Ecole Polytechnique
Master 1
SCHNEIDER Luca

RAPPORT DE STAGE DE RECHERCHE

« The Impact of the Australian Carbon Tax on Wholesales Electricity Prices »

RAPPORT NON-CONFIDENTIEL

Département: Economie
Champ: ECO591 : Microéconomie et Economie d'entreprise
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Abstract

This research internship aims to study the impact of the carbon tax on the wholesale electricity spot price within the Australian National Electricity Market (NEM). While the majority of previous studies have been performed using theoretical and simulation methods before the tax implementation, this study uses empirical methods based on data from January 2009 to June 2015. Results shows that the carbon tax would be fully passed in the wholesale electricity spot prices meaning that final consumers bear the cost of the tax while it reveals being a potential windfall profit for electricity generators even after its revocation the 1st July of 2014.

Résumé

Ce stage de recherche vise à étudier l'impact de la taxe carbone sur les prix de gros l'électricité échangée sur le « Marché National d'Electricité » australien (NEM). Alors que de nombreuses études ont été réalisées avant son implémentation le 1er juillet 2012 à l'aide de méthodes théoriques et simulatrices, cette étude utilise des méthodes empiriques basés sur des données récoltées de Janvier 2009 à Juin 2015. Les résultats concluent que la taxe carbone est essentiellement reportée dans le prix de gros signifiant que la taxe est essentiellement payée par le consommateur final et non par les producteurs d'électricité, pour lesquels, la taxe se révèle être finalement, même après son retrait de la taxe le 1er juillet 2014, une source supplémentaire de profits.

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Acknowledgements

I would like to express my deep gratitude to Professor Stefan Trueck and Professor Marjan Nazifi, my research supervisors, for their invitation to join their research work but also their patient guidance, their advice and assistance in keeping my research work on progress.

My special thanks are extended to the staff of the Faculty of Business and Economics of Macquarie University for their warm welcome and in offering me the resources to complete this research work under good conditions.

Context of the Internship

Macquarie University

Macquarie University is the third public research university in New South Wales founded by the government in 1964 and named after Lachlan Macquarie (1762-1824), a British general who has governed New South Wales. Located in a 126-hectare park-like campus in the northeast suburb of Sydney, Macquarie University enrols almost 40’000 students for 2768 member staff.

It is also ranked among the top 2% of universities[1] in the world and belongs to the 5 Australian universities awarded with 5 stars in the international QS Stars rating system[2] for its performance in teaching, employability, research, internationalisation, facilities, innovation, access and specialist subjects. Its high level research is also confirmed by achieving the maximum 5 rating by the Australian Government Excellence in Research for Australia (ERA) evaluation and the of 85% of its research activity rated as performing at world standard or higher.

Faculty of Business and Economics

Stefan Trueck (Supervisor)

Stefan Trueck joined Macquarie University in 2007, and is currently co-director of the centre for financial risk. Before holding positions in different universities across the world, he received a PhD in statistics at the University of Karlsruhe. Stefan also has a strong research portfolio and has published papers on risk management and financial econometrics including the fields of credit risk, operational risk, power markets, emissions trading and real estate finance

Courses

As a M1 “Sciences pour les défis de l’environnement” (Sciences for the environment challenges) student, my economics knowledge was limited. Therefore, for the purpose of this study, my supervisors offered me to attend the following courses at Macquarie University:

- **ECON241 Introductory Econometrics** by Fazeel Jaleel
- **AFIN828 International Investment and Risk** by Chi Truong

[1] Academic Rankingof World Universities, 2014

[2] QS World University Rankings, 2015

The Pass-through Rates of Carbon Costs on to Electricity Prices within the Australian National Electricity Market

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ABSTRACT

This research internship aims to study the impact of the carbon tax on the wholesale electricity spot price within the Australian National Electricity Market (NEM). While the majority of previous studies have been performed using theoretical and simulation methods prior to the implementation of the carbon tax, this study uses empirical methods based on data from January 2009 to June 2015. Results reveal that the carbon tax would be fully passed on in wholesale electricity spot prices, meaning that final consumers bear the cost of the tax while it proves to be a potential windfall profit for electricity generators even after its annulment on the 1st July of 2014.

Keywords and Abbreviations

AEMO	Australian Energy Market Operator
AUD	Australian Dollar: 1 AUD = 0.66 €
	Average exchange rate on xe.com as of June 2015
CO2e	Equivalent carbon dioxide
CPR	Carbon cost Pass-Through Rate
NEM	National Energy Market
NSW	State of New South Wales, Capital: Sydney
NT	Northern Territories, Capital: Darwin
QLD	State of Queensland, Capital: Brisbane
SA	State of South Australia, Capital: Adelaide
TAS	State of Tasmania, Capital: Hobart
VIC	State of Victoria, Capital: Melbourne
WA	State of Western Australia, Capital: Perth

1. Introduction

As part of their commitment to reduce their greenhouse gas emissions, the Australian government have implemented several policy tools such as a carbon-pricing scheme. This scheme aims to discourage the use of fossil fuels by charging polluters on the scale of their carbon dioxide emissions and therefore promoting the switch to cleaner energy consumption by both households and companies.

In 2010, Australia was the 8th highest emitter of the OECD countries (540 Million tonnes of CO2 equivalent emitted (CO2e)), but the 1st highest emitter per capita (24.48t of CO2e per capita, twice the OECD average).[3] One of the main reasons is the large proportion of electricity generated by coal. Australia developed its electricity production based on local coal extraction resulting in 74 % of electricity produced by coal in 2013 and an energy sector representing one third of national emissions[4]. This also explains why the electricity retail price in Australia is one of the lowest in the world (Nelson et al., 2012).

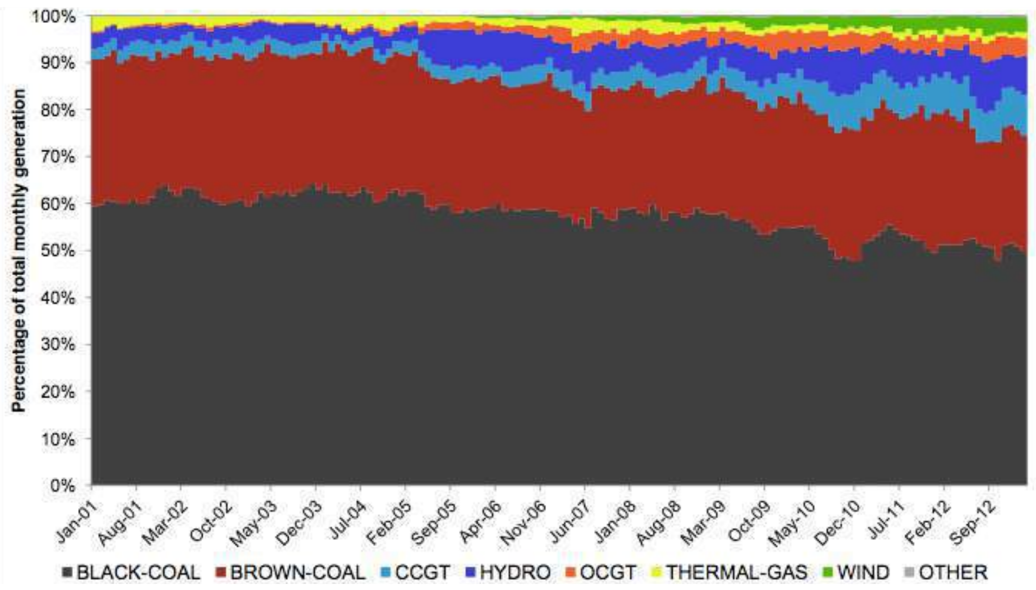

Figure 1: Origin of electricity generation in Australia between 2001 and 2013
Source: Nera (2013).

