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Border adjustments under unilateral carbon pricing: the case of Australian carbon tax

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Abstract

In the absence of a global agreement to reduce emissions, Australia adopted a carbon tax unilaterally to curb its own emissions. During the debate prior to passing the carbon tax legislation in 2011, there were concerns about the challenge that Australia's emissions-intensive and trade-exposed (EITE) industries may face in terms of decreasing international competitiveness due to the unilateral nature of the tax and hence the potential for carbon leakage. In order to address these concerns, this paper explores possible border adjustment measures (BAMs) to complement the domestic carbon regulation in Australia using the multi-sector computable general equilibrium approach. We consider four border adjustments: border adjustments on imports based on domestic emissions; border adjustments on exports via a rebate for exports; a domestic production rebate; and full border adjustment on both exports and imports. We compare the numerical simulation results of these scenarios with a no border adjustments scenario from the standpoint of welfare, international competitiveness and carbon leakage. The key finding is that BAMs have a very small impact on the overall economy and on EITE sectors. In other words, the different BAMs have minimal impact on the outcomes of carbon pricing policy. This finding is consistent with studies for EU, USA, Canada and other countries. Hence, we conclude that the border adjustments are ineffective instruments to safeguard EITE industries in Australia.

Keywords: CGE modeling, Emissions, Carbon tax, Carbon leakage, International competitiveness, Border adjustments, Australia

JEL Classification: Q56, F18

1 Background

In the absence of a global agreement to reduce emissions, Australia adopted a carbon tax unilaterally to curb its own emissions and to counter climate change. During the debate prior to passing the carbon pricing legislation in 2011, there were concerns about the challenge that Australia's emissions-intensive and trade-exposed (EITE) industries may face after the tax. Domestic climate policies to limit carbon emissions can put extra pressure on industries that use emission-intensive energy sources in their production. That essentially creates cost differentials between domestic production and production in countries where carbon emissions are not constrained. Hence, a unilateral carbon tax can result in carbon leakage within domestic industries and across trading partners. It

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has been argued that such climate policy differences could place Australian industries at a competitive disadvantage in both home and foreign markets.

Another concern is the carbon leakage which generally occurs due to increase in emissions in countries without strong climate policies when countries with climate policies reduce emissions. Such carbon leakage may take place through three specific channels. First, industries in the carbon-constrained country can lose international market shares through decrease in exports and increase in imports to the benefit of carbon-unconstrained competitors. This is known as the 'short-term competitiveness channel.' Second, stringent climate policy at home may reduce returns on investment and hence industries may relocate to countries where less stringent emissions control exists with higher returns. This is the investment channel of carbon leakage. Third, there is a fossil fuel price channel where reduction in global energy prices as a result of reduced demand for fossil fuel-based energy in carbon-constrained countries triggers higher energy demand and hence emissions elsewhere, particularly in large non-constrained developing countries.

The potential adverse impact on Australia's competitiveness and seemingly inevitable carbon leakage has been used by opponents to undermine the carbon pricing strategy in Australia. Similar reasoning was also used in defense of postponing the ratification of the Kyoto Protocol by Australian governments. Determining the extent and nature of competitive disadvantage and potential carbon leakage is important for Australia to sustain its climate policy through carbon pricing. It is also equally important to examine the possible measures to counter decrease in competitiveness and carbon leakage resulting from carbon pricing if they are affecting the Australian economy in general and EITEs industries in particular. While border adjustment has been proposed as a possible countermeasure in the policy debate in Australia, the impact of adopting border adjustments and the empirical question as to whether they are in fact warranted in the Australian case has not been widely analyzed. The exceptions are Saddler et al. (2006), which examined the issue in a rather broad framework without a formal model and Clarke and Waschik (2012), discussed in Sect. 2.

In this paper, we use a multi-sectoral computable general equilibrium (CGE) model developed for carbon pricing policy analysis of Australia (Meng et al. 2013) to simulate the impact of different border adjustment measures (BAMs) and compare them with no border adjustment outcome. In particular, four BAMs are evaluated using the CGE model: (1) border adjustment on exports; (2) border adjustment on imports; (3) border adjustment through production rebate (subsidy) to all domestic producers; and (4) full border adjustment (both exports and imports).

The rest of the paper is organized as follows. Section 2 briefly reviews previous climate change policy-related studies on border adjustments. Section 3 describes the CGE model and data used in the present analysis. Section 4 outlines the emissions intensity and trade exposure of Australian industries. The basis of the BAMs used in the paper is justified in Sect. 5. Section 6 presents results and discusses the major findings from different border adjustment measures that have been simulated. Section 5 concludes the paper.

2 Literature on border adjustments

There is a growing body of literature on the issue of using BAMs to alleviate the decrease in competitiveness and carbon leakage due to adopting a particular carbon pricing strategy. Climate change-related BAMs are primarily proposed to restore competitiveness of the domestic economy and to combat carbon leakage while promoting deeper reductions in domestic emissions. Such policies are also considered as incentives to other countries to participate in an international effort to reduce emissions. Apart from winning the support of domestic industry lobby groups, unilateral BAMs are to some extent protective trade measures in climate policies that may induce political repercussions with retaliation, harm international trade relations and may be subject to challenge by the World Trade Organization (WTO). Hence, prior to introducing BAMs it is important for a country to gauge the potential costs and benefits of such measures and to demonstrate whether they deliver the expected economic and environmental outcomes.

CGE models have been used over the last decade to establish the economic and environmental effectiveness of adopting different BAMs such as export rebates, carbon or 'green' tariffs, production rebates and forcing importers to surrender carbon allowances in a cap-and-trade system. Mckibbin and Wilcoxen (2009) used the G-Cubed model to examine how large green tariffs (i.e., import border adjustments) would need to be to offset the costs of adopting climate policies and whether the tariffs are effective in combating competitive disadvantage and reducing carbon leakage. Their study focussed on the USA and Europe under various climate policy scenarios. They found that the effects of such tariffs would be small in protecting the domestic import competing sector and would reduce leakage very modestly. Bernard and Vielle (2009), in analyzing the EU emissions trading system (ETS), found that carbon leakage may affect some specific sectors while the aggregate impact would be rather small. Kuik and Hofkes (2010) also explored some implications of BAMs in the EU ETS and concluded that some sectors may benefit, but from and environmental point of view, BAMs are not a very effective measure.

Fischer and Fox (2009) compared the effects of four BAMs (a border tax on imports, a border rebate for exports, full border adjustment and a domestic production rebate) in a setting of a unilateral emissions pricing scheme for the USA and Canada. They illustrated the results for different energy-intensive sectors in the two economies and found that such policies have varying, but rather small, impacts. According to their findings, BAMs are ineffective instruments for improving the competiveness reduced by emissions control policies and for tackling leakage effects. Domestic production rebates were preferred to other alternatives.

