The Economic Implications for Australia of Carbon Tariffs

CoPS Working Paper No. G-322, October 2021

Philip Adams
Centre of Policy Studies,
Victoria University

ISSN 1 921654 02 3

ISBN 978-1-921654-30-5

About us

Researchers at the Centre of Policy Studies have a 45-year history of continuous achievement in the development, application and dissemination of large-scale economic models. Our models and software are used around the world to analyse a diverse range of economic issues. CoPS' funders include: Australian federal and state government departments; private firms and universities in many parts of the world; central government agencies such as finance and trade ministries in many countries; and international development organisations. The Centre's GEMPACK software, used for solving large economic models, is used at more than 700 sites in over 95 countries.

Citation

Adams P.D. (2021), "The Economic Implications for Australia of Carbon Tariffs", Centre of Policy Studies Working Paper No. G-322, Victoria University, October 2021.

The Economic Implications for Australia of Carbon Tariffs

Philip Adams

13 October 2021

Abstract

A carbon tariff is a tax on foreign imports levied based on greenhouse-gas content. Such tariffs are designed to level the playing field for domestic import-competing industries whose costs have risen due to a domestic CO2-price. It is argued that carbon tariffs are necessary to avoid "carbon leakage" – local production shutting down and moving to countries without strong climate policies.

The question addressed in this paper, is what effect might carbon tariffs have on the Australian economy. Using the Victoria University Regional Model (VURM), we evaluate the potential effects arising from carbon tariffs imposed in three regions: the EU, the G7 countries plus Korea, and China. The tariff rates are calculated with carbon prices of: $US70 (= 60 euro) for the EU, and $US39 for the other two regions.

Key findings are as follows.

1. Carbon tariffs have little effect on employment in the long-run. However, the negative impact on Australia's terms of trade arising from reductions in world demand increases the real cost of capital, leading to small reductions in capital and hence real GDP.
2. Less real GDP means less real Gross National Income (GNI), a measure of economic welfare).The contractions in real GNI, though small are a little larger than in real GDP because a lower terms of trade means less purchasing power from a given level of real income.
3. Only two industries are projected to experience output and employment losses in each of the three scenarios: Coal mining and the closely related Mining services for whom the coal industry is a major customer. Indeed, the effects on coal production dominate most of the industry outcomes and are key to explaining what happens at the state level. As shown in Table 6, output and employment in those states where coal is over-represented, NSW and QLD, fall. Output and employment in states where coal is much less important rise, reflecting the positive impacts of real devaluation on non-tariffed products.

We conclude that at the national level, the carbon tariffs examined are unlikely to have a significant impact. They will, however, have noticeable impacts at the industrial and state levels. Those impacts –due, in the main, to a reduction in output and employment in the coal sector - will occur in any case for Australia to shift towards a zero emissions economy. The concern is not that these reductions happen, but that they happen in a way which is outside of Australia's control. This loss of sovereignty over what happens to our coal industry might result in non-optimal adjustment with adverse impacts on welfare, regions and workers directly affected.

Key words: Carbon tariffs, Zero greenhouse emissions, Coal.

JEL: C68, Q54, Q58

Contents

1 Introduction

In simple terms, a carbon tariff is a tax on foreign imports levied based on greenhouse-gas content[i]. Such tariffs are designed to level the playing field for domestic import-competing industries whose costs have risen due to a domestic CO2-price. It is argued that carbon tariffs are necessary to avoid "carbon leakage" – local production shutting down and moving to countries without strong climate policies.

The European Union (EU) has made a commitment to make significant emission cuts by 2030 (55% compared with 1990 levels) and to achieve carbon neutrality by 2050. As part of its commitment, the EU president, Ursula von der Leyen, proposed a tariff – known as a carbon border adjustment mechanism, or CBAM. The proposal was endorsed by the European parliament's environment committee, and is due to be tabled in parliament in the second half of 2021.

The question addressed in this paper, is what effect might carbon tariffs have on the Australian economy. Using the Victoria University Regional Model (VURM), we evaluate the potential effects arising from carbon tariffs imposed in three regions: the EU, the G7 countries plus Korea, and China. The tariff rates are calculated with carbon prices of: $US70 (= 60 euro) for the EU, and $US39 for the other two regions.[ii] These prices covers all greenhouse gases and all sources of greenhouse emissions.

The work reported in this paper was funded by the Climate Council. The Council was responsible for the concept and scope of research, and collaborated in scenario design and the setting of key assumptions. The Council's own report, which can be downloaded from their website, is: Climate Council (2021) *Markets are Moving: The Economic Costs of Australia's Climate Inaction* by Nicki Hutley.

The remainder of this paper is divided into three sections. VURM is described briefly in Section 2. Aspects of simulation design and the calculation of shocks are given in Section 3. Section 4 contains a brief discussion of the Carbon Tariff impacts for each scenario.

2 VURM

VURM is a bottom-up model of Australia's six states and two territories. By bottom-up we mean that each of the regional economies is modelled as an economy in its own right, with region-specific households, industries, prices, etc. The regions are linked via model-determined changes in inter-state trade and movement of labour and capital. In the version of VURM used for the study, there are 83 industry sectors, of which 34 are potentially affected directly by carbon tariffs.

Investment is allocated across industries to maximise rates of returns to investors (households, firms). Capital creators assemble, in a cost-minimizing manner, units of industry-specific capital for each industry. Each state has a single representative household and a state government. There is also a federal government. Finally, there are foreigners, whose behaviour is summarised by export demand curves for the products of each state and by supply curves for international imports to each state.

As is standard in CGE models, VURM determines the supply and demand for each regionally produced commodity as the outcome of optimising behaviour of economic agents. Regional industries choose labour, capital and land to maximize their profits while operating in a competitive market. In each region a representative household purchases a particular bundle of goods in accordance with the household's preferences, relative prices and its amount of disposable income.

Interregional trade, interregional migration and capital movements link each regional economy. Governments operate within a fiscal federal framework.

VURM provides results for economic variables on a year-on-year basis. The results for a particular year are used to update the database for the commencement of the next year. In particular, the model contains a series of equations that connect capital stocks to past-year capital stocks and net investment. Similarly debt is linked to past and present borrowing/saving and regional population is related to natural growth and international and interstate migration. For a detailed description of the theoretical structure of the VURM model, see Adams, *et al*. (2011)[iii].

