The impact of an ETS on Australian energy sector: an integrated CGE and electricity modelling approach

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Abstract

By employing a computable general equilibrium (CGE) model with an embedded electricity supply sub-model, this paper reports the effects of a national ETS on the Australian energy sectors. The modelling results show that the ETS can reduce emission effectively but with a mild negative impact on the economy. The impact of the ETS on the energy sectors varies. The renewable electricity generators will be the biggest winners. Brown coal electricity and oil electricity will be hit hard and effectively exit the market. Opposite to expectation, the black coal electricity will expand its production considerably. The exit of brown coal electricity will spell hardship to the brown coal sector.

Key words: carbon pricing, CGE modelling, energy resources, carbon emission

1. Introduction

Climate change and carbon emissions are major global concerns in recent decades. Although Australia's carbon emissions are relative low compared with other countries, the Australian emission per capita is very high. The then Australia Labour Government introduced a carbon tax in 2012 to reduce carbon emissions, but this legislation was repealed in 2014 after the Coalition Government came into power. Yet, the Coalition government committed to a target of a 5% emissions reduction on 2000 levels by 2020. This target is to be achieved through subsidized emission reduction activity called 'the direct action plan'. According to this plan, the government will use an emission reduction fund of A$2.55 billion to pay for emissions reduction activities. It is widely criticised that the direct action plan is inefficient and inadequate to fulfil Australia's international obligation on emission reduction. As a result, an emission reduction policy with a market mechanism like the ETS was considered by the Australian Environment Minister and the Climate Change Authority in Australia.

There are numerous studies on carbon emission reductions. Most of them are in the form of CGE modelling while some employed an electricity or energy model. The advantage of CGE modelling is that this approach treats the whole economy as an integrated system and thus can take into account the feedback effect in the economy, but the CGE modelling results are sensitive to key elasticities values. On the other hand, an electricity model or an energy model can include a great deal of details in the energy sectors and rely less on elasticity values, however, this type of model singles out the energy sector from the economy and thus ignores the interaction between sectors. This study intends to utilize the advantages of both approaches by incorporating an electricity model into a CGE model.

The balance of the paper is organised as follows. Section 2 reviews previous studies on the effect of a carbon pricing policy in Australia. Section 3 describes the model structure and database for the simulations. Section 4 presents and discusses the simulation results with special reference to the energy sectors. The final section summarises the results and provides some comments.

2. Previous studies

The effect of a carbon tax is a well-researched topic internationally. Notable research includes Beausejour et al. (1992), Hamilton and Cameron (1994), Zhang (1998), Labandeira et al. (2004), Wissema and Dellink (2007), and Devrajan et al. (2011). Due to the space limitations, we review only recent studies with an Australian context.

Adams (2007) simulated the cost of an Australian emission trading scheme as an insurance against catastrophic climate change. The core model used in this study is the Monash Multi-Regional Forecasting (MMRF) CGE model while a suit of micro models by McLennan, Magasanik Associates (MMA) is used to model the electricity industry. The integration of the two types of models is achieved through iteratively feeding the modelling results into each other: the MMA models informed the MMRF model of the changes on generation mix and capacity while the MMRF model provided the MMA models with the changes in electricity demand. The carbon permit price was also determined by the MMA models based on a specific abatement target and this carbon permit price was converted to an ad valorem tax on emission sources (e.g. coal, oil, gas, etc.). With a carbon emissions permit price rising from $18.30 per tonne of CO2-e in 2010 to $50.20 per tonne of CO2-e in 2030, the study suggested that, compared with the baseline (business as usual) case, real GDP in 2030 will fall by 1.3% and real household consumption will fall by 1.4%. Whilst employment will fall by 0.6% in the short run, it will recover in 2030, but the real wage rate will decrease by about 3.3%. Total carbon emissions in 2030 will decrease by 21.1% (or 169.6 megatonnes) compared with the baseline case.

The work of Adams (2007) became a foundation for the Australian Treasury modelling in 2008 and 2011. The final modelling framework and results were included in the Treasury report: Strong growth, low pollution – modelling a carbon price (The Treasury, 2011). Using the same modelling framework, Adams et al. (2014) simulate the impact of an emission trading scheme in Australia. In this study, the carbon permit price is projected by GTEM and converted to real Australian dollars in MMRF, starting from $24.3 per tonne in 2012 and reaching $49.3 per tonne in 2030. Electricity inputs are from an electricity model by Frontier Economics, WHIRLYGIG, which allows the electricity sector to respond to the permit price by switching technologies of electricity generation, changing the utilisation of existing capacity, and replacing old plants with more efficient plants. Road transport inputs were taken from the Australian Bureau of Infrastructure, Transport and Regional Economics (BITRE) and the CSIRO. The inputs on forestry production and forest bio-sequestration were from ABARES. Adam et al. (2014) projected a deviation from the baseline in 2030 of -0.2% for employment, -2.6% for real wages, -1.1% for real GDP, -2.3% for household disposable income, and -1.5% for real household consumption. Emissions were projected to decrease by 25.6% in 2030.

