 30 per cent, cancelling out the economic growth, which is also approximately 30 per cent.

Table 5. Industrial effects of proposed light vehicle fuel efficiency standards on production of each industry (percentage change as compared to 2025 BAU).

Industry	2012–13	2025 BAU	2025 PA	2025 PB	2025 PC
1 Livestock	13,941	208,148	−0.06%	−0.12%	−0.17%
2 CropsForFish	56,616	1,328,041	−0.06%	−0.11%	−0.16%
3 Mining	191,580	2,540,093	−0.10%	−0.17%	−0.26%
4 FoodDrinks	90,491	3,875,430	−0.02%	−0.04%	−0.05%
5 TCFs	6,508	388,823	−0.16%	−0.29%	−0.43%
6 WoodPaperPrd	25,696	948,706	−0.04%	−0.09%	−0.13%
7 PetrolDiesel	15,756	17,122	−3.95%	−7.12%	−10.29%
8 OthPetPrds	11,751	170,002	−0.04%	−0.06%	−0.09%
9 OthManufact	95,683	7,304,497	−0.08%	−0.15%	−0.21%
10 Metals	75,725	3,117,307	−0.13%	−0.24%	−0.35%
11 MVPOthTrnEq	16,386	5,941,859	−0.16%	−0.28%	−0.41%
12 OthTranEqp	8,298	198,279	−0.05%	−0.09%	−0.13%
13 ElecGasWater	86,598	2,945,254	0.05%	0.10%	0.15%
14 Construction	386,559	9,096,562	−0.04%	−0.07%	−0.10%
15 Trade	203,322	6,911,870	0.01%	0.01%	0.02%
16 HotelsCafes	72,574	3,445,597	0.07%	0.14%	0.20%
17 RoadFreight	47,198	1,020,460	−0.11%	−0.20%	−0.29%
18 RoadPassngr	6,740	99,175	0.23%	0.41%	0.60%
19 OthTransport	100,795	5,207,347	0.04%	0.08%	0.12%
20 BusinessSrv	629,841	37.429,642	0.03%	0.05%	0.07%
21 OwnerDwellng	169,806	4,708,657	0.13%	0.23%	0.33%
22 GovAdminDfnc	134,241	4,219,176	0.06%	0.11%	0.15%
23 Education	91,957	4,721,023	0.04%	0.07%	0.11%
24 HealthCommun	123,896	4,643,142	0.11%	0.19%	0.28%
25 OtherService	197,830	9,468,387	0.09%	0.17%	0.24%

The fuel efficiency improvement only occurs exogenously in ten selected services industries, where light vehicles are intensively used. Listed in Table 6, these ten service industries include trade, hotels and cafés, road passenger sector, other transport sector, business service, owners dwelling, government administration and defence, education, health and communication and other services. Petroleum use for these ten sectors has reduced by around 10 per cent in 2025 BAU, relative to 2012–13.

Table 7 shows the change in demand for petrol by each agent. In 2012, a total amount of 26,570 million litres of domestically produced and imported petrol was consumed by the local market, including households, government, and industries. In addition, 442 million litres of domestically produced petrol was consumed by the rest of the world, equivalent to total exports. In 2012, the export of petrol is small, around 1 per cent of the total petrol production. In the 2025 BAU scenario, petroleum consumption by local industries increases by about 15 per cent. However, demand for petroleum as a household commodity decreases by around 18 per cent. As for export, Australian produced petroleum consumption for the rest of the world increases by 19 per cent. Therefore, the total petroleum consumption by all agents decreases by around 823 million litres in 2025 BAU, compared to base year 2012.

Table 6. Petroleum use as an intermediate input in industries for which light vehicle fuel efficiency improves in base year 2012 and four simulations for model year 2025.

	Industries where fuel efficiency improves	**Base year 2012**	**2025 BAU**	**2025 PA**	**2025 PB**	**2025 PC**
		Million litres				
1	Trade	613	537	488	455	424
2	HotelsCafes	56	51	46	43	40
3	RoadPassngr	311	276	252	236	220
4	OthTransport	1017	928	846	793	739
5	BusinessSrv	1586	1408	1282	1201	1119
6	OwnerDwellng	8	7	7	6	6
7	GovAdminDfnc	351	308	280	262	244
8	Education	47	43	40	37	34
9	HealthCommun	130	116	105	98	92
10	OtherService	766	686	624	585	546

Table 7. Petroleum consumption (million litres) by agent by source in the business-as-usual (2025 BAU), lenient policy standard (2025 PA), medium policy standard (2025 PB) and stringent policy standard (2025 PC) scenarios for model year 2025.