3 Simulation Design and Calculation of Shocks for a Carbon Tariff

Carbon tariffs initially affect the Australian economy by reducing export demand for Australia's merchandise exports. This lowers export volumes and prices, leading to a deterioration in Australia's terms of trade. These initial effects set in place a range of second round impacts. A fall in the terms of trade reduces real income available for consumption and hence real consumption spending. Fewer exports generally means a lower value for the Australian dollar. A lower dollar has the potential to *crowd in* other exports, etc.

The role of VURM is to provide a balanced assessment of these adjustments on Australia's macro-economy and its industrial structure. To do so, the model user must first determine the economic environment within which these changes occur, and calculate the initial shocks to export demand.

3.1 Modelling Environment

We use a comparative static long-run modelling environment. This involves the following assumptions for important aspects of the macro-economy.

Labour markets

At the national level, lagged adjustment of the real-wage rate to changes in world demand for Australian merchandise products is assumed. These changes can cause employment to move away from values possible without carbon tariffs, but thereafter, real wage adjustment steadily eliminates the short-run employment consequences. This labour-market assumption reflects the idea that ultimately national employment is determined by demographic factors, which are unaffected by world trade decisions.

At the regional level, labour is assumed mobile between state economies. Labour is assumed to move between regions to maintain inter-state unemployment-rate differentials at their no-carbon tariff levels.

Private consumption and investment

Private consumption expenditure is determined via a consumption function that links nominal consumption to household disposable income (HDI).

Investment by industry responds to the carbon-tariff generated changes in export schedules in line with changes in expected rates of return on the industries' capital stocks. VURM allows for short-run divergences in rates of return from their levels without carbon tariffs. These cause divergences in investment and hence capital stocks that gradually erode the initial divergences in rates of return.

Government consumption and fiscal balances

VURM contains no theory to explain changes in real public consumption. In these simulations, public consumption is simply indexed to real household consumption. Thus, we report results for consumption as an aggregate of household and public components. The fiscal balances of each jurisdiction (federal, state and territory) as a share of nominal GDP are allowed to vary in line with projected changes in expenditure and income items.

Production technologies and household tastes

VURM contains many variables to allow for shifts in technology and household preferences. We assume that carbon tariffs have no effect on technology and tastes.

3.2 Shocks

The initial changes in export demand schedules used to shock the VURM model are calculated in three steps, as shown in Figure 1.

Step 1: Effects of a CO2 price on buyer prices for domestically produced goods

First, for each of the three regions, we estimate the impact of the assumed carbon price on the purchasers' price of domestically produced products. [iv]

A price on CO2 emissions affects prices paid in a region in line with the CO2 content of production. Calculating CO2 content is not straightforward. Take for example the production of aluminium. The aluminium industry uses little fossil fuel directly. Its main inputs are alumina and electricity. Gas is an important input to production of alumina, while electricity supply relies even now on significant amounts of coal and gas power. Aluminium production seldom occurs close to the point of alumina production, so significant amounts of transport fuel used in transporting alumina to the aluminium smelters. The same applies to moving aluminium from the smelter to downstream customer. Thus, aluminium has a relatively high carbon content, even though direct emissions at the smelter is small.

As can be seen from this example, calculating CO2 content requires knowledge of *direct* emissions at the point of production plus information on *indirect* emissions that arise through forward and backward linkages to the rest of the economy.

Our calculations are based on simulations from a specially adapted version of the GTAP global model. GTAP is rich in detail, particularly for the type of forward and backward linkages described above. [v] Appendix A contains a brief description of GTAP.

Various versions of GTAP have been used to examine the broad economic consequences of greenhouse gas pricing. For our purposes, though, we use the model for calculating the initial effects on purchaser's prices of domestically produced products stemming from an emissions charge.

To do so we impose, for each of the three regions, a CO2 price on all emissions and observe the impact on purchasers' prices under the following assumptions.

- All primary factor prices are held fixed, so that the emissions price cannot affect the unit costs of capital, labour and land. Factor prices are fixed by assuming that primary factor endowments can vary with completely inelastic supply;
- Final demand (consumption, investment, stock build up and exports) is fixed. Thus, final demand cannot respond to changes in price, allowing the CO2 charge to flow fully into final demand prices.
- All relative-price substitution elasticities are set to zero. This, along with fixed final demand, forces demand generally to be unresponsive to price.

With the model set up in this way, simulated changes in purchasers' prices give, in principle, the cost propagation of the carbon charge only.

Table 1 shows our estimates of percentage changes in purchasers' prices for domestically produced products in each of the three regions at the assumed CO2 price. Note that we show results for

Step 2: *Ad valorem* tariff equivalents to be applied to Australian products

We assume that each region imposes tariff increases on Australian imports that raise the purchasers' prices of the Australian produced item by the same amount as the increase in price of the domestically produced product from Step 1. Thus, for example, for the EU scenario the tariff imposed on Australian produced iron and steel is sufficient to increase its purchasers' price by 10.2 per cent.

However, the carbon border policies will not be inclusive of all the commodities identified in Table 1. Recent announcements from the EE suggest that if adopted their carbon tariff will only cover Australian imports of:

- Coal;
- Gas (LNG);
- Chemical products;
- Cement;
- Primary and secondary iron and steel products; and
- Alumina and primary and secondary aluminium products.

We assume that the tariffs imposed by the G7+S.Korea and China will cover the same imported lines.

Table 2 shows, for each region, the percentage changes in the duty paid price of imported Australian products that have been assumed for this study. The numbers are identical to those shown in Table 1, with two exceptions.

1. Reflecting the assumed coverage, increases in tariffs on all products not included in each scheme are set to zero.
2. Changes in duty-paid prices for coal and gas are adjusted to ensure that they include only that part associated with untaxed fugitive emissions in Australia. Combustion emissions from coal and gas will be taxed in each region regardless of the source of the product under the existing local carbon tax schemes.

Step 3: Exogenously imposed shifts in export demand schedules in VURM

Carbon tariffs directly affect Australian producers *via* a contraction in export demand. For each region and product we calculate the vertical (price) shift (%) in export demand as the product of two terms:

1. The inverse of the percentage increase in purchasers' price of the Australian-produced product given in Table 2; and
2. The share of the respective region in total export demand.