In July 2012, as part of larger environmental plan (Clean Energy Act 2011), the federal labour government of Julia Gillard (2007-13) introduced a carbon pricing scheme commonly referred to as "the carbon tax" starting at 23 AUD per tonne of CO2e. After an incremental increase the following year to 24.15 AUD, the carbon-

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[3] OECD. 2015. *Greenhouse Gas Emissions*. Available at http://stats.oecd.org/Index.aspx?DataSetCode=AIR_GHG&lang=fr.
[4] National Inventory by Economic Sector 2011-12. Australia's National Greenhouse Accounts.

pricing scheme would have ultimately evolved into an emission-trading scheme (ETS). However the carbon tax was repealed on July 2014 by the current government led by Tony Abbott.

It has been recorded that the carbon price led to an average 85% increase in wholesale electricity spot prices during its implementation (O'Gorman et al. 2014). This sudden coincidence raises the question as to whether Australian power generators fully transfer the cost of carbon into the wholesale spot prices and question the real effectiveness of this carbon tax policy. If power generators get rid of the cost of the carbon into the wholesale spot price, there would not be any incentive to substitute current production methods for lower carbon technologies.

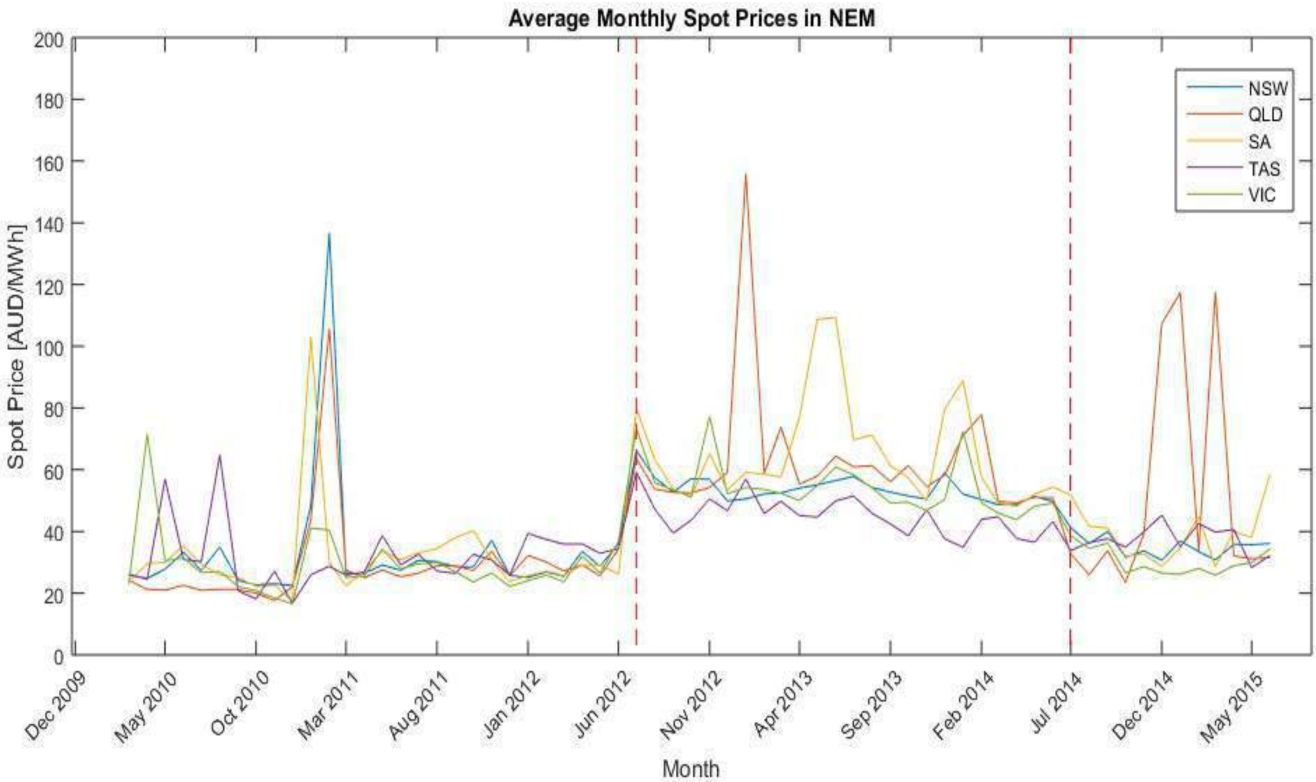

Figure 2: Average monthly spot prices in NEM. Tax period between dashed-lines. Source: AEMO data

The aim of this paper is then to answer to which proportion of the price rise is attributable to the carbon tax and focuses on the evaluation of a rate referred to as the "carbon costs pass-through rate" (CPR) in former literatures such as that of Sijm et al. (2006) and Chen et al. (2008). This study has been conducted following the publications of one of my supervisors, Fatemeh Nazifi, ("The Pass-through Rates of Carbon Costs on to Electricity Prices within the Australian National Electricity

Market", 2015), and aims to further it whilst getting more accurate results and providing supporting evidence that the carbon cost is fully passed into the wholesale spot prices.

This remainder of the paper follows the chronological steps of this research internship and is organised in the following order:

- **Section 2** provides a summary of the Australian electricity market and the carbon tax policy;
- **Section 3** reviews various existing papers related to this study;
- **Section 4** describes the dataset;
- **Section 5** conducts a preliminary analysis;
- **Section 6** concerns the econometric model and the empirical results obtained;
- **Section 7** will summarise and conclude this paper.

In addition:

- **Appendix A** sets out the MATLAB code performed for this study (electronic version only).

2. Background

2.1 Electricity in Australia

Australia is a federal state composed of 8 jurisdictions: 6 states and 2 mainland territories distributed on 7'692'024 km^2. In December 1998 the states Queensland (QLD), New South Wales (NSW), Victoria (VIC) and South Australia (SA) decided to interconnect and synchronize their electricity transmission grid to create the "National Electricity Market" (NEM). Tasmania (TAS) joined the grid in May 2005 after the achievement of a submarine cable connecting it to Victoria and resulting in the world's longest power system with a furthest distance of 4500 kilometers (AER 2013) covered, and supplying over 9 million residential and business customers in 2012-2013, accounting for an equivalent of 11.4 billion AUD of electricity traded. Western Australia (WA) and the Northern Territory (NT) remain unconnected to the NEM primarily because of geographical distance-related problems.