Alexeeva et al. (2008) have undertaken a comparison of BAMs versus an integrated emissions trading scheme where foreign competitors must purchase permits to import into the EU. They found BAMs were more effective in protecting domestic production and integrated emissions trading is better at reducing foreign emissions. They expressed concern about the extent to which BAMs cause emission abatement cost shifting to less energy-intensive industries which may have higher abatement costs. Winchester (2011) used a CGE model to compare different BAMs with alternative firm behaviors. In a study encompassing North America, Europe and some developing countries, Mattoo et al. (2009) examined a range of border adjustment policies in combination with environment policies. They found that border adjustments by high-income countries would address most of their competiveness and environmental concerns at the expense of serious consequences for trading partners. For example, China would experience its manufacturing exports declining by one-fifth with a corresponding real income drop of 3.7%. Low- and middle-income countries' exports may decline by 8% and real income by 2.4%.

Burniaux et al. (1992) use the OECD's ENV-Linkages model (a dynamic global model of 12 world regions and 22 sectors) to assess the economic effects of BAMs under alternative coalitions of countries acting to cut emissions. These authors conclude that BAMs can reduce carbon leakage for small coalitions of acting countries such as the EU because when the coalition is small, the leakage occurs mainly through the short-term competitiveness channel, rather than through the fossil fuel price channel. However, the need for, and effectiveness of, BAMs declines rapidly with the size of the coalition because the BAMs are addressing smaller rates of leakage. Burniaux et al. (1992) also found that the economic effects of BAMs are small. More strikingly, they found that BAMs do not necessarily curb output losses experienced by the EITEs. This is because the EITEs make significant use of (the higher cost) emission-intensive imports themselves and also because of market contraction effects in the home country.

Takeda et al. (2012) isolated the effects of BAMs accompanying a carbon tax policy in Japan using a multi-regional CGE model developed using the GTAP-E database. They particularly analyzed welfare decline, competitiveness loss and carbon leakage and concluded that 'no single policy is superior to the other policies' in terms of addressing simultaneously all three issues. They do note that export border adjustment is more effective in restoring the export competitiveness of Japanese industries while reducing significantly the carbon leakage. The analysis also proved that information on direct emissions (emissions from fossil fuel use) is sufficient to establishing effective border adjustment policies in Japan and indirect emissions (emissions embodied in electricity) need not be included.

Carbon-motivated BAMs have been analyzed in a study by Dong and Whalley (2012) by developing a highly aggregated multi-regional model of China, EU-27 and the USA. A range of carbon prices (US$25/ton to US$200/ton) was imposed on the model to predict the impact of border adjustments. They found the regional impact of welfare, trade and emissions of BAMs is rather small, concluding that emissions intensity of different sectors matters in relative price adjustments.

Clarke and Waschik (2012) employ a static CGE model using GTAP7 data for Australia to examine the effects of a carbon tax and assess whether the scale of carbon leakages and loss of competitiveness in Australian industry sectors warrant concern. Clarke and Waschik (2012) simulate a 27% carbon emissions abatement (in order to draw comparisons with Australian Treasury modeling on the effects of a carbon tax), and this needs a carbon price of US $26.41 in the modeling. They assume Australia acts unilaterally to achieve the 27% carbon abatement and that there is no compensation to the EITEs and no BAMs.

Examining the impact of the carbon price on domestic demand, production, exports and imports in the key EITE sectors, Clarke and Waschik (2012) find small impacts and therefore no case for compensating the Australian non-metallic mineral sector (including cement) or the iron and steel sectors. They argue there is a case for protecting the Australian non-ferrous metals sector (aluminum) because of a loss of competitiveness resulting in potentially significant carbon leakage. The authors argue that in order to meet the emission abatement target, a significant increase in the carbon price is necessary when the burden of abatement falls on the unprotected sectors. This higher price itself necessitates more compensation to the protected EITEs. A key conclusion is that access to a global carbon permit market would alleviate the need to rely more heavily on unprotected industries in order to meet abatement targets. The present study extends the Clarke and Waschik (2012) study by directly simulating and analyzing the effectiveness of a range of BAMs following the introduction of a carbon tax in Australia.

3 Model structure and database

3.1 Model

The purpose of this study is to assess the effect of border adjustment policies when a carbon tax is in place rather than forecasting the performance of the whole economy overtime under the tax. Hence, the model used for this study is a static CGE model, based on ORANI-G (Horridge 2000). The comparative static nature of ORANI-G helps to single out the effect of carbon tax and border adjustment policies while keeping other factors intact. The model employs standard neoclassical economic assumptions: a perfectly competitive economy with constant returns to scale, cost minimization for industries and utility maximization for households and continuous market clearance. In addition, zero-profit conditions are assumed for all industries because of perfect competition in the economy.

The Australian economy is represented by 35 sectors that produce 35 goods and services, one representative investor, ten household groups, one government and nine occupation groups. The final demand includes households, investment, government and exports. With the exception of the production function, the model has adopted the functions in the multi-households version of ORANI-G.

Overall, the production function is a five-layer nested Leontief-CES function. As in the ORANI-G model, the top level is a Leontief function describing the demand for intermediate inputs and composite primary factors and the rest is various CES functions at lower levels. However, we have two important modifications to demand functions for electricity generation and energy use.

First, we classify electricity generation in the economy into five types according to the energy sources used, namely electricity generated from black coal, brown coal, oil, gas and renewable resources. Once generated, the electricity commodity is homogeneous, so there must be a large substitution effect among five types of electricity generation. Hence, we use a CES function to form a composite of electricity generation possibilities. With this approach, we allow the electricity generation to shift from high-carbon emission generators (e.g., brown coal electricity) to low-carbon emission generators (e.g., gas and renewable electricity).

Second, we argue that energy efficiency is positively related to the investment on energy-saving devices, e.g., well-insulated housing uses less energy for air-conditioning. So we assume that there are some substitution possibilities between energy goods and capital and that 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. Similar treatment of energy inputs has been used by many researchers—see, for example, Burniaux et al. (1992), Zhang (1998), Ahammad and Mi (2005), Devarajan et al. (2009) and Massetti (2011).

Carbon emissions in the model are treated as proportional to the energy inputs used and/or to the level of activity. Based on the carbon emissions accounting published by the Australian Department of Climate Change and Energy Efficiency, the model treats carbon emissions in three different ways. First, fuel combustion emissions are tied with inputs (the amount of fuel used on-site). Based on the emissions data, the input emission intensity—the amount of emissions per dollar of inputs (fuels)—is calculated as a coefficient, and then the model computes emissions by multiplying the amount of input used by the emission intensity. Second, industry 'activity' emissions (these are on-site ancillary activities such as gas emitted while making cement, on-site waste disposal, etc.) are tied to the output of the industry. The activity emission intensity coefficient is also pre-calculated from the emission matrix, and it is multiplied by the industry output to obtain the activity emissions by the industry. Third, the activity emissions by the household sector are tied with the total consumption of the household sector. The total consumption emissions are obtained by the amount of household consumption times the consumption emission intensity coefficient pre-calculated from the emission matrix. All three types of emission intensity are assumed fixed in the model to reflect unchanged technology and household preferences in the short term. For the purposes of undertaking the border adjustment simulations, it was necessary to calculate emissions associated with the use of electricity generated offsite. We have termed these 'indirect emissions' and they are explained further in Sect. 5.

The functions for final demands are similar to those in the ORANI model (Dixon et al. 1982). For example, investment demand is a nested Leontief-CES function and 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 household consumption (either total or supernumerary) in ORANI-G, we assume that total consumption is proportional to total income for each household group.