Clarke and Waschik (2012) investigated the carbon pricing strategies of Australia in a global context. Using a single-country static CGE model and the GTAP database version 7, they simulated the results of carbon pricing in order to reduce Australian carbon emissions by 27%. Without any border tax adjustment or compensation for energy-intensive and trade-exposed sectors, the 27% emission abatement target resulted in a carbon price of US$26.41 per tonne. Social welfare measured by Hicksian equivalent variations fell by 0.39% and returns to labour and capital reduced by 1.1% and 1.6%, respectively. Free emissions permits or compensation to energy-intensive and trade-exposed sectors led to a higher carbon price. Their sectoral results suggested that, while compensation is justified in the case of the non-ferrous metals industries because of a relatively high potential for carbon leakage, border tax adjustments and export exemptions are unnecessary and potentially harmful because carbon leakage and adverse competitiveness effects are generally small.

Meng et al (2013) built a 35-sector (commodity) CGE model and simulated the effects of the Australian carbon tax on the environment as well as on the economy. According to the simulation results, the carbon tax of A$23 per tonne of CO2e can cut emissions effectively, but would cause a mild economic contraction. Although both nominal GDP and GNP demonstrate substantial growth in the carbon tax only scenario, the economy contracts mildly when it is measured by real GDP and real GNP. However, real GNP registers significant positive growth under a carbon tax combined with a household compensation policy. The return on capital and on land decreases substantially in both scenarios. The return on labour declines only slightly under the carbon tax only scenario and increases significantly when the household compensation policy is in place. In the absence of household compensation, the government's fiscal position improves substantially. Household consumption decreases marginally in the carbon tax only scenario, but it increases significantly when compensation is provided by the government. Importers benefit slightly under the tax only policy and benefit significantly in the carbon-tax-plus-household-compensation scenario, while exporters fare badly, with an almost 3% drop in real exports in the tax only case, and a more than 6% drop in the compensation scenario. Similar results with reference to the agricultural sectors were also demonstrated by Meng (2015).

As the Australian carbon tax policy was replaced by the direct action plan, researchers were attracted into studies on subsidized emission abatement activities. Freebairn (2014) for example, described and compared a price and a subsidy to reduce carbon emissions. Assuming an aggregate marginal abatement curve for the economy, the paper showed that a carbon price is more cost-effective even in an ideal world of broad emissions abatement potential and minimal transaction costs. Since a subsidy policy will lead to a smaller base for emission abatement and higher transaction costs, the subsidy policy will be even more inefficient when the transaction cost is taken into account. The paper also pointed out the budgetary advantage of a carbon price over a subsidy policy.

Clarke et al. (2014) were concerned whether the emissions reduction fund proposed by the Australian government can meet its international obligation on emissions reduction. Using the CGE modelling results on emissions reduction under different levels of carbon pricing, the above paper generates an aggregate marginal abatement curve for the economy. Based on this marginal abatement curve, the paper claimed that a GDP reduction of 0.33% is the cost involved in achieving Australia's international emission reduction target. Since the $2.55 billion emission reduction fund is only about 0.16% of GDP, they concluded that the direct action plan can achieve only about 50% of Australia's abatement obligation.

Using a dynamic partial equilibrium model of the power system – NEMESYS, Simshauser and Doan (2009) assess the adverse economic impact of an all-auction approach to emissions trading on electricity generators. It is claimed that once CO_2 prices exceed $17.50 per tonne, the marginal coal generator will withhold generating capacity to raise prices and recoup stranded investment, thus becoming a 'wounded bull'. This would result in an intermediate-run 300 per cent increase in wholesale power prices.

3. Model Structure and database

The model used for this study is a CGE model embedded with an electricity supply model. The CGE model is a static model, based on the multi-households version of ORANI-G (Horridge, 2000). The Australian economy is represented by 40 sectors which produce 40 goods and services, one representative investor, ten household groups, one government and nine occupation groups. The final demand includes household, investment, government and exports.

The functions for final demands are similar to those in the ORANI model (Dixon et al., 1982). For example, the investment demand is a nested Leontief-CES function, the household demand function is a nested LES-CES function. Export demand is dependent on the price of domestic goods, and government demand follows household consumption. However, unlike the assumption of exogenous supernumerary household consumption in ORANI-G, we assume that total consumption is proportional to total income for each household group. The production function is a five-layer nested Leontief-CES function. As in the ORANI model, the top level is a Leontief function describing the demand for intermediate inputs and composite primary factors and the remainder are various CES functions at lower levels. However, substantial change has been made regarding the energy inputs.