Figure 3: States within the NEM
Source: Google image

Because of the non-storable nature of electricity, the NEM functions as a "pool" where electricity generators and retailers are instantly linked through a centrally coordinated dispatch process operated by the Australian Energy Market Operator (AEMO). It has the principal task of ensuring the NEM works efficiently by aggregating and dispatching power supply to meet demand at the lowest cost possible. It works the following way:

Every 5 minutes, registered power generators offer a specific amount of electricity for a specified price. The companies have the opportunity to bid 10 times at different price scales and are only allowed to change their bids within the quantities supplied. AEMO determines the dispatch order of generators according to cost, from the lowest to highest. The last generator dispatched to meet the demand sets the dispatch price. This method of ranking generators is often referred to as the "order merit", and it is repeated for 30 minutes. The average of the six five-minutes interval dispatch prices set the wholesale spot prices and all generators dispatched during this half hour are paid at this price regardless of the price they have bid.

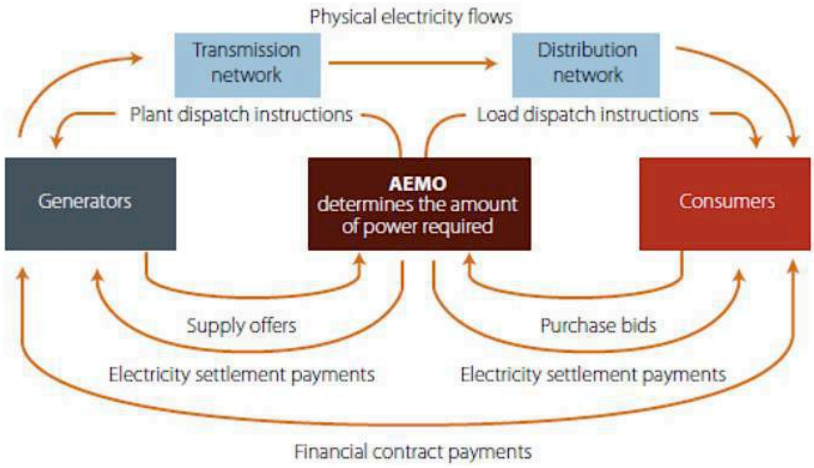

Figure 4: NEM structure
Source: Halen A. (2014)

However Australian customers do not pay this price. They purchase electricity through retailers at the commercial tariff while retailers buy large quantities of electricity and pay AEMO at the spot price level. In general, spot prices account for 20% of the retail prices. The spot price is allowed to be negative. Price may vary from -1'000 AUD per MWh to 13'100 AUD (January 2014). This limit increases each year according to the consumer price index. The volatility of spot prices can be explained by various reasons.

Generator offers are affected by different factors such as technology. For instance, coal-fired power plants have high start-up costs and may bid at a negative price to be able to run constantly, whilst gas power plants have higher operating cost and only offer supply when spot prices are high. Spot prices are also event-driven, such as high demand in summer, and can also reflect technical issues such as plant outages or constraints in the transmission network.

It is also important to take into consideration that AEMO usually set a different spot price for each of the 5 regions comprising the NEM. Additionally, network constraints prevent power supply to neighboring regions. If local power plants cannot meet the local demand, prices would rise to align across the regions concerned. Differences in spot prices along regions also reflect market structure (vertical integration), and technology generation. While Victoria has the largest concentration of brown coal-fired generation, Tasmania is almost fully supplied by its hydroelectric plants that have a larger operational cost.

2.1 Carbon Tax

The Australian federal government has introduced a carbon-pricing scheme from the 1st of July 2012 as part of its Clean Energy Future Package. The Plan targeted a reduction of at least 5% below the 2000-level for carbon emissions by 2020 (Nera 2013).

The scheme had two stages:

- A fixed price period, with a price starting at 23 AUD per tonne of CO2 and increasing by 2.5 per cent above inflation per year for each year of the fixed price period ending 30 June 2015.
- A flexible price beginning on 1 July 2015 following an emissions trading scheme (ETS), where carbon permits are issued by the government based on an overall cap on emissions.

The government also intended to link its emissions trading scheme with the European Union Trading Scheme (EUETS) to enable Australian entities to use European allowances in order to meet liabilities under the Australian scheme (Nera 2013). As mentioned earlier, the Coalition government elected in 2013 managed to repeal the carbon pricing in July 2014. However, it has renewed its 5% reduction commitment by 2020 and launched a Direct Action plan providing funds for emissions abatement activity in Australia. The plan also includes green funding to promote urban tree planting and rooftop solar installations.

Carbon Pricing mainly affects the electricity sector due to its high emission intensity. It increases the marginal cost of production for any form of electricity production releasing CO2 emissions, and relatively greater costs for the highest emissions intensive power stations such as inefficient brown coal and black coal stations. The main difference between brown and black coal is the level of moisture content explaining why brown coal contains less energy than the black coal[5].

Based on the emissions-intensity, carbon price then places the heaviest burden on brown coal- (~1.22 tCO2e/MWh (ACIL Tasman, 2009)), followed by black coal power generators (~0.86 tCO2e/MWh). Subsequently, gas power generators (~0.42 tCO2e/MWh) face less than half of the taxation imposed on those of brown coal and finally renewable generators are completely free of carbon taxation. While brown and black coals have historically been the cheapest method of electricity generation, the carbon tax significantly changes the merit order by enhancing the competitiveness of gas-fire turbine plants, hydroelectric- and renewable plants. Therefore, emissions intensive plants will become less profitable and will only operate when spot prices are high.

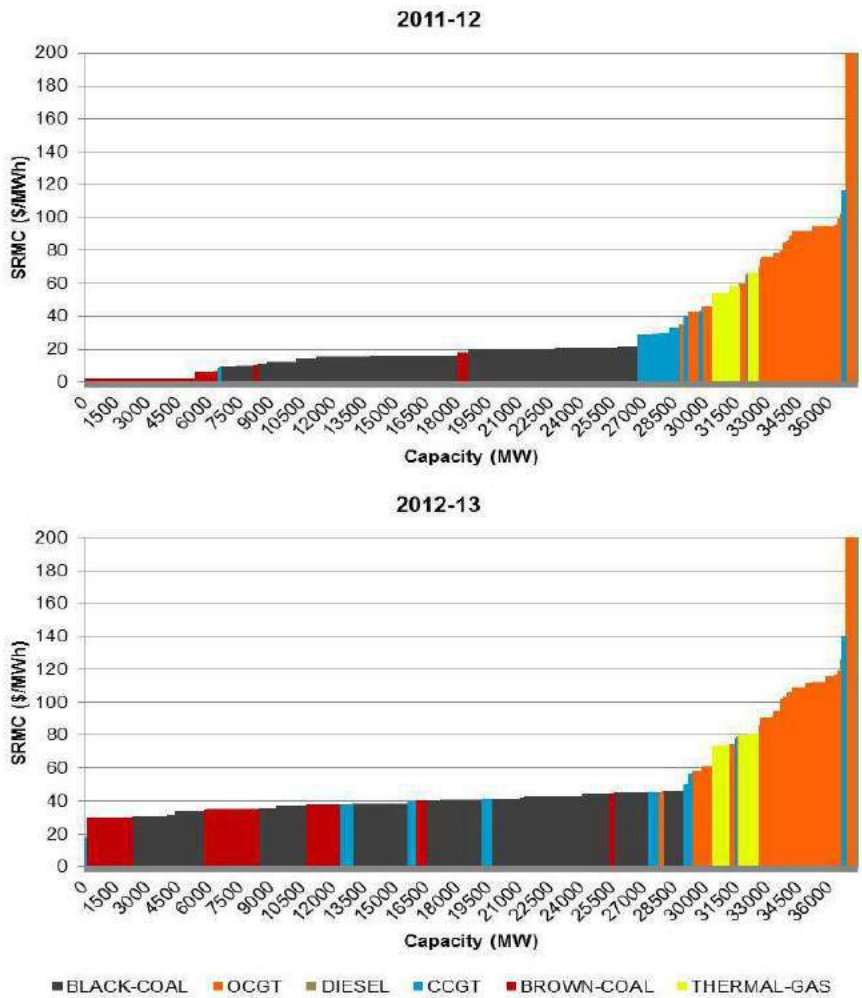

Figure 5: Merit order before and during tax implantation
Source: Nera (2013)

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[5] GDF Suez. 2015. *Coal-fired Power Station*. Available at: http://www.gdfsuezau.com/education/Coal-fired-Power-Station.