3.2 Database and parameters

The main data used for the modeling include input–output data, carbon emission data and various behavior parameters. The input–output data used in this study are from Australian Input–Output (I–O) Tables 2004–2005, published by ABS (2008). There are 109 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 35 sectors (and commodities). Specifically, the disaggregation is as follows: The coal sector is split into black coal and brown coal sectors; the oil and gas sector is separated into the oil sector and gas sector; the petroleum and coal products sector becomes four sectors—automotive petrol, kerosene, liquid petroleum gas and other petroleum and coal products; the electricity supply sector is split into five electricity generation sectors—electricity—black coal, electricity—brown coal, electricity—oil, electricity—gas and electricity—renewable and one electricity distributor—the commercial electricity sector. This disaggregation is based on energy use data published by ABARES (2005). Table 1 lists the 35 sectors of the model ranked according to emissions intensity. The table also displays export shares in output, import shares in the domestic market (import penetration) and the sectoral classification according to their respective trade exposure.

Utilizing the household expenditure survey data from ABS (2006), household income and consumption data were disaggregated into ten household groups according to income level. Similarly, the labor supply was disaggregated into nine occupation groups.

Table 1 Sectoral classification of the model

Symbol	Sector	Emissions intensity[a]	Share of exports (%)[b]	Share of imports (%)[c]	Trade exposure[d]
EBR	Electricity—brown coal	25.84	0.0	0.0	*L*
EBL	Electricity—black coal	19.43	0.0	0.0	*L*
EOI	Electricity—oil	11.45	0.0	0.0	*L*
BRC	Brown coal	10.85	0.3	1.3	*L*
EGS	Electricity—gas	8.82	0.0	0.0	*L*
AFF	Agriculture, forestry and fishing	3.29	16.4	31.2	*H*
GAS	Gas	1.73	43.1	3.4	*H*
CEM	Cement	1.18	0.3	2.0	*L*
BLC	Black coal	1.14	88.8	0.1	*H*
IRS	Iron and steel	1.12	16.3	22.1	*H*
GAD	Gas distribution	1.12	0.0	0.2	*L*
CME	Commercial electricity	1.02	0.3	0.0	*L*
RTS	Road transport services	0.83	16.1	2.8	*H*
KER	Kerosene	0.82	25.8	17.0	*H*
LIP	Liquefied petrol	0.78	31.4	14.4	*H*
CHP	Chemical products	0.64	15.0	39.6	*H*
OMP	Other metal products	0.50	40.2	10.8	*H*
WSS	Water and sewerage services	0.43	0.1	0.2	*L*
OIL	Oil	0.39	51.8	45.5	*H*
ACR	Accommodation and restaurants	0.38	24.4	7.1	*H*
ATP	Automotive petrol	0.32	3.9	17.5	*H*
PRP	Plastic and rubber products	0.32	6.5	22.0	*H*
OMI	Other mining	0.30	37.5	7.7	*H*
OTS	Other transport services	0.29	24.2	11.7	*H*
WPP	Wood, paper and printing	0.15	5.8	15.9	*H*
FBT	Food, beverage and tobacco	0.15	23.9	25.9	*H*
TCF	Textile, clothing and footwear	0.13	28.4	50.4	*H*
OPC	Other petroleum and coal products	0.10	11.5	53.4	*H*
PUS	Public services	0.08	3.3	0.9	*L*
OMF	Other manufacturing	0.07	14.5	51.9	*H*
OSS	Other services	0.06	1.6	2.9	*L*
TRS	Trade services	0.05	5.9	0.3	*L*
COM	Other business services	0.04	1.9	1.8	*L*
COS	Construction services	0.03	0.1	0.0	*L*
ERN	Electricity—renewable	0.00	0.3	0.0	*L*

[a] Emissions intensity is defined as emissions (kilotonnes) per million A$

[b] Export as a share of the total output of a sector

[c] Imports as a share of total supply (imports plus domestic output) of a sector

[d] H = either export or import share is > 15%; L = both export and import shares are < 15%

The carbon emissions data are based on the greenhouse gas emission inventory 2005 published by the Department of Climate Change and Energy Efficiency (2008). As noted earlier, there are two kinds of emissions: on-site input (fuel) emissions and on-site activity emissions. For the former, the Australian Greenhouse Emissions Information System provided emission data by sector and by fuel type. We map these data into the 35 sectors (and commodities) in our study. Based on this emission matrix and the absorption (input demand) matrix for industries, we can calculate the emission intensities by industry and by commodity—input emission intensities. The remaining emissions—the total emissions minus the fuel input emissions—are treated as the activity emissions, and they are assumed to be directly related to the level of output in each industry. We take the level of output for each industry from the MAKE matrix of the I–O tables, and we can then calculate activity emission intensities. For households, we assume their emissions are proportional to household consumption, and using the data on household consumption by commodity in the I–O table, we can calculate the consumption emission intensities.

Most of the behavioral 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 labor. The changed or new elasticities include the household expenditure elasticity, the substitution elasticities between different types of electricity generation, between different energy inputs and between composite energy and capital. Since we included in the model 10 household groups and 35 commodities, we need the expenditure elasticities for each household group and for each of the commodities. Cornwell and Creedy (1997) estimated Australian household demand elasticities by 30 household groups and 14 commodities. We adopted these estimates and the mapping into the classifications in our model. Due to the aggregation and disaggregation as well as the change in household consumption budget share, we found the share weighted average elasticity (Engel aggregation) was not unity. The Engel aggregation must be satisfied in a CGE model in order to obtain consistent simulation results. We therefore adjusted (standardized) the elasticity values to satisfy the Engel aggregation.

As stated earlier, the substitution effect between different types of electricity generation is assumed perfect, so we assign a large value of 50 to this substitution elasticity. 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, we assume 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, we assign a value of 0.1 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 we assign a value of 0.5 for substitution between black and brown coal, between oil and gas and between various types of petroleum. At the top level, we assume the substitution effect between various types of composite energy inputs is very small and assign a value of 0.1.

4 Emission intensity and trade exposure

The way in which carbon pricing affects international competiveness and carbon leakage is not straightforward. An important factor is the emission intensity of individual sectors when there is a price for carbon to pay. As given in Table 1, there is a wide variation in emissions intensity across industries in Australia. This is determined by the use of emission-intensive inputs both directly and indirectly in their production. Naturally, highly emission-intensive sectors incur significant cost increases under the carbon tax. Figure 1 depicts the emissions intensity (kilotonnes per A$ million) of 19 most polluting sectors out of 35 sectors in our model. Not surprisingly, electricity-generating sectors (EBR, EBL, EOI, EGS) are highly carbon intensive in Australia according to Fig. 1. In addition, some of the energy production sectors (BRC, GAS, KER, LIP, GAD, ATP, BLC, OMI, OIL), manufacturing sectors (CEM and IRS) and agriculture (AFF) are high in carbon emissions. These are the sectors that will be affected significantly under carbon pricing.

Figure 2 shows the export and import shares of Australia according to the destination and source, respectively. Among Australia's 11 major trading partners, Japan, USA, UK and New Zealand belong to Annex 1 countries of the Kyoto Protocol having obligations to reduce emissions. However, Australia's primary Asian trading partners including China, South Korea, India and the rest of Asia are not obliged to cut emissions. This would imply that the Australian carbon tax to regulate emissions may hurt the competitiveness of EITE sectors in Australia relative to those in China, South Korea, India and rest of Asia.