Data for export shares come from the Australian Bureau of Statistics for 2019. Shares for EU, G7+S.Korea and China are given in the first three columns of Table 3. The remaining columns of Table 3 are the calculated values for the shifts in export demand used to shock VURM.

A more detailed explanation of the Step 3 calculation is given in Appendix B.

4 Simulated Effects of Carbon Tariffs on the Australian Economy.

Results are expressed as changes (percentage or otherwise) away from a case in which carbon tariffs are not imposed.

Table 4 summarises for each region the *initial* terms of trade effects due to the shifts in overall Australian export demand.[vi] Carbon tariffs imposed in the EU are projected to reduce Australia's terms of trade by 0.17 per cent. Tariffs imposed in the G7+S.Korea and China are projected to cut the terms of trade by 0.71 per cent and 0.76 per cent respectively.

Table 5 shows the projected long-run impacts on Australian real GDP, real Gross National Income (GNI) and employment. Changes in real GNI are an indicator of change in overall welfare of the Australian population.

Key findings are given in italicised headings.

Carbon tariffs have little effect on employment in the long-run. However, their impact on the terms of trade increases the real cost of capital, leading to small reductions in capital and hence real GDP. The contractions in real GNI are larger than in real GDP because a lower terms of trade means less purchasing power from a given level of real income.

Carbon tariff effects on real GDP can be best understood by considering their effect on factor inputs (labour, capital and land), with an allowance for changes in technology. Changes in land and technology are by assumption unaffected by the tariffs. Thus, all real GDP effects stem from changes in employment and capital.

Figure 2 shows the effects of carbon tariffs on the use of labour and capital and on real GDP in each scenario. In the long-run in all three cases there is little effect on employment, but capital is down-0.04%, 0.19% and 0.24%. The contractions in capital account for the falls in real GDP shown in Table 5.

Real wage adjustment accounts for the negligible long-run employment outcome. In the short-run, carbon tariffs reduce overall employment leading to reduced wage demands. Lower wage demands encourage employment. In the long-run, nearly all of the labour-market consequences of carbon tariffs are revealed in lower real wages, with the average real wage rate projected to fall 0.09%, 0.38% and 0.40% in the three scenarios (relative to non-tariff levels).

The terms of trade deterioration tends to increase the real cost of capital. This further induces producers to shift away from relatively expensive capital towards relatively cheap labour. With employment largely unchanged, capital must fall.

The effects on real GNI are more pronounced than on real GDP, this is directly due to the cuts in terms of trade. A lower terms of trade means that each $1 that accrues to domestic residents will buy less because the price at which the economy producers for the rest of the world has fallen relative to the price at which the economy buys from the rest of the world.[vii]

As an aside, recently we have used VURM to estimate the impacts of a relatively simple but comprehensive CO2 equivalent tax in Australia. According to that work, a $95 per tonne price will reduce real GDP by around 1.8 per cent relative to its level without the tax.

On the expenditure side of GDP, the terms of trade depresses real consumption (C+G) by more than real GDP (Y). With investment (I) down in line with capital, the net volume of trade (X-M) must improve.

Overall in each of the three cases, real Gross National Expenditure (C+G+I) falls by more than real GDP. Hence, the net volume of trade must improve. To put it another way, in each scenario carbon tariffs increase domestic saving, forcing Australia's reliance on overseas saving to be reduced. Less

reliance on overseas saving means a smaller surplus on the economy's capital account and a reduced deficit on the economy's trade account.

Increased exports and reduced imports are a result of real exchange rate depreciation. Our modelling predicts that the real exchange rate will devalue by 0.26%, 1.2% and 1.2% in the three scenarios. In effect, like Dutch disease in reverse, reductions in demand for one area of exports crowd in foreign demand for other exports *via* exchange rate devaluation.

Outcomes for industry production reflect changes at the Macro-level, principally real devaluation, and the direct carbon tariff falls in export demand.

Tables 7 and 8 show the effects of carbon tariffs in each region on production and employment of industries expressed as percentage changes away from a no-tariff base case. Tables 9 and 10 show corresponding information expressed as absolute changes. We show results for 33 industries producing agricultural, mining and manufacturing goods. A single *Other* category (numbered 34) covers the production of service industries.[viii]

With only a few exceptions, the size of the effects on production and employment are small in all three scenarios. Most agricultural, mining and manufacturing industries experience increases in production of less than 1 per cent. This reflects the real devaluation that improves export prospects and encourages import replacement on local markets. Changes in production and employment in the service sectors reflect changes in the broader economy, with output moving in line with real GDP and employment in line with national employment.

Only two merchandise industries are projected to experience output and employment losses in each of the three scenarios: 9. Coal mining and the closely related 15 Mining services for whom the coal industry is a major customer. Indeed, the effects on coal production dominate most of the industry outcomes and are key to explaining what happens at the state level. As shown in Table 6, output and employment in those states where coal is over-represented, NSW and QLD, fall. Output and employment in states where coal is much less important rise, reflecting the positive impacts of real devaluation on non-tariffed products.

Activity in other industries directly affected by the shocks does not necessarily fall. This is because the falls in export demand is, in some cases, more than offset by expansions in local demand due to reductions in import penetration due to real devaluation.

5 Concluding Remark

Our modelling shows that at the national level, the carbon tariffs examined are unlikely to have a significant impact. They will, however, have noticeable impacts at the industrial and state levels. Those impacts –due, in the main, to a reduction in output and employment in the coal sector - will occur in any case for Australia to shift towards a zero emissions economy. The concern is not that these reductions happen, but that they happen in a way which is outside of Australia's control. This loss of sovereignty over what happens to our coal industry might result in non-optimal adjustment with adverse impacts on welfare, regions and workers directly affected.

Figure 1: Calculating the Initial Impacts of Carbon Tariffs on Australia's Economy

Step 1: For the region imposing the carbon tariffs, estimate by commodity the potential increases in purchasers' prices of domestically-produced products due to the CO2 charge.