3. Literature Review

Various studies have been performed on the Australian carbon pricing case. Most of them have been provided by leading Australian economic modeling firms (e.g. MMA, ACIL Tasman and ROAM Consulting) and funded by government, industry leaders and other NGO stakeholders. The Australian studies reflect a lack of independently funded or academic research while the previous ones focus on forecasting carbon pricing and its impact on electricity and other areas of the Australian economy impacted. Nelson et al. (2012) provides a summary of existing research papers and appears to be an adequate guideline for literature review for this study.

To measure the impact of carbon pricing, the previously mentioned studies evaluate the same key metric referred to as the "carbon pass-through rate" (CPR), and broadly define it as the proportion of carbon prices (expressed in AUD/t of CO2e) passed through into electricity prices (expressed in AUD/MWh) presenting it as an indication of the incidence of the tax. Low levels of CPR mean producers bear a high proportion of the tax while high levels of CPR indicate that the bulk of the tax is beared by consumers. Nelson et al. (2012) specifies that CPR is mainly driven by the combination of the following factors and may explain the different results found by various studies due to their chosen economic assumptions:

- **Emissions intensity of the existing capital stock**

  CPR might be significantly higher in an emission intensive economy as opposed to one that is not emissions intensive. As an example, the average intensity of the NEM is currently around 0.92 tCO2e per MWh, while the European average is 0.35 t (Nelson et al. 2012). Australian regional intensities reflect specific dominant technologies as mentioned earlier. In New South Wales and Queensland, black coal-fired power stations produce the majority of electricity and have emissions intensities between 0.8 and 1.0 t CO2e per MWh. However in Victoria, brown-coal fired power stations have an emissions intensity of between 1.25 and 1.55 t CO2e per MWh. By contrast, in South Australia there has been an increasing proportion of wind generation in recent years resulting in a lowering of its regional intensity down to 0.57 t CO2e per MWh. Lastly, Tasmania relies mainly on its hydro power plants, which allow to reach a regional intensity of 0.057t CO_2e per MWh. Table 1 summarizes the values for the NEM.

Table 1: Regional electricity generation

	Emission Intensity [tCO_2e/MWh]	Carbon Cost if CPR=1 [AUD]	Generation Output [TWh]
NSW	0.929	21.91	73.4
QLD	0.836	19.71	59.3
SA	0.575	13.56	14.3
TAS	0.057	1.34	8.5
VIC	1.220	28.77	56.1
NEM	0.921	21.72	211.6

Source: Trueck (2015), AEMO data

- **Demand elasticity**

  According to economic theory, the lower demand elasticity is, the greater the incidence of the tax beared by consumers rather than producers. In the case of electricity, companies and households cannot easily change their electricity consumption in the short-term. The market is thus relatively inelastic in the short term and elastic in the long-term.

- **Economics of existing substitutes**

  The CPR can be lowered by dispatching low intensive power plants that are not fully operating in order to substitute higher intensive power plants

- **Availability of 'offsets' or 'international credits'**

  Amongst different trading emission schemes, there are provisions of "offsets" or "international credits". Such allowances would reduce environmental pressures on the domestic economy. Thus the higher the allowance availability, the higher the national CPR would be.

- **Market competition**

  The incidence of a tax can be influenced by the structure of the market. The electricity market is an example of a high level of market concentration and great vertical integration that may lead to the exercise of market power. The generational pattern varies across regions of the NEM but vertical integration of power generators and electricity retailers continues (AER 2013).

Former literature about CPR can be broadly divided into two categories: Australian literature mainly prioritizes research on the potential impacts of the introduction of an emissions trading scheme in electricity markets, whilst numerous following studies have been undertaken on other emissions trading schemes already operating in Europe since 2005.

In general, Australian studies use various economic techniques according to Nelson et al. (2012) (Linear programme optimisation modelling; Linear programme modelling utilising game theory; Computable General Equilibrium modelling; and Dynamic partial equilibrium analysis), but generally implement the same approach by initially building a model of the electricity market and then running it with and without a carbon policy and finally evaluating the difference. The CPR can thus be obtained according to the following equation:

$$\text{Carbon Pass-through} = \frac{P_c - P_{wc}}{CP} \times 100$$

Where P_C stands for the price of electricity with carbon price (AUD/MWh); P_{WC} is the price of electricity without a carbon price (AUD/MWh); CP is the carbon price (AUD/t CO_2e).

Most Australian economic models forecast that brown coal-fired generators would suffer losses by 2020, whilst the black coal-fired generation case varies. However, unless prices increase beyond the 20 ~ 35 AUD per tonne of CO2e range, it is anticipated that carbon pricing will have a comparatively smaller impact on electricity prices. Nelson et al. outlines the CPR results obtained by Australian studies, while the lowest result of 17% was produced by MMA (2006) and the highest result of 393% was produced by Simshauser and Doan (2007). The mean of the studies surveyed is a pass-through rate of 93.45%, and is coincidently close to the NEM average emission intensity of 0.94 t CO_2e per MWh. The different assumptions chosen including carbon pricing alone cannot only explain the inconsistency in results according to Nelson et. Al (2012), requesting further research to be taken and to rely on the numerous posteriori European studies in order to provide guidance for policy makers. Table 2 outlines the results found by other studies used during this internship:

Carbon pricing has been repealed and any further carbon policy does not appear on the agenda of the current Abbott government. Thus, performing further carbon pricing impacts modelling seems irrelevant, but the uncertainty about the true effectiveness of this short carbon tax period and the relative scarcity in economic literature provides a motivation to undertake this study.