Petrol (million litres)	**2012**	**2025 BAU**	**2025 PA**	**2025 PB**	**2025 PC**
Intermediate	15,719	18,119	17,844	17,624	17,404
Investment	0	0	0	0	0

Petrol (million litres)	2012	2025 BAU	2025 PA	2025 PB	2025 PC
Household	9,205	7,547	7,002	6,567	6,129
Government	0	0	0	0	0
Rest of the world	442	524	524	524	524
Total by all agents	27,012	26,189	25,370	24,714	24,057

5.2. The policy scenarios

For the policy scenarios, we assume that the Australian proposed light vehicle emissions standards lead to improvements in fuel efficiency that allow industries and households to use less fuel than before, while travelling the same distance. Specifically, as addressed in the BAU scenario in the previous section, we assume that, by 2025, automotive fuel use per unit of output from service industries will decrease by 32 per cent, compared to 2012 baseline. We use the results from the VAR model for the calibration of the fuel efficiency improvements in the lenient (2025 PA), medium (2025 PB) and stringent (2025 PC) policy scenarios. For the 2025 PA scenario, fuel efficiency improves by 37 per cent, compared to 2012. In the 2025 PB scenario, fuel efficiency improvements reaches by 41 per cent, compared to 2012. The 2025 PC scenario has the highest fuel efficiency improvement overall, mounting to 45 per cent, compared to the base year 2012.

These changes in fuel efficiency in each policy scenario are equivalent to 7 per cent for PA, 13 per cent for PB and 19 per cent for PC reductions in the average rate of fuel consumption, relative to the 2025 BAU scenario. At the same time, we assume that the cost of implementing this policy is negligible for two reasons. First, CCA (2014) showed that the implementation costs are low because the current emissions testing system in Australia already includes CO_2 emissions measurements. The laboratory results in CO_2 and fuel consumption per hundred kilometres are obtained from ADR81/02 Fuel Consumption Labelling for Light Vehicles, and are already provided to consumers when purchasing new cars as per labelling requirements. Therefore, the implementation of this policy would not incur significant extra administrative costs. Second, the technology of fuel efficiency vehicles; for example, hybrid vehicles, are already available in Australian markets, and automobile users do not have to spend more on more efficient vehicles. The cost–benefit analysis approach in the CCA’s (2014) research suggested that motorists could benefit most from the proposed mandatory standards. Under the stringent policy scenario (2025 PC), the present value of fuel savings over the life of new vehicles, relative to BAU, reaches up to $5000 for the model year 2025. The estimated cost associated with switching to a more fuel-efficient vehicle that meets the stringent standard incurs less than $1000 in the model year 2025. Therefore, the net benefit to motorists under the most ambitious target is $4000 for the model year 2025. Even without technological improvement, households could choose to purchase smaller cars or manual variants to reduce both fuel consumption and CO_2 emissions per distance travelled. For these reasons, we do not simulate any costs in implementing the policy.

As shown in Table 2, the macroeconomic pictures of the policy scenarios are very similar to that of the BAU 2025 scenario. When carbon emissions standards on light vehicles are implemented, GDP, private consumption and government expenditure grow slightly higher than the 2025 BAU scenario. However, growth in investment, imports and exports slows lightly, compared to the BAU scenario.

The petroleum industry figures all shrink in the three policy scenarios, compared to 2025 BAU. Total inputs and outputs reduce most in the 2025 PC scenario, where the most stringent light vehicle fuel efficiency standard is applied across the Australian economy. As a result, the share of the petroleum industry in GDP decreases from 1.04 per cent to 0.69 per cent, in the 2025 PC scenario. This change indicates that the reliance on the petroleum industry is lower in the policy scenarios than in the 2025 BAU scenario.

For the industrial results, the variations between policy scenarios and BAU are small. However, it is noteworthy that most of the agricultural and industrial sectors shrink slightly in the policy scenarios, such as livestock, food and drink, construction, metals and petrol production. On the other hand, most service sectors expand, including trade, hotel and cafes, education, etc. This change shows that the economy will become more dependent on service-oriented industry under the light vehicle emissions standards.

Compared to the 2025 BAU scenario, all of the policy scenarios generate a lower demand for petroleum in both firms and households. The volume of export of petrol remains the same for each of the policy scenarios as the 2025 BAU. For total petroleum consumption by all agents, the stringent policy (2025 PC) scenario has the largest reduction compared to 2025 BAU, followed by the medium policy (2025 PB) scenario and then the lenient policy (2025 PA) scenario.