Step 2: For the region imposing the carbon tariffs, infer the *ad valorem* tariffs applied to Australian products that increase their landed duty-paid price by the increases in domestically-produced substitutes calculated in Step 1

Step 3: For Australia, calculate shifts in export demand by commodity faced by Australian producers for input to the VURM model

Figure 2: Projected Long-run Changes in real GDP, Capital and Labour.

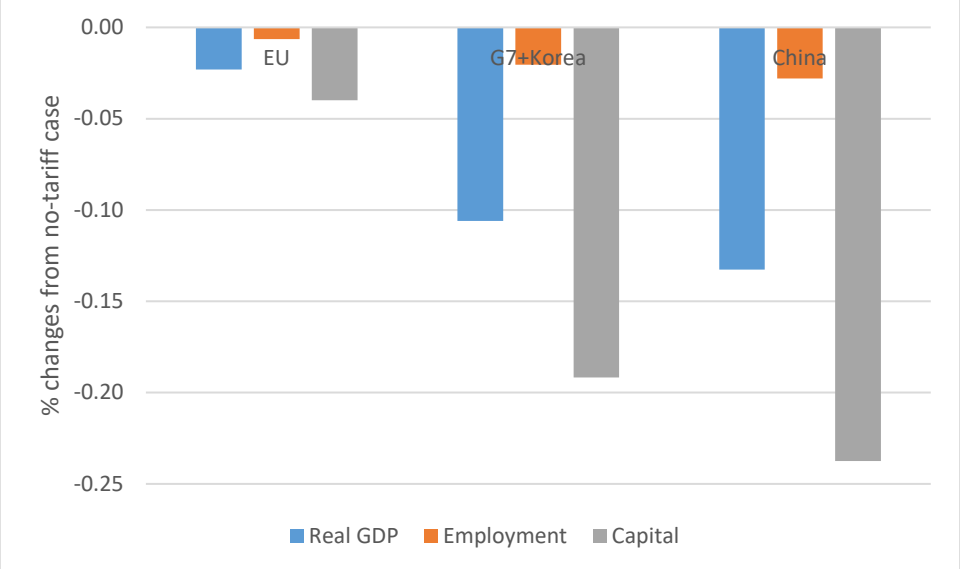

Table 1: Estimated percentage changes in buyer prices of domestically produced products

Product (merchandise only)	% change in price		
	EU	**G7+S.Korea**	**China**
1. Sheep and cattle (live)	9.5	5.0	5.7
2. Grains	10.0	5.2	6.0
3. Dairy cattle and raw milk	8.4	4.4	5.1
4. Other crops	9.8	5.1	5.9
5. Other agricultural products	1.8	0.9	1.1
6. Fishing products	1.4	0.8	0.9
7. Forestry and logging	2.4	1.3	1.5
8. Agricultural services	2.6	1.3	1.5
9. Coal mining	341.7	178.9	204.0
10. Oil mining	1.3	0.7	0.8
11. Gas mining and LNG	31.3	16.4	18.5
12. Iron ore mining	1.0	0.5	0.6
13. Other non-ferrous metal ores	2.2	1.2	1.4
14. Non-metallic mining products	2.2	1.1	1.3
15. Mining services	1.6	0.8	1.0
16. Meat products	4.6	2.4	2.8
17. Dairy products	4.1	2.1	2.5
18. Sugar (refined and raw)	4.4	2.3	2.6
19. Other food products	2.6	1.4	1.6
20. Drink (and tobacco) products	1.8	0.9	1.1
21. Textiles, clothing and footwear	0.8	0.4	0.5
22. Wood products	1.8	1.0	1.1
23. Paper products	1.7	0.9	1.0
24. Refined oil products	18.1	9.5	10.9
25. Basic chemicals, plastics, rubber	1.9	1.0	1.2
26. Non-metallic building product	2.2	1.1	1.3
27. Iron and steel	14.7	7.7	10.0
28. Alumina refining	5.3	2.8	3.6
29. Aluminium smelting	5.8	3.1	4.0
30. Fabricated metallic products	3.7	1.9	2.5
31. Motor vehicles and parts	1.1	0.6	0.7
32. Other transport equipment	2.4	1.3	1.4
33. Other manufacturing	0.9	0.5	0.6

Table 2: Estimated percentage changes in landed duty-paid prices of Australian products

Product (merchandise only)	% change in price		
	EU	**G7+S.Korea**	**China**
1. Sheep and cattle (live)	0.0	0.0	0.0
2. Grains	0.0	0.0	0.0
3. Dairy cattle and raw milk	0.0	0.0	0.0
4. Other crops	0.0	0.0	0.0
5. Other agricultural products	0.0	0.0	0.0
6. Fishing products	0.0	0.0	0.0
7. Forestry and logging	0.0	0.0	0.0
8. Agricultural services	0.0	0.0	0.0
9. Coal mining	23.9	12.5	14.3
10. Oil mining	0.0	0.0	0.0
11. Gas mining and LNG	6.3	3.3	3.7
12. Iron ore mining	0.0	0.0	0.0
13. Other non-ferrous metal ores	0.0	0.0	0.0
14. Non-metallic mining products	0.0	0.0	0.0
15. Mining services	0.0	0.0	0.0
16. Meat products	0.0	0.0	0.0
17. Dairy products	0.0	0.0	0.0
18. Sugar (refined and raw)	0.0	0.0	0.0
19. Other food products	0.0	0.0	0.0
20. Drink (and tobacco) products	0.0	0.0	0.0
21. Textiles, clothing and footwear	0.0	0.0	0.0
22. Wood products	0.0	0.0	0.0
23. Paper products	0.0	0.0	0.0
24. Refined oil products	0.0	0.0	0.0
25. Basic chemicals, plastics, rubber	1.9	1.0	1.2
26. Non-metallic building product	2.2	1.1	1.3
27. Iron and steel	14.7	7.7	10.0
28. Alumina refining	5.3	2.8	3.6
29. Aluminium smelting	5.8	3.1	4.0
30. Fabricated metallic products	3.7	1.9	2.5
31. Motor vehicles and parts	0.0	0.0	0.0
32. Other transport equipment	0.0	0.0	0.0
33. Other manufacturing	0.0	0.0	0.0