Table 2: Summary of economic reports studied and rates of carbon pass-through (CPR)

Year	Study	Methodology	CPR	Commentary
2006	Sijm J, Neuhoff K, Chen Y	Empirical and linear program models	60-117% in Europe	Evaluates CPR and potential windfalls for generators in Europe
2012	Nelson T, Kelley S, Orton F	Reviews previous Australian model studies	17%-393% Mean: 93.4%	Focuses on the CPR in the NEM
2012	Wild P, Bell P, Foster J	Linear program modelling of NEM	40%-91%	Australian electricity sector specific modelling
2013	Nera Economic Consulting	Collection of 3 linear program models including game theory of NEM: investment planning, market simulation and optimal hedging strategies	Max for VIC 115-125%	Australian electricity sector specific modelling
2015	Nazifi F	Empirical model	>100%	Focuses on the CPR in the NEM

4. Dataset

The dataset is constructed based on market data provided by the AEMO website[6]. It is comprised of the half-hourly observations for demand of electricity and wholesale spot prices for each states market within NEM. For the purposes of this study, we selected AEMO data from January 2009 to June 2015 and perform calculations on MATLAB in order to find for each respective state the:

- Daily and weekly average spot prices
- Daily and weekly volume-weighted prices
- Daily and weekly average demand for electricity
- Daily and weekly total demand for electricity

Volume-weighted prices allow us to take in consideration differences in daily electricity prices and demand and is calculated as follow for a specific period:

$$\frac{\sum\ halfhourly\ spot\ price \times halfhourly\ demand}{\sum halfhourly\ demand}$$

In addition, we consider the peak period as defined by AEMO. The peak period refers to the period from 7.00 to 22.00 AEST on weekdays excluding public holidays, whilst the off-peak period indicates all other remaining periods. We take into consideration the following national public holidays in the course of this study:

Table 3: Public holidays considered for peak period

Public Holiday	Date
New year's day	1st of January
Australia Day	26th of January
Good Friday	*Varies*
Easter Monday	*Varies*
Anzac Day	25th of April
Queen's Birthday	Second Monday of June
Christmas Day	25th of December
Boxing Day	26th of December

Source: AEMO

We then calculate the:

- Daily and weekly average peak prices
- Daily and weekly volume-weighted peak prices

[6] AEMO. 2015. *Price and Demand*. Available at: http://www.aemo.com.au/Electricity/Data/Price-and-Demand.

- Daily and weekly average off-peak prices
- Daily and weekly volume-weighted off-peak prices

5. Preliminary analysis

As performed by Sijm et al. (2006), an initial approach to evaluate the impact of the carbon tax on wholesale spot prices is to compare the day-ahead half hourly spot prices under the assumption that the dynamics of power prices can be fully explained by CO_2 costs while other costs are assumed to remain constant over the study period. We set the 3 following periods relative to this study:

1) The **pre-tax** period corresponds to the 1st of July 2009 to 30th of June 2012
2) The **in-tax** period starts from the 1st of July 2012 to 30th of June 2014
3) The **post-tax** period is from the 1st of July 2014 to 30th of June 2015

We also split our observations into the different quarters of the year to reflect seasonal market trends into our comparisons. Quarters 1 and 4 stand for the summer season in Australia while quarters 2 and 3 stand for the winter season. We finally plot values for NSW, as it is where Macquarie University is located. Figure 6 describes the median hourly spot prices for the 3 considered periods. The differences between curves related to the pre-tax period are plotted in Figure 7. Finally the difference between in- and pre-tax periods is divided by the cost of the carbon (i.e. NSW's emission intensity x the average of carbon costs over the in-tax period) in order to obtain an estimation of the CPR in Figure 8. Those figures invite some observations:

(1) As can be noticed from Figures 6 and 7, differences between prices of pre- and in tax decrease along the seasonal daily peak. Because less emissions intensive and more expensive generation units are in general dispatched during peak hours (i.e. a gas power plant setting the margin unit according to the merit order), price differences would indeed decrease if carbon costs were the difference main reason. This reasoning is confirmed later by regression results in table 8 and 9 as CPR would be lower during peak hours.
(2) In Figure 7, the post-tax curve is always higher than pre-tax curve. The carbon tax would have deeply altered the market as several coal-fired power stations have been shut down since 2012 (AER, 2013). This might have lead to more expensive power stations dispatched such as gas power stations and explains the price difference between before and after tax implementation.
(3) From Figure 8, the CPR can be roughly estimated above to be 100% in NSW, confirming our initial assumptions of windfalls for power generators.

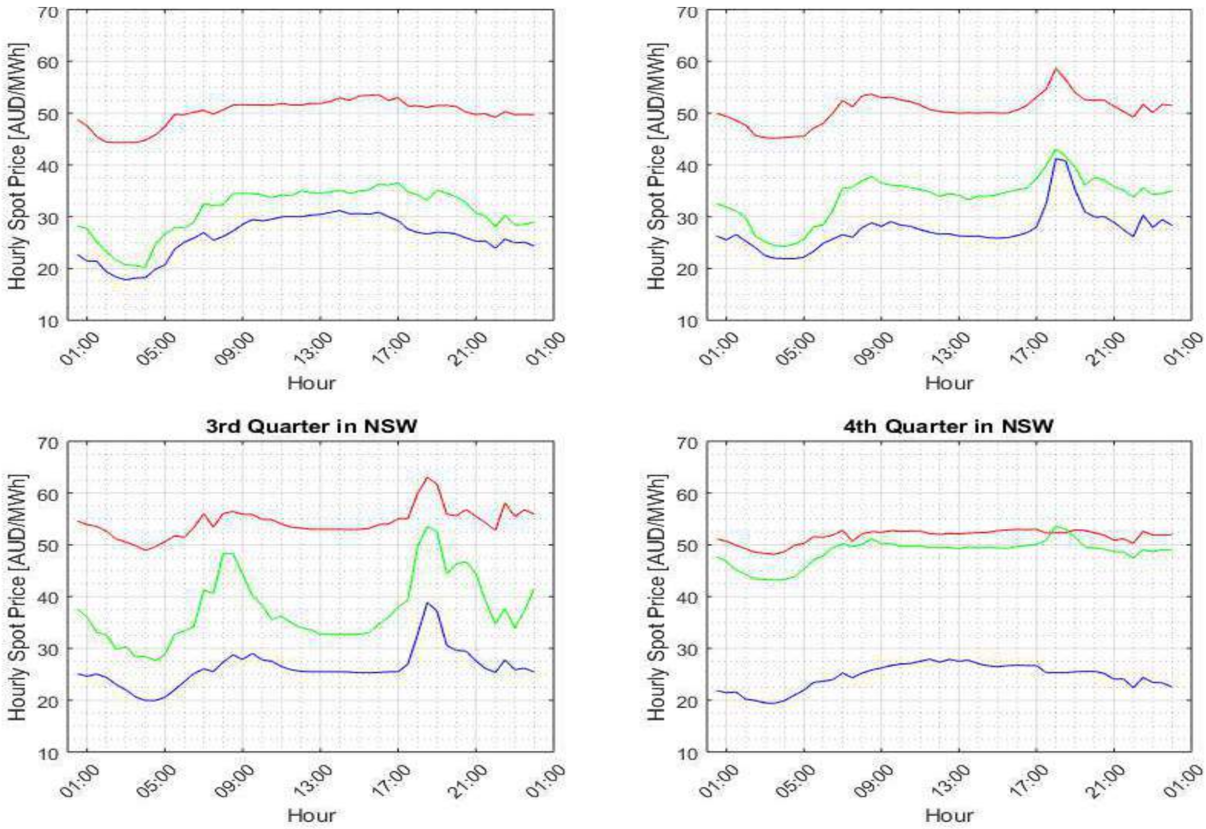

Figure 6: Median hourly spot prices in NSW for pre- (blue), in- (red) and post-Tax period (green)
Source: AEMO data