Figure 3 displays three dimensions which are important determinants of relative competitiveness of individual sectors under climate policy: emission intensity, export exposure and output. Using data from Table 1, we have selected 15 sectors that have export shares above 15% as export intensive and are likely to be affected by the cost increases

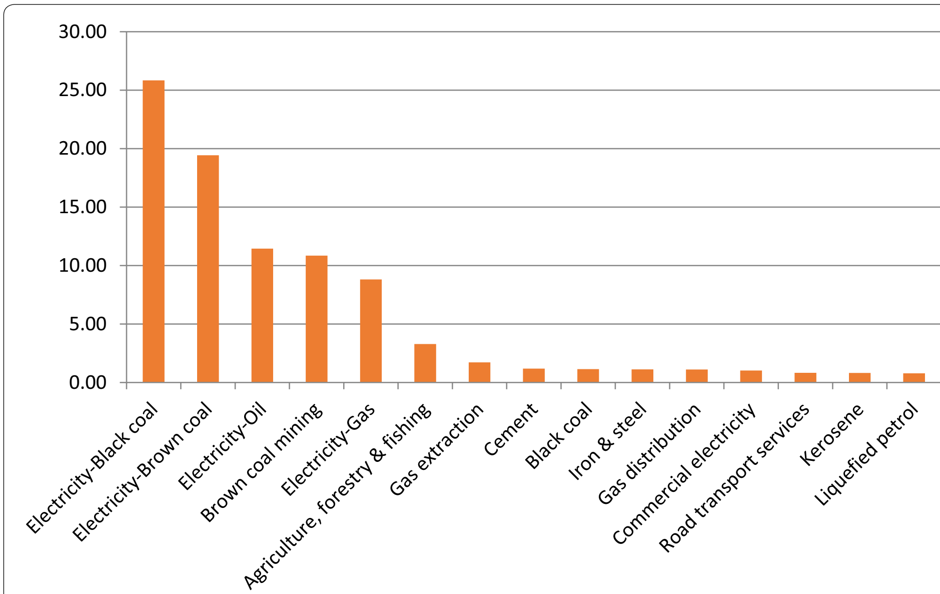

Fig. 1 Carbon emissions intensity by sector in Australia (kilotonnes/A$million). *Source* Calculated from data obtained from the Department of Climate Change and Energy Efficiency (DCCEE)

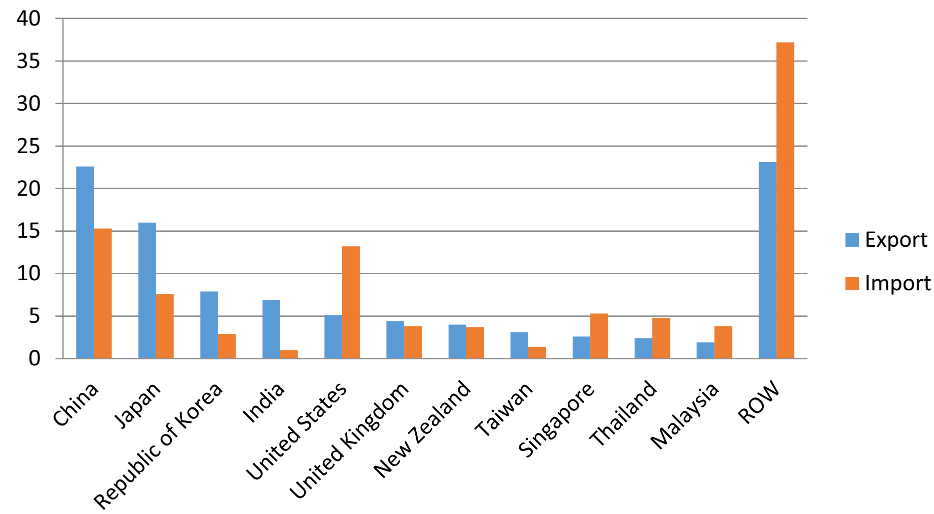

Fig. 2 Export and import shares of Australia's total trade by trading partner (%). *Source* Calculated from data obtained from the Department of Foreign Affairs and Trade (DFAT)

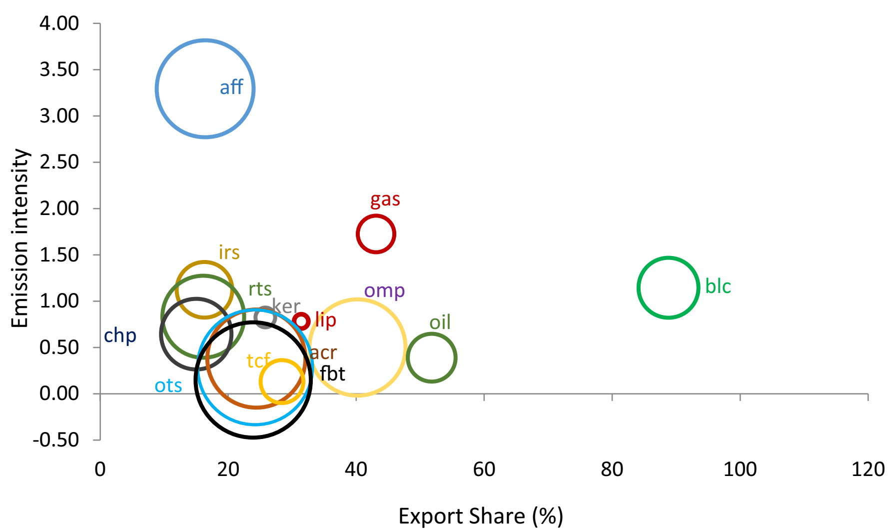

Fig. 3 Emissions intensity and export exposure of sectors. *Note* Size of bubble represents output. *Source* Calculated from data obtained from DCCEE, DFAT and ABS

under the carbon tax policy, depending on their respective emissions intensity. The size of the 'bubble' represents output. As can be seen from the figure, there is a wide range of variability in the three dimensions while many sectors cluster toward the horizontal axis of the diagram implying low to moderate emissions intensity and high trade intensity. It is noticeable that sectors agriculture, forestry and fishing (AFF) and black coal (BLC) are located away from horizontal and vertical axes, respectively. The former exports about 20% of its output and is regarded as a major source of activity emissions. It is the most emission-intensive trade sector. The latter is highly export intensive (about 90% of output is exported) and shows a moderate emissions intensity. The domestic emissions generated by BLC are mainly coming from its production activities, and its major contribution to emissions occurs in importing countries (i.e., out of Australia).

A similar observation is shown in Fig. 4 where emissions intensity, import exposure and output are displayed simultaneously. There are 12 sectors that face import competition and may have been disadvantaged under the policy of domestic emissions control. A majority of these import competing sectors experience low to moderate emissions intensity accompanied by high import penetration. These imports are primarily sourced from countries which are not under obligation to cut emissions. Agriculture, forestry and fishing (AFF) stands out in Fig. 4 showing the highest emissions intensity among import competing sectors.