In this study, energy inputs are assumed substitutable with capital because energy efficiency is positively related to the investment on energy-saving devices. The size of substitution effect depends on the cost and the availability of energy-saving technology, which is reflected in the value of the substitution elasticity. Limited substitution effects are also assumed between different types of energy inputs. Specifically, four levels of CES functions are used to form the energy-and-primary-factor bundle. At the bottom level, various CES and Leontief functions are used to form composite energy: CES functions are used to combine black coal and brown coal to form composite coal, to combine oil and gas to form composite oil&gas, and to combine automobile petrol, kerosene, LPG, other fuel and petroleum products to form composite petroleum. Seven types of electricity generations are aggregated to form a composite electricity generation. A Leontief function is then used to combine composite electricity generation and electricity distribution to form commercial electricity. At the second level, composite coal, oil&gas, petroleum and commercial electricity are combined by a CES function to form composite energy. At the third level, a CES function is used to combine composite energy and capital to form capital-energy composition. At the fourth level, a CES function is used to combine capital-energy composition, labour and land to form the primary factor.

Carbon emissions in this paper are counted when the emissions occur, so this treatment of emission is in the category of direct carbon emissions accounting, which are different from the indirect (or embedded) emissions accounting. The direct emissions are put into two major categories: stationary emissions and activity emissions. The first comes from the fuel combustion and the second includes other emissions, including emissions with no specific source (e.g. emissions from production procedures). The stationary emissions are treated as proportional to the energy inputs used, while the activity emissions are tied to the level of activity (or output). Based on the Australia's National Greenhouse Accounts published by the Department of the Environment, the emission intensities of both stationary emission and activity emission can be calculated for each industry and household group. These emission intensities are assumed unchanged during the modelling to reflect unchanged technology. The fixed emission intensities are used to calculate the changes in emission level when the level of production or consumption has changed.

The electricity industry is extremely important for this study because this industry accounts for the bulk of total emission in the economy. The industry is disaggregated to eight sectors: black-coal-fired electricity, brown-coal-fired electricity, oil-fired electricity, gas-fired electricity, hydroelectricity, electricity from wind mills, electricity from solar panel and biofuel, and electricity distribution. The first seven sectors are seven types of the electricity generation sectors which are modelled by a firm-level electricity supply model. The last sector – electricity distribution – purchases electricity from seven electricity generation sectors to form commercial electricity, which is sold to households, the government and industries.

The electricity supply model is designed to mimic the price bidding (or merit order) system in the electricity wholesale market in Australia. In this system, each electricity generation station submits a selling price and quantity for each half hour. For each half hour, the national electricity market (NEM) purchases electricity starting from the lowest bidder until the electricity demand is satisfied. The price paid by NEM to each station is the same – the marginal bidding price, or the price of the highest bidder. For this study, we collected information about all electricity generation stations in Australia, including the type of fuel used, generation capacity, outage rate, minimum generation requirement, variable cost, and cost due to carbon pricing (depending on the level of carbon price).

In reality, each station can engage in a strategic bidding game, i.e. to bid a supply which is much lower than its marginal cost. But this is risky because this bid may bring loss to the station when it is the marginal bidder. To simplify the case, each station in the model bids according to its current (or effective) generation capacity and variable cost (inclusive of carbon emission cost when a carbon price is in place). The effective generation capacity is calculated from the generation capacity and outage rate and the effective capacity of solar electricity generators are set as zero during the night. Since some stations (e.g. brown-coal or black-coal fired stations) have minimum generation requirement, these stations will bid at a zero price for the amount within its minimum generation requirement.

The simplified bidding behaviour above is modelled through a ranking procedure. Each station is ranked based on its variable cost (inclusive of carbon emission cost) lowest to highest. Based on this ranking, the effective generation capacity of the lower bidder for each half hour will be added to that of the higher bidder to form an accumulated generation capacity. By comparing this accumulated generation capacity with the total electricity demand for each half hour, we can find out which station will supply how much electricity to the market. This ranking-and-allocation procedure is repeated for each half hour during one year and generates a one-year output for each station. Although the 2014 half-hour electricity demand data are used for this study, these time series data can be scaled up or down based on the change in total electricity demand in the CGE model. In other words, only the pattern of 2014 electricity demand matters.

The electricity supply model is integrated in to the CGE model through the shares of electricity generation sectors. First, the one-year output of each station will be aggregated based on the fuels used to obtain the sectoral output at each step of simulation. The sectoral output can be used to calculate the sectoral shares in the total electricity supply. These sectoral shares together with the change in electricity demand will determine the change in output and further determine the input demand of each electricity generation sector.