The direct rebound effects in all three policy scenarios are moderate. Shown in Table 8, the expected reductions in petrol for intermediate use for 2025 PA, 2025 PB and 2025 PC is 571, 1060 and 1549 million litres, respectively, compared to 2025 BAU. On the other hand, the actual reduction for each policy scenario for the intermediate use is less than half the expected reduction. These results imply that, for the intermediate usage of petroleum at the firm level, the direct rebound effect of fuel efficiency standards is over 50 per cent. At the other extreme, the actual reduction in petrol consumption at the household level is even larger than supposed in the fuel efficiency standards, yielding a negative or close to zero direct rebound effect in each of the policy scenarios. In this dataset, firms and households are the only economic agents that are affected by the light vehicle fuel efficiency standards. The rest of the world is not affected by the policy and the government and investment do not consume petrol in this dataset. Therefore, the direct rebound effect by all agents ranges from 25 per cent to 30 per cent. Even though the stringent policy scenario (2025 PC) generates the largest direct rebound effect of 29 per cent, the actual reduction in overall petrol consumption is the highest (2132 million litres) among the three policy scenarios.

This result is closer to previous studies on the direct rebound effect of fuel efficiency improvement in Australia than in the US. For example, in the econometric analyses on the direct and indirect rebound effect by Murray (2013), the direct rebound effect from improved fuel efficiency at the household level in Australia is estimated to be around 0.25. However, the result from this research is slightly larger than the studies on the rebound effect of fuel efficiency improvements in the US. When comparing the results, we suggest that the rebound effect in the CGE framework represents the long-run rebound effect instead of the short-run rebound effect, because the closures in the simulations taken are the typical long-run closures. Greene (2012) showed in his econometric study based on panel data for the US that the rebound effect decreased from about 0.4 to 0.1 between 1966 to 2007 for the long run. Similarly, Small and Van Dender (2007) obtained a similar result to that of Greene by using panel data for the US for the years between 1966 and 2001. They showed long-run rebound effect ranges from 0.1 to 0.2. This difference between the Australian and the US studies suggest that rebound effects could differ from country to country.

Table 8. The direct rebound effects of each economic agent at three policy scenarios.

Expected reduction in petrol (million litres)	**2025 PA**	**2025 PB**	**2025 PC**
Intermediate use	571	1060	1549
Investment	0	0	0
Household	528	981	1,434
Government	0	0	0
Rest of the world	0	0	0
Total by all agents	1099	2041	2983
Actual reduction			
Intermediate use	275	495	715
Investment	0	0	0
Household	545	980	1418
Government	0	0	0
Rest of the world	0	0	0
Total by all agents	819	1475	2132
Direct rebound effects			
Intermediate use	52%	53%	54%

Expected reduction in petrol (million litres)	2025 PA	2025 PB	2025 PC
Investment	0	0	0
Household	−3%	0%	1%
Government	0	0	0
Rest of the world	0	0	0
Total by all agents	25%	28%	29%

The magnitude of the direct rebound effect in this study falls between 0.25 and 0.29, which falls to the range of the empirical estimates of the price elasticity of petroleum demand for Australia (Burke and Nishitateno, 2013). However, it might be reasonable to assume that the rebound effect would decrease over time.

At the economy-wide level, we use life-cycle GHG emissions intensity measured by Dey (2008) to calculate the rebound effect. As the life-cycle approach takes into account the GHG emissions generated during the production process, the producers are excluded when calculating the total GHG emissions. As shown in Table 9, the total GHG emissions, taking a life-cycle approach, can be divided into three groups: private households, export and government. In 2012, total Australian GHG emissions are around 560 million tons of CO_2-e, contributed mainly by the household (46 per cent) and export (43 per cent). Compared to 2012, the 2025 BAU scenario sees a significant surge in the overall GHG emissions, mounting to 705 million tons of CO_2-e. All agents increase emissions more than 20 per cent by 2025 in the business-as-usual scenario, if no climate policy is implemented. Each of the 2025 policy scenarios show that the overall GHG emissions reduces slightly compared to the 2025 BAU scenario when the light vehicle fuel efficiency standard is in action. The stringent policy (2025 PC) has the most significant reduction in GHG emissions reduction of the three policy scenarios.

The economy-wide rebound effect measured by life-cycle GHG emissions is obtained via the method shown in Table 10 for each of the policy scenarios, compared to the 2025 BAU scenario. The expected GHG emissions reductions are translated from the direct reduction in light vehicle fuel use explained in the above context. To repeat, the three policy scenarios are supposed to decrease fuel use by 7 per cent (equivalent to 2.86 million tons of CO_2-e), 13 per cent (equivalent to 5.31 million tons of CO_2-e), and 19 per cent (equivalent to 7.76 million tons of CO_2-e), respectively, compared to the 2025 BAU level. The actual GHG emissions reduction in each of the policy scenarios is much smaller than the expected reduction. The difference of the expected and the actual GHG emissions reduction gives the rebound effect, which is around 50 per cent for all of the policy scenarios.

Table 9. Life-cycle greenhouse gas emissions by agents at three policy scenarios (million tons of CO_2-e).