5 Carbon tax and border adjustment

This section describes the basis of our model simulations to examine the impact of different BAMs. The Australian government's previous carbon pricing policy used the carbon tax at the rate of A$23 per tonne of CO_2 equivalent with the exemption of agriculture, road transport and household sectors. In our experiments, we have used this carbon tax rate in each simulation scenarios. The government proposed a number of compensation plans outlining the ways the revenue collected through the tax will be used. They included compensation to selected manufacturers and exporters, reform of income tax thresholds and family tax benefits such as a clean energy advance, clean energy supplement and single income family supplement. These measures were quite complex, and it is hard to capture them all in a single model. In the model simulations, we adopt a modest and simplified compensation plan. We use in each scenario a revenue-neutral straightforward household compensation plan; that is, we transfer all of the carbon tax revenue in equal lump sums to households of the poorest six income deciles of the Australian economy.

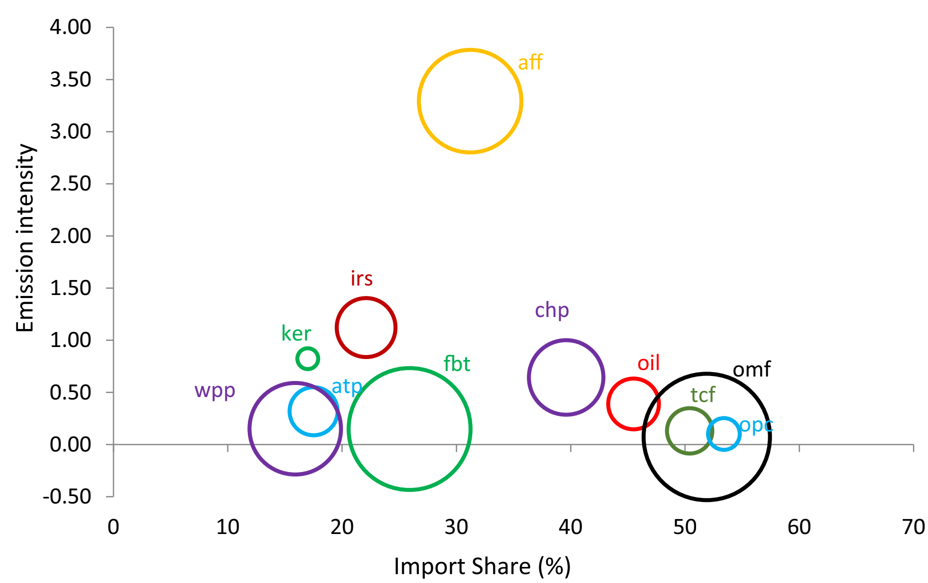

Fig. 4 Emissions intensity and import exposure of sectors. *Note* Size of bubble represents output. *Source* Calculated from data obtained from DCCEE, DFAT and ABS

In general, BAMs are used to compensate countries where environmental taxes are levied. For example, exporting countries may give a rebate (subsidy) to exporters to relieve them from increased cost due to a carbon tax, which would otherwise make them uncompetitive in global markets, and importing countries may impose carbon tariffs (green tariffs) equivalent to what would have been charged had the products been produced domestically. The export rebate and carbon tariffs are to be determined according to the carbon content of exports and imports to maintain a levelled playing field and to ensure the effectiveness of border adjustment policies.

We have adopted four border adjustment scenarios as summarized in Table 2. No border adjustment (NBA) scenario is the base simulation where $23 carbon tax is imposed. The BAE scenario involves providing an export rebate when the carbon tax is in place, whereas BAI introduces a carbon tariff on imports. In addition, we can use a policy to mitigate the impact of carbon regulation on domestic costs of production by giving rebates to all domestic producers, not only exporters. In Table 2, BAP refers to this border adjustment policy. The final measure, BAEI, is the full border adjustment where both export rebate and carbon tariffs are applied to both exports and imports simultaneously to mitigate the domestic impact of carbon tax.

For the purposes of this study, all BAMs have been based on the direct emissions (on-site fuel and activity emissions, as explained above) plus our separate calculations of indirect emissions (emissions embodied in energy inputs, e.g., the use of electricity generated offsite). Following Takeda et al. (2012), we let q_j^{CO2T} to be the total amount of CO_{2e} generated by the jth sector. Then, we define q_j^{CO2T} to include both direct and indirect emissions. That is:

$$q_j^{\mathrm{CO2}T} = q_j^{\mathrm{CO2}D} + q_j^{\mathrm{CO2ID}}$$

where q_j^{CO2D} and q_j^{CO2ID} are the direct and indirect CO_{2e} emissions by the jth sector, respectively. By definition, direct emissions of CO_{2e} are obtained via:

$$q_j^{\mathrm{CO2}D} = \sum \phi_{ej} q_{ej}$$

where ϕ_{ej} is the emissions coefficient of fossil fuel e in sector j and q_{ej} is the amount of fossil fuel used by sector j.

In order to estimate the indirect emissions in our study, we first define θ_j^{ELE} as the share of electricity used in sector j via:

$$\theta_j^{\mathrm{ELE}} = d_j^{\mathrm{ELE}} / q_{\mathrm{ELE}}$$

Table 2 Border adjustment scenarios

Scenario	BA for exports	BA for imports	BA for production
NBA	None	None	None
BAE	All sectors	None	None
BAI	None	All sectors	None
BAP	None	None	All sectors
BAEI	All sectors	All sectors	None

where d_j^{ELE} is the amount of electricity used by sector j and q_{ELE} is total supply of electricity. We also define the total direct emissions of CO_{2e} by the electricity sector as $q_{\mathrm{ELE}}^{\mathrm{CO2}T}$ and then calculate the indirect emissions attributed to each sector j from the formula:

$$q_j^{\mathrm{CO2ID}} = \theta_j^{\mathrm{ELE}} q_{\mathrm{ELE}}^{\mathrm{CO2T}}.$$

Finally, CO_{2e} emissions per unit of output (emission intensity) in sector j, (δ_j), are obtained as:

$$\delta_j = q_j^{\mathrm{CO2}T} / q_j$$

where q_j is the total output (A$ value) of sector j.

The carbon tariff (or subsidy) assigned to each sector (commodity) based on the emission intensity is then defined by:

$$\pi_j = p^{\mathrm{CO2}} \delta_j$$

where p^{CO2} is the price of carbon per tonne of CO_{2e}. In scenario BAI, an import tariff of π_{j} is imposed on all imports; in scenario BAE, a subsidy of π_{j} is used for each exportable good. In the case of scenario BAP, a subsidy of π_{j} could be given to each sector. As the scope of the subsidy is much wider (all producers instead of all exporters) in this scenario, this policy would cause much larger government spending. For comparison purposes, the shocks of the production subsidies applying to all producers are scaled down so that the total production subsidy in this scenario equals the total subsidy to exporters in scenario BAE.

As our concern is the short-run impact of border adjustments, we have used the short-run closure of the model in all simulations. The underlying features of the closure include fixed real wages and capital stocks, free movement of labor but immobile capital between sectors, and government expenditure to follow household consumption. In addition, a flexible exchange rate regime is used in order to be consistent with Australia's exchange rate policy.