The main data used for the modelling include input-output data, carbon emission data, electricity demand data, electricity production data, and various behavioural parameters. The input-output data used in this study are from Australian Input-output Tables 2009-2010, published by ABS (2010). There are 131 sectors (and commodities) in the original I-O tables. For the purpose of this study, we disaggregate the energy sectors and aggregate other sectors to form 40 sectors (and commodities). Utilizing the 2009-2010 household expenditure survey data by ABS (2011), the household income and consumption data were disaggregated to 10 household groups according to income level, and labour supply was disaggregated to 9 occupation groups. The 2014 electricity demand data and electricity production data are collected from the Australian Electricity Market Operator (AEMO) and from AGL limited.

The carbon emissions data are based on the Greenhouse Gas Emission Inventory 2009, published by the Department of the Environment. There are two kinds of emissions: energy emissions and other emissions. The former is mainly stationary energy emissions (emissions from fuel combustion), for which the Australian Greenhouse Emissions Information System provided emission data by sector and by fuel type. These data were mapped into the 40 sectors (and commodities) in our study. The other emissions – the total emissions minus the stationary emissions – are treated as activity emissions. The activity emissions by household are assumed proportional to household consumption and, using the data on household consumption by commodity in I-O table, the consumption emission intensities can be calculated.

Most of the behavioural parameters in the model are adopted from ORANI-G, e.g. the Armington elasticities, the primary factor substitution elasticity, export demand elasticity, and the elasticity between different types of labour. The changed or new elasticities include the household expenditure elasticity, the substitution elasticities between different electricity generations, between different energy inputs and between composite energy and capital. Since the model 10 household groups and 40 commodities are included, the expenditure elasticities for each household group and for each of the commodities are needed. Cornwell and Creedy (1997) estimated Australian household demand elasticities by 30 household groups and 14 commodities. these estimates were adopted and mapped into the classification in our model.

The substitution effects among energy inputs and between composite energy and capital are considered very small, so small elasticity values between 0.1 and 0.6 are commonly used in the literature. In our model, it is assumed that the cost of energy-saving investment is very high given the current technology situation and thus there is a very limited substitution effect between capital and composite energy. Consequently, a value of 0.1 was assigned for this substitution elasticity. There are two levels of substitution among energy goods in our model. At the bottom level, the energy inputs have a relatively high similarity, so a value of 0.5 was assigned for substitution between black and brown coal, between oil and gas and between various types of petroleum. At the top level, it is assumed that the substitution effect between various types of composite energy inputs is very small, so a value of 0.1 was assigned. Since the substitution effect between electricity generations has already been taken care of by the electricity supply sub-model, the elasticity between energy inputs is set as zero for all electricity generation sectors. Considering the large (nearly 100%) output decrease in brown-coal electricity and oil electricity, zero elasticity between energy input and primary factors is also assumed for these two sectors so as to avoid a -100% change (e.g. 100% decrease in employment) in modelling results.

4. Simulation Analysis

The level of carbon price for the ETS is designed to achieve Australia's 2020 international obligation on emission reduction, i.e. 5% emission reduction of 2000 levels. Since the emissions tend to increase as the size of the economy grows over time, the targeted emissions level in 2020 has to be converted to the base year. Based on average economic and emission growth rates in recent years, 5% emissions reduction of 2000 levels by 2020 is converted to an equivalent 12% emissions reduction in the base year.

This study is mainly concerned with the short run effects, so a short-run macroeconomic closure is assumed, e.g. fixed real wages for all sectors and fixed capital stocks for all sectors except for the brown-coal electricity sector and the oil electricity sector, free movement of labour but immobile capital between sectors, and government expenditure to follow household consumption. The exchange rate is set as exogenous so the CPI can be set as endogenous. Nominal wages are 50% index to CPI. Unless specified, all projections reported in this paper are shown in terms of percentage changes.

4.1 Macroeconomic and environmental effects

The macroeconomic and environmental effects are listed in Table 1. The results are categorized into 3 panels, i.e. carbon emissions and energy consumption results in panel 1, price effects in panel 2, and GDP and GNE, as well as its expenditure-side and income-side components in panel 3. The environmental results are discussed first.

The simulation results in the first panel suggest that a price of $28.11 per tonne of carbon emissions is required to achieve a 12% carbon emissions reduction target. This carbon price level is significantly higher than the carbon tax of $23 per tonne to achieve an 11.986% of emission reduction in Meng et al. (2015). This difference may result from the different base years used in the two studies. However, the different model structure may also be a contributing factor. The 12% emission reduction target is equivalent to a total of 101.873 mega tonnes emission reduction in the Australian economy. The vast majority of emission reduction is achieved from stationary emission reductions (98.923 mega tonnes). This is consistent with the fact that the Australian stationary emission base is considerably larger than its activity emission base. The close relationship between emission reduction and energy use is indicated by the significant change (-2.859%) in energy consumption in the economy.