Table 3: Vertical (price) shift (%) of Australian export demand schedules

	Product (merchandise only)	Regional share (%) in total Australian exports of product			Vertical shift (%) in Australian export demand schedule for product		
		EU	G7+Korea	China	EU	G7+Korea	China
1.	Sheep and cattle (live)	4.9	3.8	52.2	0.0	0.0	0.0
2.	Grains	11.0	22.2	24.8	0.0	0.0	0.0
3.	Dairy cattle and raw milk	0.0	0.0	0.0	0.0	0.0	0.0
4.	Other crops	3.0	14.3	43.3	0.0	0.0	0.0
5.	Other agricultural products	10.9	22.1	24.7	0.0	0.0	0.0
6.	Fishing products	2.4	38.6	42.9	0.0	0.0	0.0
7.	Forestry and logging	2.4	9.1	20.5	0.0	0.0	0.0
8.	Agricultural services	5.9	32.4	32.0	0.0	0.0	0.0
9.	Coal mining	5.2	38.7	39.0	-1.0	-4.3	-4.9
10.	Oil mining	0.0	7.1	17.4	0.0	0.0	0.0
11.	Gas mining and LNG	0.0	7.1	22.4	0.0	-0.2	-0.8
12.	Iron ore mining	0.0	12.9	48.7	0.0	0.0	0.0
13.	Other non-ferrous metal ores	0.6	41.1	33.0	0.0	0.0	0.0
14.	Non-metallic mining products	13.1	12.8	62.8	0.0	0.0	0.0
15.	Mining services	0.0	0.0	0.0	0.0	0.0	0.0
16.	Meat products	1.6	49.1	26.0	0.0	0.0	0.0
17.	Dairy products	0.6	23.5	30.2	0.0	0.0	0.0
18.	Sugar (refined and raw)	3.2	24.8	32.2	0.0	0.0	0.0
19.	Other food products	3.3	18.0	27.7	0.0	0.0	0.0
20.	Drink (and tobacco) products	6.9	14.4	16.0	0.0	0.0	0.0
21.	Textiles, clothing and footwear	9.6	22.9	32.8	0.0	0.0	0.0
22.	Wood products	0.8	22.9	49.6	0.0	0.0	0.0
23.	Paper products	1.6	10.7	4.7	0.0	0.0	0.0
24.	Refined oil products	0.1	5.4	5.8	0.0	0.0	0.0
25.	Basic chemicals, plastics, etc.	12.5	36.0	23.4	-0.2	-0.4	-0.3
26.	Non-metallic building product	6.1	17.1	8.3	-0.1	-0.2	-0.1
27.	Iron and steel	2.5	23.7	1.7	-0.3	-1.7	-0.2
28.	Alumina refining	0.0	0.3	0.0	0.0	0.0	0.0
29.	Aluminium smelting	0.0	65.3	0.8	0.0	-1.9	0.0
30.	Fabricated metallic products	8.1	59.2	20.2	-0.3	-1.1	-0.5
31.	Motor vehicles and parts	9.5	28.3	2.7	0.0	0.0	0.0
32.	Other transport equipment	15.3	64.2	3.4	0.0	0.0	0.0
33.	Other manufacturing	13.9	4.0	90.2	0.0	0.0	0.0

Table 4: Initial changes to Australia's overall Terms of Trade due to imposition of carbon tariffs.

	% change		
	EU	**G7+S.Korea**	**China**
1. Initial change to the Terms of Trade	-0.17	-0.71	-0.76

Table 5: Projected change in real GDP, real GNI and national Employment relative to levels without carbon tariffs.

	EU	**G7+S.Korea**	**China**
1. Real GDP (%)	-0.02	-0.11	-0.13
2. Real GNI (%)	-0.07	-0.29	-0.33
3. Employment (%)	-0.01	-0.02	-0.03
4. Real GDP ($m, 2021 prices)	-421.4	-1,948.8	-2,450.8
5. Real GNI ($m, 2021 prices)	-1,752.9	-5,867.1	-6,645.5
6. Employment ('000 jobs)	-0.8	-2.6	-3.6

Table 6: Projected change in real GSP and state Employment relative to levels without carbon tariffs.

	EU	G7+S.Korea	China
1. Real GSP - NSW (%)	-0.10	-0.42	-0.44
2. Real GSP - VIC (%)	0.08	0.34	0.41
3. Real GSP - QLD (%)	-0.33	-1.44	-1.69
4. Real GSP - SA (%)	0.09	0.40	0.55
5. Real GSP - WA (%)	0.30	1.23	1.25
6. Real GSP - TAS (%)	0.16	0.59	0.76
7. Real GSP - NT (%)	0.31	1.05	0.61
8. Real GSP - ACT (%)	-0.04	-0.16	-0.18
9. Employment - NSW (%)	0.10	0.46	0.53
10. Employment - VIC (%)	-0.25	-1.07	-1.24
11. Employment - QLD (%)	0.13	0.54	0.67
12. Employment - SA (%)	0.23	0.94	0.96
13. Employment - WA (%)	0.15	0.60	0.72
14. Employment - TAS (%)	0.21	0.75	0.49
15. Employment - NT (%)	-0.02	-0.07	-0.07
16. Employment - ACT (%)	-0.10	-0.40	-0.43
17. Real GSP - NSW ($m, 2021 prices)	-641.5	-2,596.3	-2,703.6
18. Real GSP - VIC ($m, 2021 prices)	327.4	1,444.6	1,735.0
19. Real GSP - QLD ($m, 2021 prices)	-1,173.2	-5,058.0	-5,905.5
20. Real GSP - SA ($m, 2021 prices)	103.2	439.8	603.1
21. Real GSP - WA ($m, 2021 prices)	855.4	3,454.0	3,520.9
22. Real GSP - TAS ($m, 2021 prices)	48.4	177.4	226.5
23. Real GSP - NT ($m, 2021 prices)	76.3	261.5	152.3
24. Real GSP - ACT ($m, 2021 prices)	-17.3	-71.7	-79.4
25. Employment - NSW (‘000 jobs)	-2.8	-11.1	-11.4
26. Employment - VIC (‘000 jobs)	3.3	14.9	17.2
27. Employment - QLD (‘000 jobs)	-6.3	-26.7	-31.0
28. Employment - SA (‘000 jobs)	1.1	4.6	5.8
29. Employment - WA (‘000 jobs)	3.2	13.3	13.5
30. Employment - TAS (‘000 jobs)	0.4	1.5	1.8
31. Employment - NT (‘000 jobs)	0.3	1.1	0.7
32. Employment - ACT (‘000 jobs)	0.0	-0.2	-0.2