6 Simulation results

This section compares the results of the BAMs (BAE, BAI, BAP and BAEI) simulations with the no border adjustments (NBA) option when the carbon tax is in place at $23 per tonne. The general presumption is that the policy of carbon control with the tax will hurt EITE sectors in the Australian economy; hence, some measures of compensation are needed to ensure a levelled playing field with their overseas competitors. Applying the CGE model outlined earlier, we examine the economic and environmental effects of BAMs. Particularly, we focus on changes in Australia's GDP and employment level, aggregate trade outcomes, domestic emissions reductions and sectoral outputs, exports and imports.

6.1 Macroeconomic and trade impact of BAMs

The results from border adjustment policy simulations are reported in Table 3 for key macroeconomic variables and trade aggregates. It is not surprising to see that carbon

Table 3 Key macroeconomic and trade results from the simulations. *Source* Model simulations

	NBA	BAE	BAI	BAP	BAEI
Carbon tax (A$/t$CO_2$)	23	23	23	23	23
Real GDP	− 0.53	− 0.41	− 0.54	− 0.42	− 0.42
Aggregate employment	− 0.83	− 0.65	− 0.84	− 0.65	− 0.66
Export volume	− 4.98	− 4.42	− 5.07	− 4.48	− 4.5
Import volume	0.80	0.87	0.75	0.83	0.82
Export price	− 0.73	− 0.70	− 0.73	− 0.70	− 0.70
Import price	− 1.25	− 1.16	− 1.26	− 1.17	− 1.17
Terms of trade	0.53	0.47	0.54	0.47	0.48
Nominal exchange rate	− 1.25	− 1.16	− 1.26	− 1.17	− 1.17
Real devaluation	− 1.28	− 1.18	− 1.30	− 1.19	− 1.20
Equivalent variation (A$ m.)	5066.9	5264.1	5058.9	5498.2	5256.9

(1) All projections are in percentage changes from the base period except the equivalent variation (EV). (2) Export price and import price are measured in terms of domestic currency terms

pricing lowers Australia's real GDP by 0.53% in the NBA scenario. The emission controlling new tax distorts resource allocation to some degree causing inefficiency. Facing an increase in production costs, the industries will respond to the tax by reducing outputs which has a direct negative impact on Australia's real GDP. Due to the reduction in real GDP, aggregate employment in the economy tends to be lower by 0.83 percent compared to the baseline. These consequences may partly be attributed to losing competitiveness due to the environment tax to reduce domestic emissions without a global agreement.

The impact of the four BAMs on real GDP and employment is shown in the second and third rows of Table 3. How does each border adjustment policy fare in the economy is an interesting question. As Australian industries are compensated for their loss in competitiveness through these measures, one should expect some improvement according to the economic analysis of border adjustments. It appears that the domestic production rebate (BAP) and export border adjustment (BAE) have a modest cushioning effect (i.e., GDP and employment reduction is less than in NBA). Interestingly, however, there seems to be no discernible benefit to the economy by using import border adjustment or green tariffs (BAI). The simultaneous use of BAE and BAI (the BAEI scenario) does not improve the outcome beyond what BAE does.

We next consider what happens to trade aggregates when BAMs are in place to support the EITE sectors in the economy. The policy of export rebate (BAE) is targeted to assisting exporters where the additional costs of production incurred due to the carbon pricing policy are rebated when goods are exported from Australia. Our projections show that the reduction in export volume is lowered by using BAE and BAP to some degree, but again, it is interesting to note that the adoption of green tariffs in Australia is likely to further deteriorate exports as shown by a 5.07% reduction in the export volume compared to the NBA outcome (− 4.98%). The imposition of tariffs makes inputs to export producers more expensive. Hence, there is a squeeze in the profit margins in the absence of their ability to pass on the increased costs to customers. As given in Table 3, carbon regulation causes a rise in export prices and BAI has no impact toward easing them. Again, BAE, BAP and BAEI (reflecting the BAE component of BAEI) cause a very modest easing of export price increases.

In our model simulations, we have adopted a flexible exchange rate and hence the carbon tax tends to appreciate the nominal rate by − 1.28%. In general, importers benefit from the carbon tax (NBA scenario) as there appears to be a real appreciation of the Australian dollar. Local consumers are encouraged by the extra purchasing power created by the stronger Australian dollar initiating additional demand for imports. The end result of this would be that domestic import competing sectors lose competitive advantage, adding to carbon leakage. As shown in Fig. 2, Australia's major sources of imports include many Asian countries (China, South Korea, India, Taiwan, Singapore, Thailand and Malaysia) which do not have commitments to reduce emissions. Hence, the increased demand for imports by Australia from these sources is likely to contribute to carbon leakage under a unilateral carbon tax. The policy of green tariffs (BAI) appears ineffective in preventing such carbon leakage according to our model projections.

Table 3 also shows the impact on welfare measured in terms of the equivalent variation (EV) as a result of carbon tax and BAMs. Although the carbon tax raises domestic prices in general, Australia's welfare rises in NBA scenario. This is due to the improved terms of trade and the household compensation mechanism by which entire carbon tax revenue is transferred to households of the poorest six income deciles in equal lump sums. Even though the original border adjustment policies were not designed for improving welfare but to sustain the competitiveness of domestic EITE industries while limiting the carbon leakage, results reported in Table 3 demonstrate that export rebates (BAE) and production rebates (BAP) can improve the welfare impact of carbon mitigation.

6.2 Environmental impacts

The simulated environmental impacts of BAMs are compared with the base simulation (NBA) in Table 4. According to model projections, the introduction of the carbon tax is effective as it reduces Australia's emissions by about 70 Mt. Given Australia's aggregate emissions base of 587Mt in 2004–2005, this gives a 12% reduction rate. The real question is how far this domestic emissions cut contributes to carbon leakage. As our model is a single-country model and has no disaggregation to include Australia's trading partners, we cannot project the carbon leakage rate. Nevertheless, it is reasonable to speculate that a considerable leakage may occur given that more than a third of Australia's imports are sourced from developing countries in Asia which do not face mandatory emission cuts.

A closer observation of the impact of BAMs on emission reduction reveals that export and production rebates work against the environmental objectives of the carbon pricing. That is, both of these policies tend to discount Australia's effort to cut emissions compared to the base case scenario (NBA). While these two measures are appealing for

Table 4 Selected projections on environmental variables. *Source* Model simulations

	NBA	BAE	BAI	BAP	BAEI
Carbon tax (A$/t$CO_2$)	23	23	23	23	23
Aggregate reduction in carbon emissions (Mt)	− 70.3	− 67.3	− 70.2	− 67.2	− 67.3
Percentage reduction in emissions	− 11.97	− 11.47	− 11.96	− 11.45	− 11.46
Carbon tax revenue (A$ billions)	6.1	6.2	6.1	6.2	6.2

reducing potential carbon leakage and mitigating the loss of competitiveness, they do tend to undermine Australia's effort to reducing its own emissions. Nevertheless, the modest increase in carbon tax revenue due to using such measures to assist domestic industries may provide some support to their proponents.

6.3 Impact on competitiveness of EITE sectors

Thus far, our focus of the analysis is on aggregate impacts of border adjustments on Australia's macroeconomy, trade and environmental concerns. In this section, we consider the impact on competitiveness of sectors using changes in sectoral exports, imports and outputs. The adjustments to the economy are based on carbon emissions by sectors (emission intensity) in the border adjustments framework, and therefore, relative price movements play a key role in the sectoral behavior in response to the policy.