The changes in price level in the second panel indicate how the ETS affect the economy. It is not a surprise to see significant increases in the GDP deflator, CPI, terms of trade, aggregate energy price, and nominal wages. A constraint on carbon emissions forces the industries to pay for their emissions and this cost will be passed on to other industries and final demands through commodity flows and factor flows. This causes a cost-push inflation. The relatively larger increase in the GDP deflator than in the CPI indicates the ETS affect the producer more than the consumer. Terms of trade is defined as the ratio of the price of exports to the price of imports. The prices of imports are assumed unchanged in a single country model, so the 0.172% increase in terms of trade implies an increase of the same degree in the price of exports. The 0.191% increase in nominal wage results from the simulation design: the nominal wage is 50% index to CPI. The 9.221% increase in energy price reflects the substantial impact of an ETS on the energy market. This hike in energy price also explained the significant decrease in energy consumption shown in the first panel.

The negative impact of factor prices (e.g. capital and land rental prices) stems from the scaling back of production when the ETS is in place. As the ETS increases the price of commodities, the consumer will respond by decreasing his/her demand, and thus the producer has to reduce production. As a result, the demand for primary factors and the price of primary factors will decrease. The significantly greater decrease in land rental can be explained by the large activity emission base in the agricultural sector. A large emission base implies a large emission reduction task under an ETS. Consequently, this leads to a large reduction in production and in demand for land, which necessitates a large decrease in land rental.

It is noticeable that, in the third panel, although the changes in nominal GDP and GNE are positive, the rest of the results are negative. The positive results for nominal GDP and GNE result from the significant increase in prices. For example, adding 0.408% change in the GDP deflator to -0.234% change in real GDP gives a 0.174% increase in nominal GDP. The negative numbers in this panel show the adverse impact of an ETS on the economy. The decrease in the real GNE is smaller than the decrease in the GDP because the latter does not include the effect of the decrease in net exports. As an income-side component of GDP, employment decreases at a much greater degree than the GDP. This is largely due to the short-run assumption: the stock of both capital and land is fixed (except for brown-coal electricity sector and oil electricity sector). On the expenditure side, a 0.300% decrease in household consumption and 0.443% decrease in exports contribute significantly to the reduction in the GDP. The decrease in household consumption and export can be easily comprehended considering the increase in commodity price in the wake of an ETS. The 0.119% decrease in import volume is unexpected because the prices of imports are unchanged during the simulation. This negative result can be explained by the income effect: as production is scaled back thanks to the ETS, household income will decrease, so households have to reduce their consumption of imports. As the decrease in exports is greater than the decrease in imports, the contribution of balance of trade (or net exports) to GDP decreases slightly.

Table 1 Macroeconomic and environmental effects

Description	An ETS targeting 12% reduction in emissions
Change in total carbon emissions*	-101873
Change in stationary carbon emissions*	-98923.8
Change in activity carbon emissions*	-2768.89
Change in energy consumption	-2.859
Price on carbon emissions ($/tonne)	28.11
GDP deflator	0.408
Consumer price index	0.382
Terms of trade	0.172
Average nominal wage	0.191
Average energy price	9.221
Average capital rental price	-1.879
Average land rental	-5.927
Nominal GDP	0.174
Nominal GNE	0.211
Real GDP	-0.234
Real GNE	-0.163
Aggregate employment	-0.356
Real household consumption	-0.3
Import volume	-0.119
Export volume	-0.443
Contribution of BOT to GDP (change)	-0.072

*Nominal change: kilotonne.

4.2 Sectoral performance

Table 2 lists the key indicators of sectoral performance such as sectoral output, employment, and profitability. Since the capital stock is assumed fixed for each sector, the sectoral profitability is indicated by capital rental price. as the focus of this paper is on the energy and resource sectors, the of these sectors are selected and put in the first panel, the results for the rest of the sectors are listed in the second panel as a comparison.

Most sectors experience a negative change in output. This indicates the pervasive negative impact of an ETS on the economy. Energy and resource sectors, especially electricity sectors, are affected to a greater degree. Almost a 100% decrease in output for the brown-coal electricity sector and oil electricity sector indicates the devastating effect of the EST on these sectors. The 100% decrease in output of the oil electricity sector is due to its very high operating cost. This high cost gives no chance for the sector to bid successfully to supply electricity. In reality, oil electricity generators do have limited chance to supply electricity when the demand for electricity is high and when a lot of outage happens at the same period of time. This kind of unforeseen rare situation is unable be modelled, so the 100% output decrease for the oil electricity sector may partly come from the limitations of the model. By this reasoning, the oil electricity sector may not exit the market, but its market share will be very small.

Because of the high carbon emission costs for the brown coal sector, it has no chance to bid a profitable price for supplying electricity to the market. The tiny remaining sectoral output is due to the sector's non-profitable bidding because of the minimum generation requirement. In considering this, the modelling results actually suggest that the brown coal electricity generators have to stop producing and exit the market permanently. As the brown coal electricity sector almost stops production, the demand for brown coal decreases dramatically, so the output of brown coal sector reduces substantially.