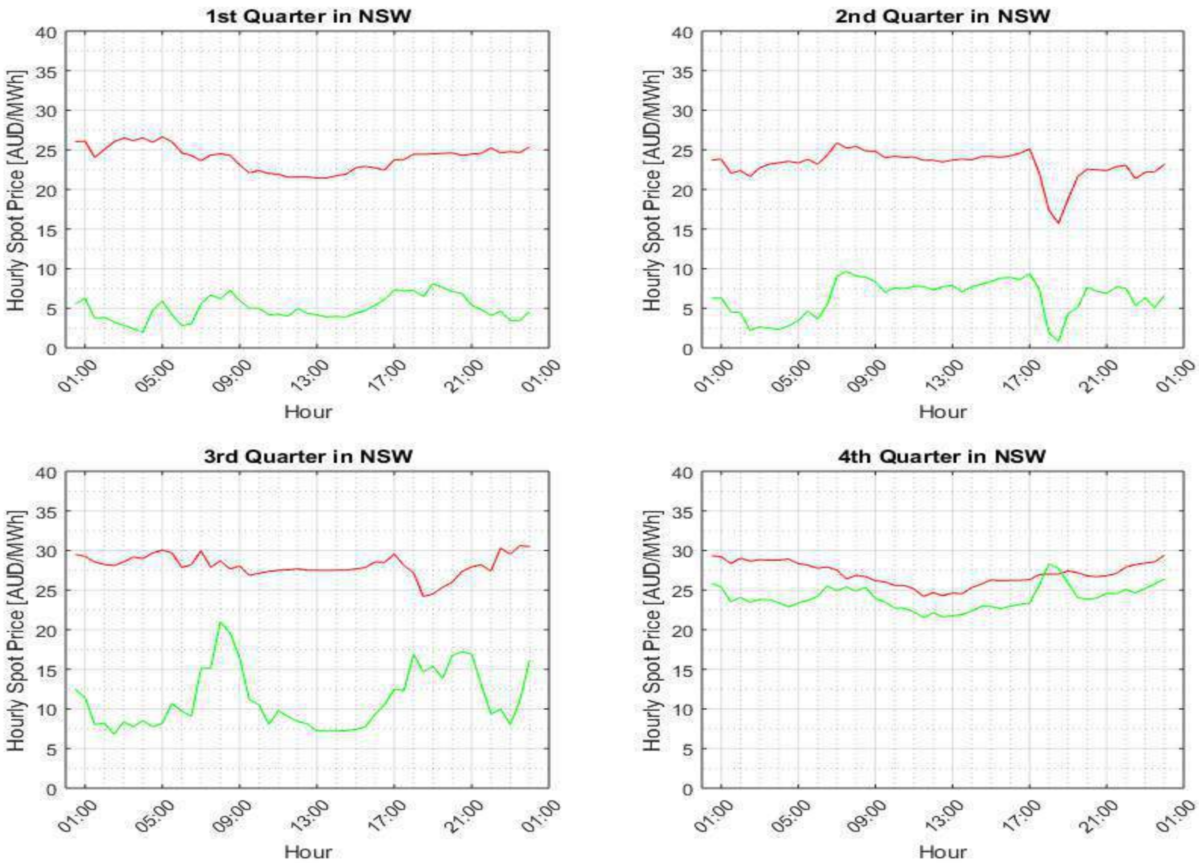

Figure 7: Price differences in NSW between pre- and in-Tax period (red) and between pre- and post-Tax period (green)
Source: AEMO data

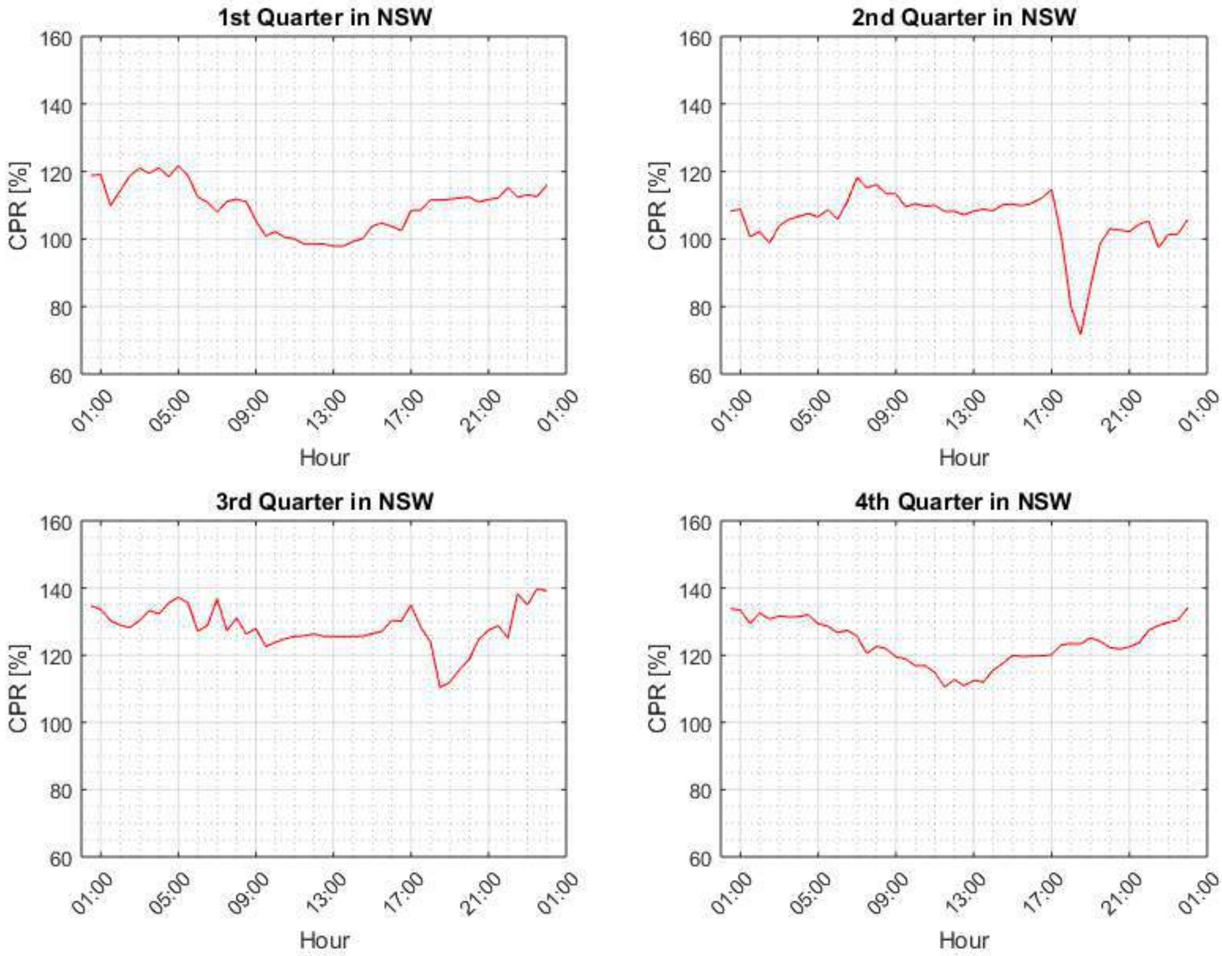

Figure 8: Estimation of the CPR in NSW
Source: AEMO data

6. Statistical estimates of CPR

6.1 Estimation procedure

In order to evaluate the CPR with more accuracy, we assess it empirically by employing a model based on a regression analysis. According to Nazifi, 2015, the volatile spot prices can be explained, in addition to the carbon cost and fuel costs, by the demand in order to capture event-driven factors such as demand-related events, weather-related or equipment failure-related events. While Figure 9 confirms this reasoning, we assume a cubic relationship between demand and electricity and apply the following model for each of the five states within the NEM:

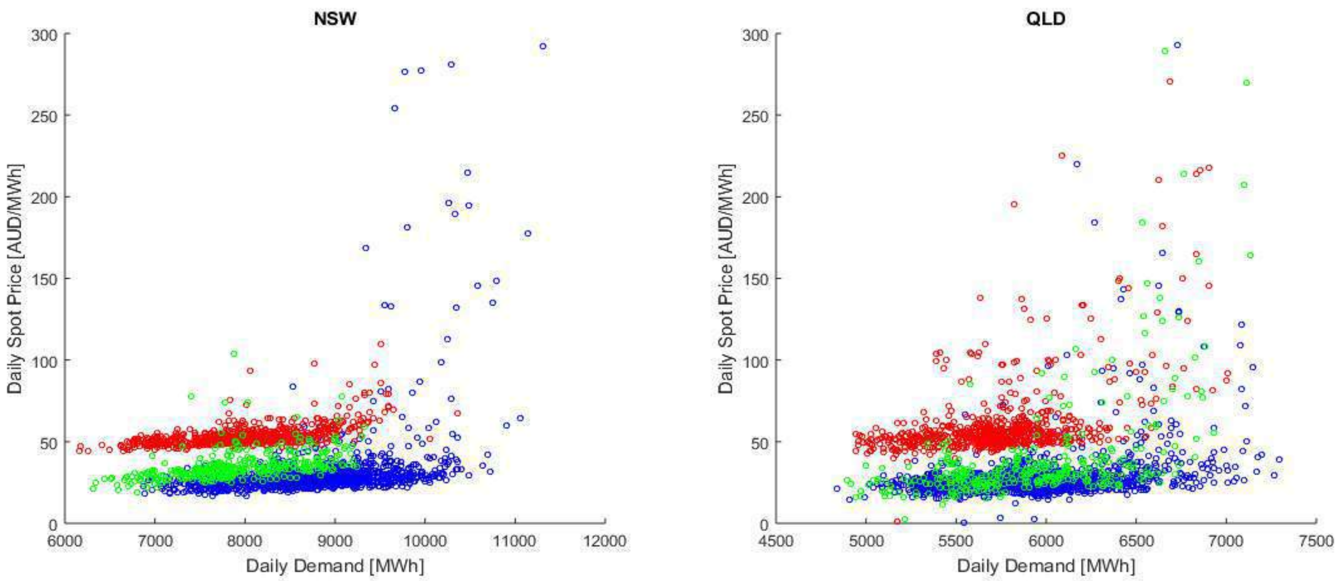

Figure 9: Relationship between daily demand and spot prices for NSW and QLD during pre- (blue), in- (red) and post-Tax period (green)
Source: AEMO data

$$P_t = \alpha + \beta_1 D_t + \beta_2 D_t^2 + \beta_3 D_t^3 + \gamma_1 Du_{tax} + \gamma_2 Du_{PostTax} + e_t$$

Where the left side of the equation refers to the spot prices (P_t), terms on the right side evaluate the cubic impact of the electricity demand (D_t) and α is the intersect. To capture the impacts of the carbon tax, a first dummy (Du_{tax}) variable is created for the period tax, which equals 1 during it and 0 otherwise and a second one for the post tax period ($Du_{PostTax}$), which equals 1 since 1 July 2014 until the end of the data and 0 otherwise. γ_1 represents the average component of the price attributable to the tax period. As assuming any price differences during the tax period can be fully explained by the carbon price mechanism, γ_1 divided by the cost of the carbon required to the power generators (i.e. state emission intensity x average carbon tax) can be interpreted as the CPR. Finally the non-stable components in the spot prices, such as the fuel price volatility, are captured by the error term (e_t).

6.2 Empirical Results

Given high volatility of spot prices, we filter the price spikes (above 200 AUD), as they are probably explained by other factors as regular demand, in a first recursive approach model (Trueck 2015) before estimating the specified equation by means of the Ordinary Least Square (OLS) regression method for each state. Table 4 and 5 report the coefficients model results for VIC that reached the highest coefficient of determination. Table 6 to 9 present estimations of the CPR for each states based on different calculation approaches used.

Table 4: Regression results for VIC **Average Daily Prices**

Coefficient	α	β_1	β_2	β_3	γ_1	γ_2
Estimates	-3591.3	201.15	-3.71	0.0227	**26.63**	**10.08**
SE	113.97	5.92	0.1	0.00057	0.91	1.23
t-Stat	-31.511	33.93	-36.44	39.2	29.2	8.19
p-Value	0	0	0	0	0	0
R^2			0.664			

Source: AEMO data

Table 5: Regression results for VIC **Average Daily Volume-Weighted Prices**

Coefficient	α	β_1	β_2	β_3	γ_1	γ_2
Estimates	-4326.5	242.5	-4.48	0.027	**26.69**	**10.7**
SE	135.35	7.03	0.12	0.00068	1.08	1.46
t-Stat	-31.96	34.46	-37.06	39.9	24.69	7.34
p-Value	0	0	0	0	0	0
R^2			0.658			

Source: AEMO data

The high statistical significance of the coefficients confirms the robustness of this simple demand-based model and coefficient γ_1 and γ_2 support that the implementation and removal of the carbon tax contribute to an increase in electricity prices in Australia. The estimates of CPR range from 0.89 to 10.33 according to states and reveal that carbon cost have been generally passed to consumers.

Table 6: Carbon Pass-Through Costs **Average Daily Prices**

	γ_1	Emission intensity	CPR	γ_2	R^2
NSW	28.03	0.929	**1.28**	10.47	0.592
QLD	35.33	0.836	**1.79**	10.91	0.515
SA	31.27	0.575	**2.31**	16.55	0.73
TAS	14.02	0.057	**10.43**	6.69	0.158
VIC	26.63	1.22	**0.93**	10.09	0.664

Source: AEMO data

Table 7: Carbon Pass-Through Costs **Average Daily Volume-Weighted Prices**

	γ_1	Emission intensity	CPR	γ_2	R^2
NSW	27.99	0.929	**1.28**	10.85	0.571
QLD	36.01	0.836	**1.83**	11.72	0.492
SA	31.02	0.575	**2.29**	17.57	0.734
TAS	13.89	0.057	**10.33**	6.79	0.16
VIC	26.69	1.22	**0.93**	10.73	0.658

Source: AEMO data

Table 8: Carbon Pass-Through Costs **Average Daily Peak Prices**

	γ_1	Emission intensity	CPR	γ_2	R^2
NSW	24.93	0.914	**1.16**	11.58	0.664
QLD	37.46	0.824	**1.93**	17.19	0.479
SA	30.16	0.574	**2.23**	22.27	0.878
TAS	13.15	0.054	**10.33**	6.21	0.16
VIC	24.77	1.185	**0.89**	8.95	0.768

Source: AEMO data

Table 9: Carbon Pass-Through Costs **Average Daily Off-Peak Prices**

	γ_1	Emission intensity	CPR	γ_2	R^2
NSW	27.72	0.929	**1.27**	7.98	0.71
QLD	32.25	0.836	**1.64**	7.58	0.512
SA	31.716	0.575	**2.34**	11.54	0.421
TAS	13.77	0.057	**10.25**	6.56	0.0789
VIC	26.822	1.22	**0.93**	5.92	0.792

Source: AEMO data

Before proceeding to further analyses, it should be mentioned that results have to be cautiously interpreted. The model assumptions could lead to an overestimation of the CPR as other factors explaining the spot prices, such as fuel costs, investment in transmission network or new plants, market structures, seasonal factors, or plant-failure events, have not been taken into considerations due to lack of available data. Moreover this model doesn't take into consideration change in the merit order that might affect the CPR. As seen from Figure 5, this effect can be assumed trifling as carbon tax didn't lead to a main change in the dispatch of power plants. Finally, results have not been corrected for heteroscedasticity and autocorrelation due to the lack of knowledge in econometrics, but estimates should not be biased.