Agent	2012	2025 BAU	2025 PA	2025 PB	2025 PC
Household	264	329	328	327	326
Export	242	297	297	297	296
Government	63	79	79	79	79
AU total	569	705	703	702	701

The economy-wide results are similar to the majority of the CGE studies on the rebound effect of an energy efficiency improvement. A significant finding of this study is that the economy-wide rebound effect is less than 100 per cent, which indicates that a "backfire" is unlikely to happen when introducing a fuel efficiency standard in Australia. This result is in line with the findings by Broberg et al. (2015), Allan et al. (2007) and Anson and Turner (2009). For example, in the study of Broberg et al. (2015), the economy-wide rebound effect ranges between 40 per cent and 70 per cent when an energy efficiency improvement is introduced across industries in the Swedish economy. Similar to the results obtained by Broberg et al. (2015), Allan et al. (2007) argued that a backfire is not possible because the economy-wide rebound effect ranges between 30 to 50 per cent when simulating an energy efficiency improvement in all production sectors in the UK economy. Discussing the sensitivity of the rebound effect to the value of the key elasticities parameters, Anson and Turner (2009) suggest the rebound effect is between 30 and 70 per cent, taking reasonable value of the elasticities when simulating a fuel efficiency improvement in the commercial transport sector in the Scottish economy. Both Stern (2011) and Gillingham et al. (2015) stress the important role energy efficiency improvement plays in economic growth.

Table 10. Economy-wide rebound effects at three policy scenarios (million tons of CO_2-e).

	2025 PA	2025 PB	2025 PC
Expected GHG emissions reduction	2.86	5.31	7.76
Actual GHG emissions reduction	1.43	2.62	3.87
Economy-wide rebound effect	49.99%	50.63%	50.13%

However, there is evidence showing that an energy efficiency scheme could actually increase the energy consumption. According to Haney et al. (2005), a backfire result is observed in a simulation of an energy efficiency improvement across the Scottish economy. Similar to Haney et al. (2005), Brännlund et al. (2007) argued that a costless fuel efficiency improvement in the transport sector could be counterproductive as it will result in more GHG emissions based on simulations in the Swedish economy.

This difference suggests that the scope of the energy efficiency improvement may play an important role in determining the magnitude of the economy-wide rebound effect. A sector-specific energy efficiency improvement, for example, a fuel efficiency improvement in light vehicles, may result in less rebound effect than an across-the-board energy efficiency improvement in all industrial sectors. Besides, different countries show different patterns in terms of the economy-wide rebound effect. Although in Australia the simulation suggests that the rebound effect does not cause backfire, it does not guarantee it is the same case for other countries as the economy structure and consumer preferences vary across countries.

6. Conclusion

This study takes a CGE approach to examine and compare the effects of a set of policy scenarios on light vehicle fuel efficiency standards on light vehicle petroleum use and the economy-wide GHG emissions. By focusing on rebound effects that may undermine the desired effect of a light vehicle emissions standard, this study shows which of the policy scenarios can achieve the greatest reduction in overall GHG emissions for Australia in the model year 2025.

There are four major findings in this study, which can be summarised as follows. First, simulation results indicate that the Australian proposed light vehicle fuel efficiency standards would lead to direct rebound, which could offset the expected fuel savings by around 30 per cent. Despite that, the most stringent policy target shows a largest direct rebound effect measured by percentage; this scheme could achieve the most reduction in physical use of petrol in terms of million litres by 2025. This significant finding suggests that the focus of the research on a fuel efficiency standard should not be limited to estimate the direct rebound effect, but also consider the physical use of the energy source.

Second, we show that all policy scenarios achieved around half of the desired reduction in GHG emissions at an economy-wide level. Using a life-cycle approach, the overall GHG emissions from the economy do not exhibit a reduction at a desired level from each of the policy scenarios, because consumers choose to spend the rest of their money saved from fuel on other goods and services, which has embedded GHG emissions taking into account the production, transport, consumption and waste management processes.

Third, we show the most stringent policy target is the most desirable when considering the rebound effect and the actual reduction in the economy-wide GHG emissions. The three policy scenarios have around the same magnitude of the economy-wide rebound effect, measured as a percentage of the expected savings. Therefore, choosing the policy that has the largest expected savings would achieve the most GHG emissions reduction at the economy-wide level for Australia.

Fourth, it was shown that a backfire is unlikely to happen when introducing light vehicle fuel efficiency standards. Although the magnitude of the direct and economy-wide rebound effects is significant across the three policy scenarios, the economy still sees a decrease in the overall GHG emissions. The rebound effect could be reduced when a cost is introduced alongside the policy, as the consumers would have fewer savings relocated on other goods and services.

Further work could be focused on examining the sensitivity of the rebound effect, fuel use and GHG emissions, under alternative assumptions on the additional costs associated with the policy and the value of the elasticities parameters pre-set in the CGE model. Also, it may be useful to compare a petroleum tax or carbon tax scenario to the light vehicle fuel efficiency standards.

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