The black-coal electricity sector and the gas electricity sector will gain substantially at the expense of the brown coal electricity sector. With the brown coal electricity sector's almost stopping production, it gives away its share of electricity demand to other sectors. Since the emission intensity of black coal and gas is much lower than that of brown coal, the emission cost on black-coal fired and gas fired electricity generators is much lower, so they have more chance in bidding successfully for supplying electricity. However, this may change if the higher emission reduction target is adopted (i.e. the higher carbon price is to be imposed).

Renewable electricity generators are the big winners under the ETS. Wind electricity is the biggest winner with its output more than doubled. The solar and biofuel electricity sector will also increase its output by 43.979% while hydroelectricity will increase its output by 17.034%. These results are consistent with the cost structure and emission profile for these sectors. Wind electricity has a high fixed cost but very low variable cost and little emissions, so this sector has an advantage in the electricity bidding system under the ETS. Hydroelectricity has little emissions but has high operating costs, so it can be successful in bidding only when the electricity demand is relatively high. The solar and biofuel sector has low variable costs but has slightly higher emission cost (mainly from biofuels), so its performance is poorer than wind electricity but is better than hydroelectricity. Overall, electricity generation will decrease significantly due to a decrease in electricity demand under an ETS, thus the electricity distribution decreases by 2.534%.

The impacts on other energy and resource sectors are much smaller than on the aforementioned sectors but are relatively greater than the sectors in the second panel. The size of the negative impact is largely determined by both the emission base of the sectors and the amount of electricity used. A few sectors experience an increase in output level, e.g. 0.128% increase in gas supply, 0.401% increase in water supply, and 0.476% increase in construction. The increase in gas supply can be explained by the substitution effect between electricity and gas supply: as electricity becomes too expensive due to the ETS, people substitute electricity with gas. There is no direct substitution effect in the case of either water supply or construction. The significant increase in output in these sectors is worth further investigation.

Table 2 Percentage change in sectoral output, employment and profitability

Sectors	Output	Employment	Profitability
Black coal	-0.204	-1.139	-2.288
Brown coal	-24.349	-62.657	-86.313
Oil	-0.053	-0.394	-0.646
Gas	-1.160	-1.930	-5.888
Other mining	-0.102	-0.007	-0.088
Auto petrol	-1.240	-1.627	-5.528
Kerosene	-0.655	-0.880	-2.869
LPG	-4.662	-5.583	-20.271
Other fuel	-1.080	-0.771	-9.206
Petroleum products	-2.047	-2.663	-3.531
Electricity (black coal)	28.061	29.789	189.184
Electricity (brown coal)	-99.739	-99.739	0
Electricity (oil)	-100.000	-100.000	0
Electricity (gas)	16.214	16.690	110.418
Electricity (hydro)	17.034	17.964	62.411
Electricity (wind)	124.636	133.739	469.268
Electricity (solar & biofuel)	43.979	47.051	302.497
Electricity distribution	-2.534	-0.640	-7.117
Gas supply	0.128	0.707	1.553
Water supply	0.401	1.315	2.569
Agriculture	-1.737	-5.778	-12.535
Food manufacturing	-0.878	-1.201	-3.112
Textile, wood, print	-0.500	-0.577	-1.796
Chemical	-1.168	-1.509	-4.871
Iron and steel	-1.674	-1.710	-6.556
Other metal	-1.106	-0.725	-4.019
Non-metal products	-0.722	-0.760	-2.677
Construction	0.476	0.960	2.107
Wholesale	-0.458	-0.622	-1.476
Retailor	-0.423	-0.532	-1.284
Hospitality	-0.475	-0.472	-1.727
Road transport	-1.284	-0.387	-4.271
Other transport	-0.388	-0.433	-1.397
Publishing	-0.176	-0.410	-0.738
Finance	-0.147	-0.296	-0.405
Real estate	-0.144	-0.291	-0.471
Public services	-0.037	-0.017	-0.071
Education	-0.137	-0.133	-0.404
Health care	-0.061	-0.043	-0.204
Other services	-0.507	-0.689	-1.556

The change in employment follows the same pattern as the change in output, but the magnitude is generally greater. This is largely due to the short-run simulation design: the capital is fixed for each sector, so the changes in employment have to be larger due to the constant-scale assumption. However, not all sectors follow this rule because labour has mobility among the sectors. For brown-coal electricity and oil electricity, the change in employment is exactly the same as the change in output because of the assumption of zero elasticity between energy inputs and primary factors.

The large decrease in employment in some sectors is depressing news for workers, for example, 100% reduction in the brown coal electricity sector and the oil electricity sector, and 62.657% reduction in the brown coal sector. However, these decreases will partly be offset by the increase in employment in other sectors. The economy-wide employment amounts to 0.356% reduction shown in Table 1.