Table 7: Projected changes (%) in Australian Production

		EU	G7+Korea	China
1.	Sheep and cattle (live)	0.40	1.66	1.78
2.	Grains	0.49	2.02	2.16
3.	Dairy cattle and raw milk	0.22	0.92	0.98
4.	Other crops	0.18	0.76	0.81
5.	Other agricultural products	0.20	0.82	0.88
6.	Fishing products	0.26	1.07	1.15
7.	Forestry and logging	0.24	1.02	1.08
8.	Agricultural services	0.25	1.04	1.12
9.	Coal mining	-3.69	-15.49	-17.66
10.	Oil mining	0.78	3.24	3.48
11.	Gas mining and LNG	1.22	3.83	1.14
12.	Iron ore mining	0.73	3.01	3.23
13.	Other non-ferrous metal ores	0.57	2.44	3.47
14.	Non-metallic mining products	0.31	1.30	1.40
15.	Mining services	-1.21	-5.16	-5.99
16.	Meat products	0.35	1.47	1.56
17.	Dairy products	0.19	0.77	0.82
18.	Sugar (refined and raw)	0.31	1.30	1.39
19.	Other food products	0.22	0.90	0.95
20.	Drink (and tobacco) products	0.16	0.66	0.70
21.	Textiles, clothing and footwear	0.67	2.78	2.96
22.	Wood products	0.16	0.63	0.65
23.	Paper products	0.15	0.65	0.70
24.	Refined oil products	0.18	0.71	0.78
25.	Basic chemicals, plastics, etc.	0.04	1.18	1.46
26.	Non-metallic building product	0.07	0.40	0.43
27.	Iron and steel	-0.06	-0.41	0.75
28.	Alumina refining	1.02	4.15	4.52
29.	Aluminium smelting	0.77	-3.63	3.84
30.	Fabricated metallic products	-0.28	-0.97	1.24
31.	Motor vehicles and parts	0.45	1.86	1.97
32.	Other transport equipment	0.07	0.25	0.16
33.	Other manufacturing	0.30	1.23	1.30
34.	Other industries	-0.01	-0.11	-0.13

Table 8: Projected changes (%) in Australian Employment

		EU	G7+Korea	China
1.	Sheep and cattle (live)	0.50	2.10	2.25
2.	Grains	0.64	2.69	2.87
3.	Dairy cattle and raw milk	0.28	1.17	1.25
4.	Other crops	0.27	1.11	1.18
5.	Other agricultural products	0.29	1.21	1.30
6.	Fishing products	0.31	1.28	1.37
7.	Forestry and logging	0.33	1.42	1.50
8.	Agricultural services	0.25	1.05	1.12
9.	Coal mining	-3.89	-16.27	-18.54
10.	Oil mining	0.88	3.63	3.90
11.	Gas mining and LNG	1.24	3.95	1.27
12.	Iron ore mining	0.88	3.63	3.90
13.	Other non-ferrous metal ores	0.65	2.77	3.89
14.	Non-metallic mining products	0.35	1.48	1.59
15.	Mining services	-1.28	-5.46	-6.34
16.	Meat products	0.38	1.59	1.70
17.	Dairy products	0.22	0.90	0.95
18.	Sugar (refined and raw)	0.33	1.37	1.46
19.	Other food products	0.24	1.01	1.07
20.	Drink (and tobacco) products	0.25	1.05	1.12
21.	Textiles, clothing and footwear	0.72	2.97	3.16
22.	Wood products	0.15	0.62	0.64
23.	Paper products	0.17	0.72	0.78
24.	Refined oil products	0.25	1.01	1.11
25.	Basic chemicals, plastics, etc.	0.07	1.28	1.57
26.	Non-metallic building product	0.10	0.50	0.53
27.	Iron and steel	-0.03	-0.20	0.63
28.	Alumina refining	1.14	4.64	5.07
29.	Aluminium smelting	0.55	-2.52	3.13
30.	Fabricated metallic products	-0.24	-0.82	1.34
31.	Motor vehicles and parts	0.48	1.99	2.11
32.	Other transport equipment	0.09	0.35	0.27
33.	Other manufacturing	0.32	1.30	1.38
34.	Other industries	-0.01	-0.02	-0.03

Table 9: Projected changes ($m, 2021 prices) in Australian Real Value Added

		EU	G7+Korea	China
1.	Sheep and cattle (live)	33.5	139.1	148.7
2.	Grains	24.6	102.0	109.1
3.	Dairy cattle and raw milk	5.3	22.1	23.6
4.	Other crops	24.2	100.5	106.8
5.	Other agricultural products	11.4	47.6	50.9
6.	Fishing products	3.1	12.9	13.7
7.	Forestry and logging	3.2	13.8	14.6
8.	Agricultural services	7.0	28.9	31.0
9.	Coal mining	-790.4	-3,317.6	-3,781.7
10.	Oil mining	50.5	208.5	224.0
11.	Gas mining and LNG	107.8	339.1	99.3
12.	Iron ore mining	388.3	1,598.7	1,715.0
13.	Other non-ferrous metal ores	78.6	335.5	471.8
14.	Non-metallic mining products	6.6	27.8	29.9
15.	Mining services	-161.5	-689.2	-799.1
16.	Meat products	24.9	103.6	110.5
17.	Dairy products	5.5	23.0	24.5
18.	Sugar (refined and raw)	5.6	23.2	24.7
19.	Other food products	23.0	95.4	101.3
20.	Drink (and tobacco) products	11.8	48.7	51.6
21.	Textiles, clothing and footwear	18.5	76.7	81.7
22.	Wood products	6.6	26.7	27.5
23.	Paper products	5.9	25.5	27.5
24.	Refined oil products	14.1	56.9	62.8
25.	Basic chemicals, plastics, etc.	4.9	148.8	184.4
26.	Non-metallic building product	7.7	41.5	44.5
27.	Iron and steel	-2.1	-15.0	27.7
28.	Alumina refining	12.1	49.2	53.6
29.	Aluminium smelting	6.8	-32.5	34.0
30.	Fabricated metallic products	-34.0	-118.8	155.5
31.	Motor vehicles and parts	23.7	97.6	103.5
32.	Other transport equipment	3.3	12.3	8.6
33.	Other manufacturing	52.3	211.5	222.5
34.	Other industries	-404.2	-1,792.7	-2,254.7