First of all, NSW and VIC have a CPR close to one reflecting their relative emission intensity. From this reasoning, CPR results for QLD, SA and SA seem more surprising. QLD CPR result might indeed have been affected by some spike prices (see figure 1) due to unusual hot temperatures in January 2013 (Nazifi, 2015) that have been probably captured into γ_1. While Tasmanian CPR should have benefit from the lowest emission intensity rate within the NEM, it has the highest CPR obtained. Despite the low coefficient of determination of the model for Tasmanian case (i.e. max 16%), electricity trade through the Baselink Interconnector between TAS and its neighbour VIC might bring some clues. Before tax implantation, TAS relied on importation of the low cost Victorian brown coal-generated electricity, as hydroelectric plants with higher marginal cost are predominant in TAS. The carbon pricing reversed the situation by enhancing the competitiveness of Tasmanian electricity and resulted in a net export towards VIC (see figure 10). This change might have lead to a sudden relative large electricity price increase for TAS and lower one for VIC even though the latter was more susceptible to carbon cost because of its highest emission intensity of the NEM. SA case is similar as the state imported usually around 25% of its electricity consumption to VIC (AER, 2013) before tax implementation. The sudden price increase can be thus associated with the dispatch of local gas power plants more attractive due to the carbon pricing (Nazifi, 2015) and the shutdown of some important plants, which lead to a net import from VIC during the tax period (AER, 2013).

In summary, CPRs obtained for NSW, QLD and VIC reveal that power plants recover from the cost of carbon by passing it entirely onto the spot prices. It seems also to be a windfall for those power plants in NSW and QLD as their respective

CPRs deviate from 1 (see table 9). Results obtained for SA and TAS can be explained by a major change in the merit order and in their electricity generation origin and thus cannot be interpreted entirely as windfalls for power plants, as coal power plants are also a minority in those states[7].

Table 9: Carbon Pass-Through Rate

	CPR
NSW	1.16 ~ 1.28
QLD	1.64 ~ 1.93
VIC	0.89 ~ 0.93

Source: AEMO data

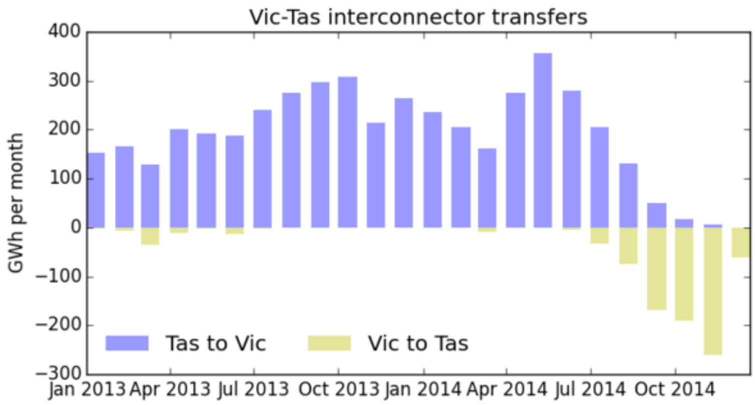

Figure 10: Electricity traded between TAS and VIC from January 2013 to December 2014
Source: Trueck, 2015

[7] A page of Wind in the Bush. *Wind farms in South Australia*. Available at: http://ramblingsdc.net/Australia/WindSA.html

7. Conclusion

This paper intended to study the impact of the carbon tax on electricity prices. More specifically, it examines through two steps the increase in the spot prices during and after tax implementation based on data from January 2009 to June 2015. Despite strong assumptions, a first hourly spot prices simple comparison for NSW shows carbon tax lead to an increase during tax period as expected but more surprisingly post-tax prices remain relatively higher than pre-tax period prices. The price difference also appears lower during peak hour because of less emission intensive generation mix supporting that price difference can be mainly explained by the carbon price in order to proceed calculating the CPR. Secondly, an econometric model based on the electricity demand has been used to estimate the CPR with more accuracy. It empirically results supports the hypothesis that power plants in NSW and VIC have been able to pass the cost of the carbon into the whole spot prices as CPR obtained were close to 1. Results for QLD, SA and TAS deviates largely from 1 and should be interpreted cautiously as large changes in the merit order and demand-related events occurred in those states. The possibility of windfalls for some power generators cannot thus be excluded.

Those results address also several policy implications. Positive effects of the Australian carbon price mechanism remain mitigated. As predicted by consulting reports, the 23 AUD carbon tax has been too low to bring any real change in the merit order. Electricity demand was also already declining since 2008 for other reasons and despite the shutdown of several coal power plants and an 11% reduction of emissions during the tax period, emissions and emission intensities have now almost returned to their initial levels[8]. Far from having revealed any efficiency, it has mainly resulted in unfavorable outcomes for consumers. Despite any regulation to protect final consumers from “double dipping” (i.e. consumers charged by retailers and generators for carbon costs, Nazifi, 2015) during the tax period, the experiment of the carbon tax resulted finally in potentials windfalls profit for some generators and a final higher-level price than during the pre-tax period without any real environmental progress. According to Nazifi, 2015, a transition to an emissions trading scheme would have

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8 Renew Economy. 2015. *One year on from the carbon price, Australia's emissions rebound is clear*. Available at: http://reneweconomy.com.au/2015/one-year-on-from-the-carbon-price-australias-emissions-rebound-is-clear-65643.

also contributed to the increase of the CPR as it as been shown in Europe by Sijm et al., 2006.

The degree of CPR should also be a warning of carbon pricing effectiveness for policy makers. Due to policy uncertainty, markets did not have the likely expectation that the carbon price was to remain in place and thus little incentive for closing high emission generators and for investment in less emission intensive generation infrastructure. According to O'Gorman et al. (2014), a stable and politically uncontested policy framework is needed in order to obtain a long-term expectation of carbon pricing and the full effect of a carbon price.

Finally, despite strong assumptions, the simple model of this study provides relatively robust results. During this internship, mention has been made of the idea of an econometric model based on fuel costs, daily emission intensities and generators marginal costs in order to model the merit order daily and evaluate the CPR precisely. Marginal costs are of course kept secret, but have been estimated by ACIL Tasman, 2009. However a lack of time and finance knowledge didn't allow for this paper to investigate this in detail, however further research should be taken in this direction.

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