The change in profitability (or capital rental price) is even greater than the change in employment. This is also related to the fixed capital assumption in the short run: as capital cannot be changed, the changes in demand for capital have to be realized in variation in capital rental price. A few sectors experience double-digit reductions, i.e. - 86.313% for the brown coal sector, -20.271% for the LPG sector, and -12.535% for the agricultural sector. The results for brown coal electricity and oil electricity are zero. This is due to the assumption of zero elasticity (or Leontief function) between primary factors for these two sectors. Since the Leontief function requires that the primary factors change at the same proportion, the capital is endogenized and the capital rental price is exogenized. Given almost 100% reduction in capital in these two sectors, the return to capital will decrease by 100% even if the capital rental price is unchanged. In the long run, capital can move among sectors, so the changes in capital rental price will be smaller.

Broadly speaking, these results agree with the results in Meng et al. (2015). For example, the brown coal electricity sector will be hit hard and renewable electricity will benefit greatly. However, due to the different ways in modelling electricity in these two studies, the detailed results are different. The brown coal electricity will experience an only 18.55% decrease in output and the oil electricity will experience an increase in output in Meng et al. (2015), but the brown coal electricity and oil electricity will exit the market (a decrease in their output by almost 100%) in the current study. The renewable electricity in Meng et al. (2015) will experience an 11.81% increase in output, 67.15% increase in employment and 191.18% increase in capital price but the current study suggests much larger benefit the ETS can bring to the renewable electricity sectors. Moreover, the black coal electricity in Meng et al. (2015) will experience an 8.57% decrease in output, a 3.71% decrease in employment and a 58.82% decrease in capital price, but this sector will increase output and profitability in the current study. Since electricity generation in the current study is modelled by a micro-level electricity supply sub-model rather than by assumed value for elasticity of substitution, the results in the current study should be more close to reality.

4.2 Sectoral emissions and energy consumption

This section considers the environmental contribution of each sector under the ETS. Table 3 displays the amount change (kilotonne) in stationary emission, activity emission, and percentage change in energy consumption. These are discussed in turn.

From the first column of Table 3 it is clear that the energy sectors have played a vital role in emission reduction. The electricity industry makes the most contribution to emission reduction. The retirement of brown coal electricity reduces emissions by 103.809 mega tonnes. Ceasing the production of oil electricity reduces emissions by 2.780 mega tonnes. However, these emission reductions will be partially offset by the increase in emissions from the black coal electricity, gas electricity, renewable electricities, and electricity distribution. The gas sector and the coal products sector also contributes significantly to emission reduction. Other energy sectors decrease emissions in the range of 2.457 to 52.255 kilo tonnes. Despite the high emission intensity of brown coal and 24.349% output reduction in this sector (see Table 2), the emission reduction in the brown coal sector is only about 41.161 kilo tonnes. This is because emissions are counted when they are generated. Since most coal is burnt in the downstream rather than during the mining process, the stationary emission base for the brown coal sector is small and thus the emission reduction is small.

It is somewhat surprising to see considerable amounts of emission reduction in the non-energy sectors in the second panel. For example, the road transport sector reduces emission by 10.933 mega tonnes, the non-metal products sector by 1.713 mega tonnes, the other metal sector by 1.548 mega tonnes, and the textile-wood-print sector by 1.153 mega tonnes. One reason is that these sectors use significant amounts of coal or petroleum products, e.g. the road transport sector uses a substantial amount of petrol and diesel, the metal production uses large amounts of coal. The other reason is that the manufacturing sectors consume substantial amounts of electricity. As the price of electricity surges under the ETS, these sectors will cut back production and thus reduce emissions significantly.

Compared with the reductions in stationary emissions, the reductions in activity emissions are relatively small. Most energy sectors display zero activity emission reduction because of their negligible activity emission base. A few energy sectors reduce their activity emission significantly, e.g. the black coal sector by 60.868 kilo tonnes, the brown coal sector by 285.383 kilo tonnes, and the gas sector by 81.907 kilo tonnes. The size of the reduction is largely in line with the sector's emission base and the size of the sectoral output reduction. The gas supply and the water supply sectors increase their activity emissions due to the increased output under the ETS.

Most service sectors show zero activity emission reductions because of negligible activity emission base for service sectors. The exception is the other-service sector, that reduces activity emission by 83.188 kilo tonnes. Most manufacturing sectors contribute significantly to the reduction of activity emissions. Notably, the non-metal products sector reduces activity emissions by 145.464 kilo tonnes, the iron and steel sector by 105.469 kilo tonnes, the chemical sector by 63.280 kilo tonnes, and the other metal sector by 145.464 kilo tonnes. The agricultural sector is the most important contributor to activity emission reduction due to the sector's high activity emission base. The high electricity prices may also contribute to the high activity emission reduction for the agricultural sector.