Table 10: Projected changes ('000 jobs) in Australian Employment

		EU	G7+Korea	China
1.	Sheep and cattle (live)	0.6	2.3	2.5
2.	Grains	0.2	0.7	0.8
3.	Dairy cattle and raw milk	0.1	0.4	0.4
4.	Other crops	0.2	0.9	1.0
5.	Other agricultural products	0.1	0.4	0.4
6.	Fishing products	0.0	0.1	0.1
7.	Forestry and logging	0.0	0.1	0.1
8.	Agricultural services	0.1	0.3	0.3
9.	Coal mining	-3.1	-12.9	-14.7
10.	Oil mining	0.1	0.4	0.4
11.	Gas mining and LNG	0.3	0.9	0.3
12.	Iron ore mining	0.5	2.0	2.2
13.	Other non-ferrous metal ores	0.4	1.5	2.1
14.	Non-metallic mining products	0.1	0.2	0.2
15.	Mining services	-1.0	-4.5	-5.2
16.	Meat products	0.3	1.0	1.1
17.	Dairy products	0.0	0.2	0.2
18.	Sugar (refined and raw)	0.1	0.2	0.2
19.	Other food products	0.3	1.1	1.2
20.	Drink (and tobacco) products	0.1	0.5	0.5
21.	Textiles, clothing and footwear	0.3	1.4	1.5
22.	Wood products	0.1	0.2	0.2
23.	Paper products	0.1	0.4	0.5
24.	Refined oil products	0.0	0.1	0.1
25.	Basic chemicals, plastics, etc.	0.1	1.5	1.8
26.	Non-metallic building product	0.0	0.1	0.1
27.	Iron and steel	0.0	-0.1	0.2
28.	Alumina refining	0.2	0.9	1.0
29.	Aluminium smelting	0.0	0.0	0.0
30.	Fabricated metallic products	-0.2	-0.5	0.8
31.	Motor vehicles and parts	0.3	1.2	1.3
32.	Other transport equipment	0.0	0.1	0.1
33.	Other manufacturing	0.7	2.9	3.1
34.	Other industries	-1.7	-6.8	-8.4

Appendix A: Brief overview of the GTAP model with Environmental Enhancements

The GTAP family of models and VURM are based on a common theoretical framework – the ORANI model of the Australian economy. Each of the GTAP family can be likened to a series of ORANI models, one for each national region, linked by a matrix of bilateral international trade flows. Similarly, VURM can be likened to a series of ORANI models, one for each Australian state and territory, linked by a matrix of inter-state trade flows. However, unlike the static ORANI model, VURM and GTAP-COPS are recursively dynamic models, developed to address long-term global policy issues, such as climate-change mitigation costs.

The version of GTAP used in this paper is labelled GTAP-COPS

Structure of demand

GTAP-COPS models demand and supply by region, and the inter-regional linkages arising from the flows of tradable goods and services and of capital. In doing so, it ensures that each region's total exports equals total imports of these goods by other regions.

There are four sources of demand: (1) Industry demands for current production; (2) Demands for inputs to capital creation; Household demand; and Government demand.

Industry demand for current production

Industry demands in each region in GTAP-COPS are derived from solutions to a cost-minimization problem involving a multi-level production function. Common to all GTAP models, in GTAP-COPS regional substitution is allowed between different national regions.

GTAP-COPS's structure of industry demand differs from that specified in GTAP by making explicit allowance for substitution possibilities between capital and energy and between different forms of energy. Such substitution is relative-price induced.

A maintained assumption in both models is that producers are price takers in both input and output markets. GTAP recognises two broad categories of inputs: intermediate inputs and primary factors. Industries in each region are assumed to choose the mix of inputs that minimises the costs of production for their level of output. They are constrained in their choice of inputs by a production technology of several branches, each with a number of levels (or nests).

At the first level, the primary-factor bundle (value added) and bundles of intermediate inputs (including energy units) are used in fixed proportions to produce output. The value-added and intermediate-input bundles are formed at the second level. The primary-factor bundle is a constant-elasticity-of-substitution (CES) combination of labour, fixed capital and agricultural land. Each intermediate-input bundle is a CES combination of a domestically produced good and an internationally imported composite.

At the third level, the import-composite is formed as CES combination of goods from each foreign region. Note that the regional structure of imports is not user-specific.

In GTAP-COPS, energy is taken out of the intermediate bundle and is incorporated into the value-added nesting. This is done in two steps. First, energy commodities (primary fossil fuels, refined

petroleum and electricity) are separated into two: electricity and non-electricity. Some CES-substitution is allowed within the non-electricity group and between electricity and non-electricity.

Second, the energy bundle is combined with capital to produce an energy-capital composite. This is combined with other primary factors in a value-added-energy (VAE) bundle.

Demand for inputs to capital creation

The second major form of demand is for inputs to capital creation (investment). The cost-minimizing capital creator in each region in GTAP-COPS combines inputs to assemble units of capital, subject to a nested production technology similar to that facing each sector for current production. Thus, Figures 2a and 2b apply to demands by the single investing producer, as well as demand for inputs to current production.

Investment in each region is financed from a global pool of savings. In standard comparative-static GTAP, there are two alternative ways of allocating this pool to investment in each region. The first makes investment in each region a fixed proportion of the overall size of the pool – if the pool increases by 10 per cent, investment in each region increases by 10 per cent. The second relates investment allocation to relative rates of return. Regions that experience increases in their rate of return relative to the global average will receive increased shares of the investment pool, whereas regions experiencing reductions in their rate of return relative to the global average will receive reduced shares.

In GTAP-COPS, we adopt a third way. It is similar to the second approach adopted for comparative static modelling, but allows for a dynamic relationship between capital growth (investment) and expected rate of return. To ensure that at the global level savings matches investment, saving by region is endogenously adjusted in an equi-proportion way to ensure that the global condition holds.