Figure 5 displays the changes in export volumes by EITE exporting sectors under the policy of carbon tax and their response to border adjustments. The first thing to notice is most of these export intensive sectors experience a significant reduction in export volumes when emissions are controlled with the tax (NBA scenario). The heavily affected sectors are kerosene (KER), accommodation and restaurants (ACR), iron and steel (IRS), chemical products (CHP) and liquefied petrol (LIP). These sectors have relatively high export shares, and any increase in domestic cost creates a loss of competiveness in the foreign markets. There are a further seven sectors (OMP, FBT, RTS,TCF, OTS, OIL and AFF) that are projected to be losing export competiveness and hence experience reduced export volumes. Energy goods sectors, gas (GAS), other mining (OMI) and black coal (BLC), are exceptions. As carbon pricing is introduced, these sectors experience reductions in domestic demands but foreign demand rises as these energy goods are becoming relatively cheaper to foreign customers. Unilateral domestic policy to control emissions tends to reduce domestic consumption of energy-intensive goods putting a downward pressure on prices for such goods at the global level.

The application of BAMs affects exports of different sectors by small margins according to our findings. The BAMs (excluding BAI) work modestly to reduce the sectoral export volume declines of the NBA. The agriculture, forestry and fishing (AFF) sector appears to be improving its exports more significantly under BAP, BAE (and BAEI) in comparison with many other exports. Again, however, the green tariffs (BAI) make exports from EITE sectors even lower than in NBA. The competiveness of exportable goods deteriorates as a result of imposing green tariffs on imports. This is attributed to additional costs experienced by exporting industries due to the tax.

Figure 6 depicts the change in import volumes under different BAMs in comparison with NBA. We have identified 12 sectors that are exposed to import competition, and carbon pricing leads to an increase in imports in 10 of them, and with kerosene (KER) imports, in particular. The two exceptions are the iron and steel sector (IRS), which experiences a lower level of imports when emissions control is in place, and agriculture, forestry and fishing (AFF), for which there is almost no change under NBA. In general, and with the exception of BAI, the BAMs tend to reduce the increase in imports very slightly in most of the sectors. Although marginal, this is the desired effect because imports are becoming less competitive in the domestic market when border protections are imposed, than in NBA case.

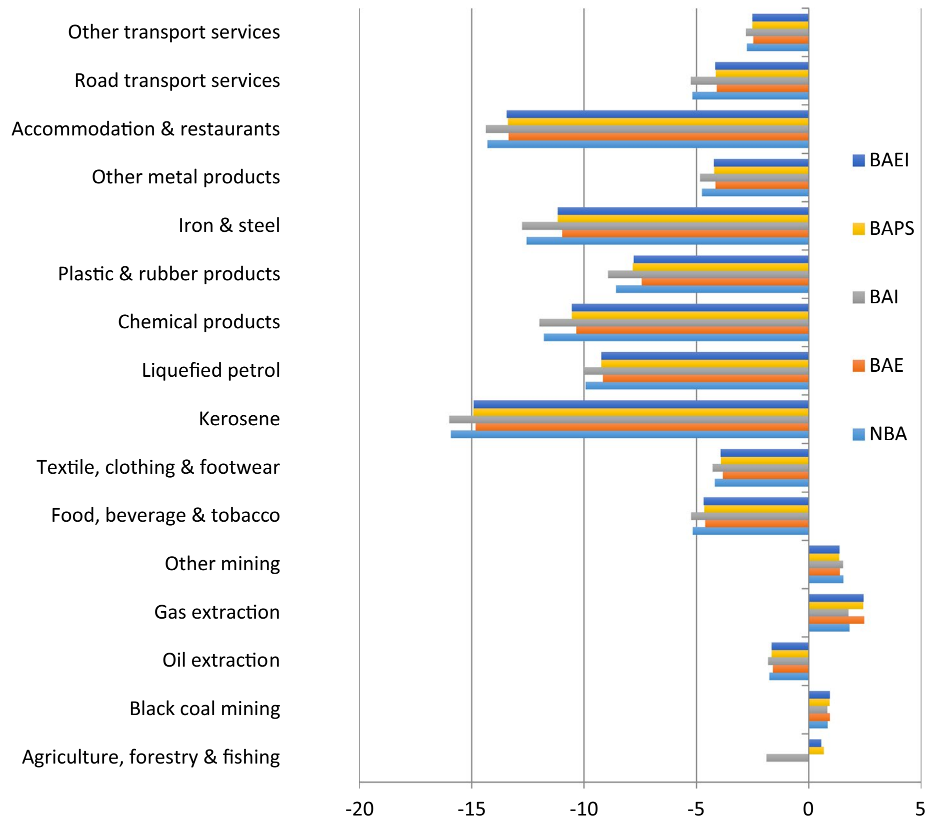

Fig. 5 Percentage change in export volumes by sector. *Source* Model simulations

The change in outputs of EITE sectors of the Australian economy under a carbon tax is compared with outcomes of BAMs in Fig. 7. Under NBA, output declines due to the import competition and decreases in exports, showing a wide range of deviation across sectors. The highest reduction in output is projected in iron and steel (IRS), followed by other metal products (OMP), plastic and rubber products (PRP) and the other mining (OMI) sectors. As noted before, a border adjustment policy of green tariffs (BAI) has no alleviating effects on the decline in exports and may even cause exports to decrease further. On the other hand, export and production rebates ease the decrease in exports to some degree, making output reductions slightly smaller than in NBA.

7 Conclusions

In this paper, we have analyzed possible carbon-motivated border adjustment policies in Australia using a multi-sectoral general equilibrium model of the Australian economy. The model was first simulated under a $23 carbon tax to produce the benchmark solution (NBA). Then, we introduced four BAMs to compare with the NBA scenario to examine how such measures could affect macroeconomic, and trade outcomes. With these projections, the analysis was then directed to assessing the key issues of competitiveness and carbon leakage in relation to the performance of the EITE sectors in the Australian economy. The most important finding from this analysis is that border adjustment policies have a very small impact on the overall economy and on EITE sectors. In