Table 3 Sectoral emissions and energy consumption

Sectors	Stationary emissions	Activity emissions	Energy consumption
Black coal	-52.255	-60.868	-1.825
Brown coal	-41.161	-285.383	-69.575
Oil	-2.457	-1.345	-1.688
Gas	-1147.511	-81.907	-4.630
Other mining	-20.424	0.000	-0.858
Auto petrol	-29.249	0.000	-1.410
Kerosene	-5.774	0.000	-0.744
LPG	-40.253	0.000	-5.260
Other fuel	-802.345	0.000	-1.240
Petroleum products	-18.597	0.000	-2.328
Electricity (black coal)	24465.805	0.000	45.548
Electricity (brown coal)	-103808.734	0.000	-99.739
Electricity (oil)	-2780.021	0.000	-100.000
Electricity (gas)	2331.538	0.000	20.509
Electricity (hydro)	0.021	0.000	44.130
Electricity (wind)	0.025	0.000	363.817
Electricity (solar & biofuel)	102.867	0.000	122.124
Electricity distribution	25.788	0.000	-5.366
Gas supply	0.032	3.839	-0.815
Water supply	0.410	11.532	-1.164
Agriculture	2.417	-1919.964	-3.883
Food manufacturing	-821.814	-1.503	-4.142
Textile, wood, print	-1153.712	0.000	-3.180
Chemical	-582.986	-63.280	-2.004
Iron and steel	-238.900	-105.469	-3.245
Other metal	-1548.282	-35.887	-4.293
Non-metal products	-1713.291	-145.464	-3.217
Construction	53.018	0.000	-0.011
Wholesale	-5.575	0.000	-0.923
Retailor	-4.755	0.000	-2.105
Hospitality	-11.144	0.000	-3.115
Road transport	-10933.179	0.000	-6.230
Other transport	-112.468	0.000	-1.312
Publishing	-3.337	0.000	-1.868
Finance	-1.178	0.000	-0.312
Real estate	-5.658	0.000	-1.694
Public services	-3.973	0.000	-1.236
Education	-1.152	0.000	-2.707
Health care	-3.845	0.000	-1.953
Other services	-11.634	-83.188	-1.527

Energy consumption results in the third column are largely correlated to total emission reductions, for example, the large emission reduction in black coal electricity and oil electricity is accompanied by the highest reduction in energy consumption while the large emission increase in the black coal electricity sector is accompanied by a considerable increase in energy consumption. From this point of view, a price on energy can also accomplish the task of emission reduction. However, the correlation between emissions reduction and energy saving is not very high. There are many cases where industries with a greater emission reduction may not have a greater decrease in energy consumption. For example, the 4.142% decrease in energy consumption in the food manufacturing sector is larger than the 3.180% reduction in the textile-wood-print sector, but the emission reduction of the latter is much greater than that of the former. Similar situations can be found between the iron-and-steel sector and the other-metal sector, between the other-transport sector and the publishing sector, between the publish services sector and the education sector, and between the health care sector and the other-services sector. In the case of the electricity distribution sector, energy consumption decreases by 5.366%, but its emissions go in opposite direction – an increase of 25.788 kilotonnes. These cases indicate that an extra price on energy (e.g. energy tax) is less effective than a carbon price in reducing emissions.

5 Conclusions

Using a CGE model with an imbedded electricity sub-model, this study gauges the impact of an ETS designed to fulfil Australia's international obligation to emission reduction by 2020. The simulation results show that, to achieve the 12% emission reduction target, the ETS price needs to be $28.11 per tonne of emissions. The total emission reduction of 101.873 megatonnes mainly comes from reduction in stationary emissions. The impact on the macro economy is mild but significant. The ETS will cause a mild inflation indicated by 0.382% increase in CPI and 0.408% increase in GDP deflator. However, the energy price will increase by 9.221%. The increase in price levels help to produce a positive GDP or GNE, but the real GDP or GNE will decrease by 0.234% and 0.163% respectively. There will be significant decreases in employment and in returns to capital and land, and mild decreases in household consumption and in net exports.

The sectoral impact of the ETS on sectors varies. The renewable electricity generators will be the biggest winners. Wind electricity will increase its output by 124.636%, solar & biofuel electricity will increase its output by 43.979%, and hydroelectricity will increase by 17.034%. Brown coal electricity and oil electricity will effectively exit the market. Opposite to the expectation, black coal electricity will expand its production by 28.061%. The exit of brown coal electricity will spell hardship in the brown coal sector: a 24.349% decrease in output, 62.657% decrease in employment and 86.313% decrease in profitability. Most of other energy and non-energy sector will be hit mildly while a few sectors (e.g. gas supply, water supply and construction sectors) will benefit modestly from the ETS.

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