Household demand

In the GTAP-family, in each region household (private) consumption is distinguished from government (public) consumption. It is assumed that the household demands goods and services to maximises utility from a given level of income. The utility maximising decision is based on given prices and a utility function with a constant-difference of elasticities (CDE) function form. Once the consumption of good c is determined, then the household decides on how much domestically-produced c to use and how much of imported good c to use. The sourcing allocation of imports is determined in line with the general allocation decision made for all users.

Government demand

In GTAP government consumption expenditures is assumed to be based on Cobb-Douglas allocation across all commodities. Summary of Environmental enhancements in GTAP-COPS

Brief summary of environmental enhancements in GTAP-COPS

- Global emissions database that includes all major sources of greenhouse gases, except land-use change. This database is built primarily from data compiled for the GTAP-E model. That model, however, ignores most non-CO2 emissions associated with agriculture, fugitives, industrial processes and waste. Data for these non-combustion emissions come from work largely undertaken at the CSIRO.
- As in VURM, in GTAP-COPS it is assumed that combustion emissions of CO2 are proportional to the quantity of fuel combusted, while non-CO2 emissions are proportional to the level of production in the industry generating them.

- Emission response functions are defined for non-CO2 emissions. These specify abatement as increasing functions of the rate of carbon tax and reflect the assumption that the marginal cost of abatement rises with the level of abatement.
- GTAP-COPS has the facility to use the “technology-bundle” approach to model electricity generation, transport and steel manufacture. Under this approach, multiple technologies are specified for the production of the relevant output. The shares of the technologies in aggregate output depend on their relative profitability but there is no input substitution within technologies.
- For emerging electricity generation technologies, such as solar and geothermal, learning-by-doing mechanisms are added. These lower primary-factor input requirements per unit of output over time.
- In some mining industries, factor productivity is assumed to decline with increases in the cumulative level of resource extraction, reflecting increasing extraction costs as the resource base diminishes.

Appendix B: Calculating the exogenously imposed shifts in export demand schedules in VURM

We start with the assumption that world demand for Australian exports is determined with a constant elasticity. Hence, if X is the volume of Australian exports and P is the world price, then:

$$X = \left(\frac{P}{F}\right)^{\sigma} \qquad (1)$$

where:

X is the volume of Australian exports;

P is the world price of the exported product;

F allows for vertical shifts in export demand; and

σ is the export demand elasticity (a number like -5).

We assume that there are no transport costs and that all bi-lateral exchange rates are one. Under these assumptions, the world price is the same as the fob export price in Australia and the cif import price in any importing region.

The approximate percentage change form of (1) is:

$$x = \sigma\left(p - f\right) \qquad (2)$$

where variables written with lower case letters signify percentage changes in variable written in corresponding upper case letters. For example "x" is the percentage change in the volume of Australian exports (X). Note that (2) is accurate for small changes.

For commodity c, export demand equals global import demand. In other-words, for commodity c:

$$\sigma(c)\left(p(c) - f(c)\right) = \sum_{r} S_r(c) \times \sigma(c)\left(p(c) + t_r(c)\right) \qquad (3)$$

The LHS of (3) is the same as the RHS of (2) with the addition of the commodity (c) index. The RHS of (3) is the sum of region-specific demands for commodity c exported from Australia. We assume that the import substitution elasticity is the same across all regions and equal to the export demand elasticity. The variable $t_r(c)$ is the percentage change in the purchases' price of imports due to the imposition of a carbon tariff; $p(c) + t_r(c)$ is therefore the percentage change in duty-paid cif price in region r. S_r is the share of region r in total import demand for commodity c.

Simple manipulation of (3) yields

$$f(c) = -\sum_{r} S_r(c) t_r(c) \qquad (4)$$

Equation (4) says, for commodity c, that the vertical shift in export demand equals a trade-share weighted sum of percentage changes in purchases' prices due to the imposition of a carbon tariff.

Equation (4) is our formula for generating the shifts in export demand required as input to the VURM simulations of carbon tariff effects. 2019 data for export shares come from the Australian

Bureau of Statistics. Shares for EU, G7+S.Korea and China are given in the first three columns of Table 3. The remaining columns of Table 3 are values for the shifts in export demand calculated using (4) for each of the three settings of r, using values for $t_r(c)$ given in Table 2. Note that an adjustment is made to remove the approximation arising from second-order effects not included in equation (2).

Endnotes

[i] Greenhouse gases are gases such as CO2 that trap heat in the atmosphere. In this paper we generally use the term CO2 (carbon dioxide) to refer to the range of greenhouse gases.

[ii] EU - €59 (ETS price as at 27 August 2021).
G7+S Korea - US$39, based on the IHS Weighted global carbon price.
China. There's no live price for China. We therefore use the same global average as we do for G7+Korea.

[iii] Philip Adams, Janine Dixon and Mark Horridge (2015), "The Victoria University Regional Model (VURM): Technical Documentation, Version 1.0", July, *Working Paper* G-254, Centre of Policy Studies, Victoria University, Melbourne.

[iv] By CO2 emissions we mean emissions from all greenhouse gases. The correct term is CO2-equivalent (or CO2-e) emissions. CO2-e is a metric measure calculated as a weighted sum of emissions from all greenhouse gases. The weights are based on each gas' global-warming potential (CO2 = 1).

The purchasers' price of a commodity is the producer price plus any margins and taxes that facilitates the transfer of the commodity from producer to purchaser (e.g., freight and transport). Producer price is the unit cost of production, covering all inputs including labour and capital.

[v] GTAP and VURM have a similar design. Whereas VURM is a bottom –up model of Australian regions, GTAP is a bottom up model of global regions. GTAP's database contains a detailed description of economic inflows and outflows within individual economies, as well as the trade flows that connect economies. In addition, contained within a satellite account, GTAP has detailed data on greenhouse emissions by region, by all emitting activities and by gas.

[vi] The terms of trade is the price of exports relative to the price of imports, and is a key determinant of real income accruing to Australians.

[vii] Real GDP is GDP deflated by the price of production. Real GNI is GDP that accrues to domestic residents deflated by the price of consumption. A fall in the terms of trade, all else unchanged reduces the price of production relative to the price of consumption, thereby reducing real GNI relative to real GDP.

[viii] VURM recognised 83 industries. 50 of these are service related and are aggregated into the miscellaneous "other" category.