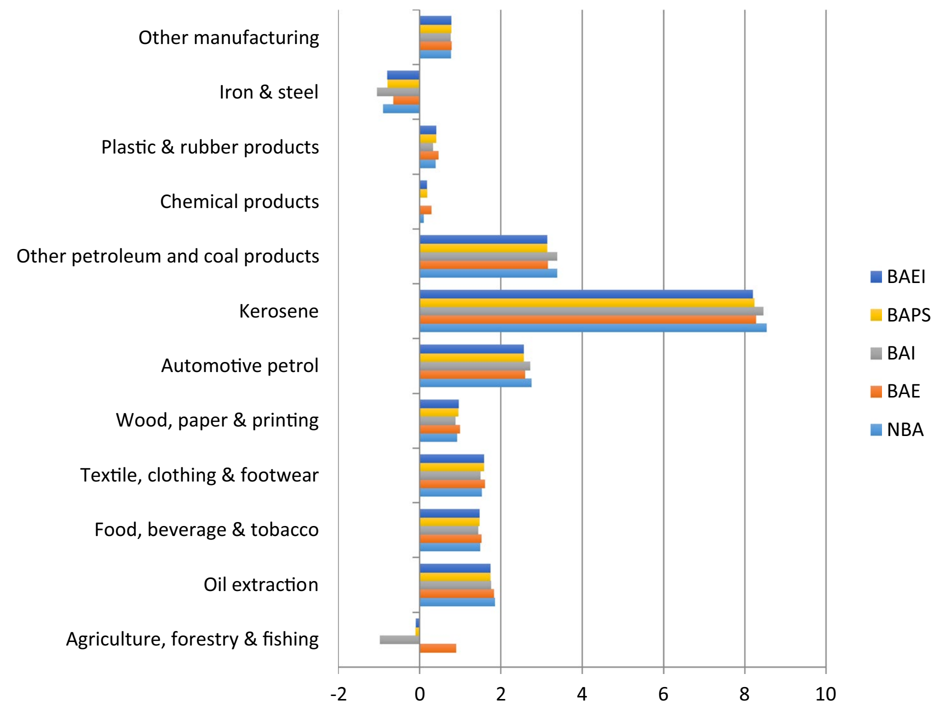

Fig. 6 Percentage change in import volumes by sector. *Source* Model simulations

other words, the different BAMs that we have considered are unlikely to change the outcomes of carbon pricing policy in Australia in any significant way. This finding is consistent with studies for EU, USA, Canada and other countries.

Among the four policies analyzed, production and export rebates are somewhat appealing even though their effects toward easing the negative impact on EITE sectors are fairly small. The green tariffs do not appear to be playing any significant role at all to alleviate the import competition in the domestic economy and thus have no discernible influence on reducing carbon leakage. They do, in fact, cause Australia's exports to decrease further due to a cost–price squeeze. Full border adjustment with green tariffs and export rebates is unlikely to change the outcomes beyond what export rebates may achieve alone.

When BAMs are based on Australia's (importing country) emissions, a small impact implies that barriers imposed are small. If all sectors had the same carbon intensity, then we could expect a neutral relative price effect. Contrary to this, our results do indicate that BAMs are not neutral due to sector-specific tax adjustments leading to relative price shifts, even though the impact is rather small.

As analyzed in "Results" section, BAMs do produce slight GDP improvements (except in the BAI scenario). However, this improvement comes at the expense of the emissions reduction effects of carbon pricing. When border adjustments reduce the overall emissions reduction rate, carbon tax revenue to the government becomes greater. Thus, such higher revenue enables the government to compensate poor households better than before, improving the welfare outcome of the carbon pricing strategy.

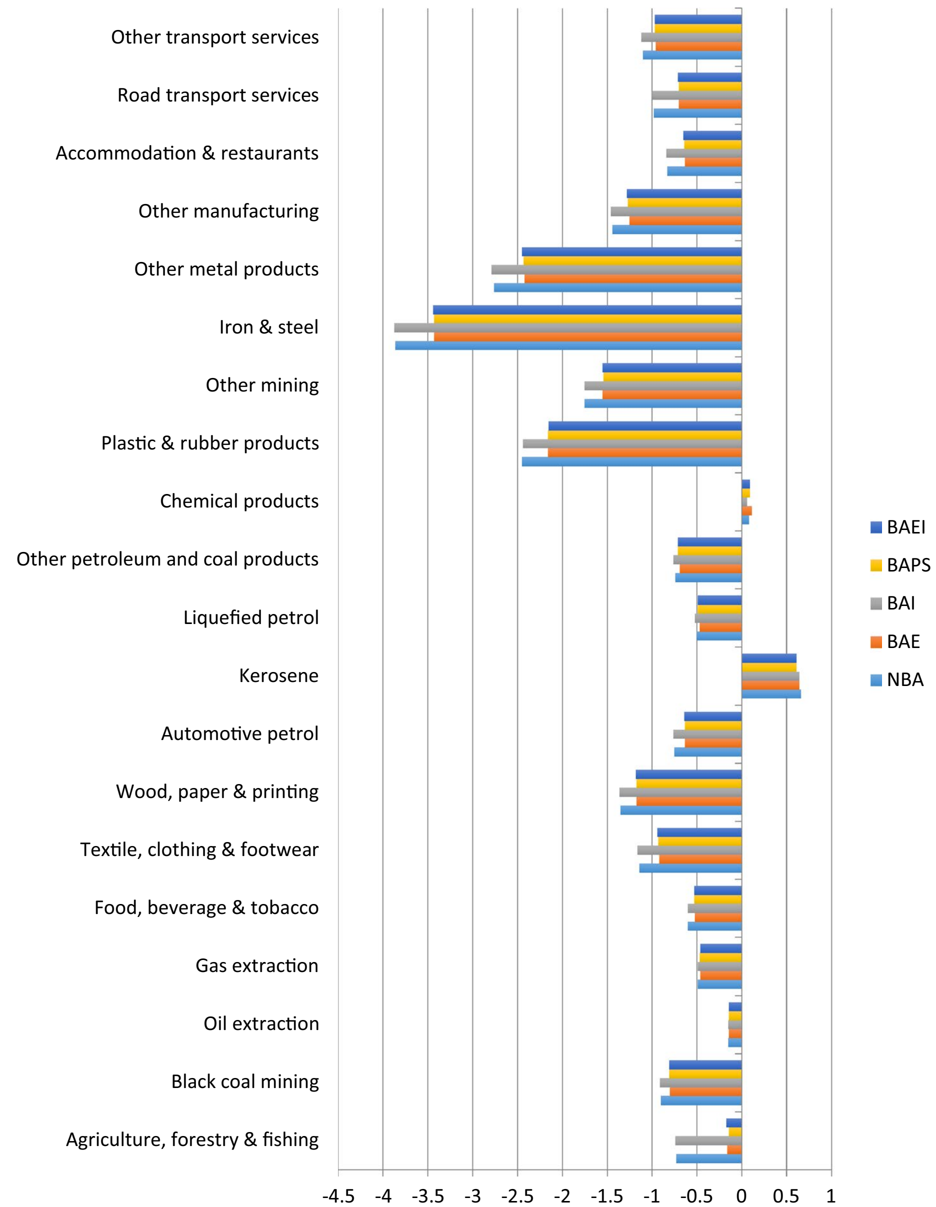

Fig. 7 Percentage change in outputs by sector. *Source* Model simulations

The smallness of numerical findings confirms that BAMs would be unimportant as part of environmental policy in Australia even though critics of the carbon pricing policy, along with industry lobby groups, pressured the Australian government to introduce such measures to support EITE sectors in the economy. Hence, a key policy implication of the analysis presented in this paper is that border adjustments are not warranted in the Australian case to safeguard EITE industries. They make no significant difference to Australia's commitment to a low-carbon economy.

The findings are subject to some limitations of the underlying features of the CGE model used in the analysis. Since we have used a single-country model, it is not possible to project what would be the experience and reaction of the rest of the world to

Australia's carbon pricing strategy and border adjustments. To mitigate this limitation, it is necessary to use a multi-country model such as GTAP-E for assessing BAMs, incorporating Australia's trading partners' behavior.

Authors' contributions

Authors MS (80%), SM (10%) and JM (10%) read and approved the final manuscript.

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