ERIA Discussion Paper Series

No. 387

Economic and Emission Impact of Australia–China Trade Disruption: Implication for Regional Economic Integration

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July 2021

Abstract: *This study examines the debates on supply chain resilience and the economic and emissions impact of supply chain rerouting using Australia and China trade as an example. The estimations demonstrate that, in both export and import cases, a trade embargo between Australia and China, despite being compensated by alternative supply chains, will cause gross domestic product loss and emissions increases for both countries. Moreover, even if all other countries gain from the markets left by China, many of them suffer from overall gross domestic product loss and emissions increase. The findings that ASEAN and China may also suffer from an Australia–China trade embargo, despite a gain in trade volume, suggests that no country should add fuel to the fire. The results suggest that countries need to defend rules-based trading regimes and continuously promote regional economic integration.*

Keywords: COVID-19; supply chain; global value chain; economic integration; Australia; China.

JEL Classification: F18; Q56

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[§] This research was conducted as a part of the project of 'ERIA Research on COVID-19 and Regional Economic Integration'. The opinions expressed in this paper are the sole responsibility of the authors and do not reflect the views of ERIA.

1. Introduction

The ongoing US–China tension and the shocks from COVID-19 highlight the issue of supply chain resilience, with China at the centre of the storm. COVID-19 disrupted global supply chains, some of which are essential. Many countries dependent on China are considering rerouting their supply chains. As part of economic stimulus packages, many governments provide incentives to bring home or 'reshore' manufacturing. For example, the Trump administration was campaigning to exclude China from US and its allies' trade networks (Goldthau and Hughes, 2020). Japan is incentivising its domestic production through financial subsidies of ¥240 billion (US$2.3 billion). Australia is a key case and is working with Japan and India to shift supply chains from China to Association of Southeast Asian Nations (ASEAN) member states and India. China is also preparing for a more diversified and secure supply chain, motivated not by COVID-19, but by US sanctions on Huawei and other high technology companies. Even for primary resources such as iron ore, China will seek to diversify its supplies (Raby, 2020).

Such momentum of political intervention on supply chains, or global value chains (GVCs) will undermine the global trade regime and regional economic integration, particularly in East Asia, which has significantly benefited from integrated regional production networks (Kimura, 2019; Obashi and Kimura, 2018). Current supply chain network configurations are a result of relatively free trade and economic integration. More political interventions will undermine the benefits of trade due to comparative advantages. While such interventions may reduce dependence on vulnerable supply chains, they will create complicated consequences given the complexity in the global production network. One obvious consequence is the benefit lost, as this is exactly the opposite of what a free trade agreement does (Kimura, 2019). The global integration comprising cross-border trade and investment drives down costs and encourages learning and innovation (Goldthau and Hughes, 2020). It has been reported that the Trump administration's 30% tariff on US imports of crystalline silicon photovoltaic products, which was intended to protect its domestic industry, has actually cost 62,000 jobs and 10.5 gigawatts of capacity (roughly equivalent to US photovoltaic deployment in 2018) between 2017 and 2021 (SEIA, 2019). More seriously, a long-term impact could be the collapse of the multilateral trading system (Kimura, 2019).

Further understanding the costs and benefits of supply chain manipulation, and their distribution amongst major countries, can inform policy at both national and regional levels. Quantitative studies that accommodate both direct and indirect impacts, however, are limited. The impacts of COVID-19 on supply chains have been frequently examined in the literature. The existing studies on COVID-19 and GVCs mostly focus on the impact on supply chains (Guan et al., 2020), the overall measurement of resilience (Golan et al., 2020; Hobbs, 2020), an alternative concept for supply chains (Ivanov, 2020), prediction of the impact (Guan et al., 2020) or regional collective responses (Kimura et al., 2020). However, there is no study on the vulnerability of specific supply chains and the impact of alternatives.

These issues are particularly important for East Asian countries as they are amongst the largest beneficiaries of the multilateral trading system (Kimura, 2019). The successfully developed international production networks (IPNs) in ASEAN and East Asia since the late 1980s were made possible by the rule-based trading institutional infrastructure (Kimura, 2019). As a third-country group in the US–China trade war, ASEAN may benefit in the short run, but is unlikely to do so in the long run, and thus should be proactive in defining the World Trade Organization-based global trade regime.

The Australia–China trade relationship is a salient example of how COVID-19 may impact regional economic integration. Amid increasing tensions between Australia and China, there are ongoing debates that Australia should reduce its dependence on China. The latest data confirm Australia's significant trade exposure to China. In 2018–19, about 30% of Australia's total exports went to China, with imports accounting for 24.5% of Australia's total. As in the rest of the world, COVID-19 amplifies questions around vulnerabilities stemming from China's importance in Australia's supply chains.

In this study, we examine supply chain challenges and the impact of supply chain rerouting with Australia and China trade as an example. We first identify the most vulnerable supply chain between Australia and China. Next, we study the impact of alternative supply chains for Australian exports to, and imports from, China, with a particular focus on ASEAN and India.

The research estimates the supply chain dependence between Australia and China by augmenting the transitional hypothetical extraction method (HEM) with a computable generation equilibrium (CGE) model. We also address urgent issues faced

by policymakers by simulating the impact of alternative supply chains. The policy implications from the case study of the Australia–China trade are likely to be applicable elsewhere in the developed world.

The report proceeds as follows. The next section presents the current debates on supply chain resilience and the initiatives that are rerouting supply chains away from China. Section 3 explains the methodology, followed by the modelling results in Section 4. The last section concludes the report with some policy implications.

2. Debates on supply chain resilience: an Australia–China relations perspective

2.1 Overall debates on supply chain resilience

Two recent developments – the US–China trade war and the COVID-19 pandemic – have meant that the concentration of global supply chains in China is increasingly vulnerability to disruption.

The US–China trade war, initially motivated largely by then-US President Trump's ambition to reverse sustained bilateral trade deficits with China, has come to reflect a broader array of issues, particularly in the security domain. The US has argued, for instance, that Chinese supply chains for telecommunications pose a threat to cybersecurity and pressured allies to exclude Chinese firms such as Huawei (Ferguson and Chambers, 2020). The trade war overall has generated considerable uncertainty around supply chains based in China, particularly for those dealing with high technology (Bovino and Roache, 2019).

Another oft-cited vulnerability is the potential for China to leverage its dominance in critical supply chains for economic coercion as an unofficial response to political disputes, with China's restriction of rare earth minerals exports to Japan in 2010 being a high-profile example (Tiezzi, 2019).

Second, the COVID-19 pandemic has provided fresh impetus to concerns about the vulnerability of China-based supply chains, particularly for medical products. Then-US Secretary of State Pompeo, for example, stated on 29 April 2020 that the US had discussed with partners, '…global supply chains, keeping them running smoothly…how we restructure…supply chains to prevent something like this from ever happening again' (Pompeo, 2020a). US Senator Josh Hawley contended that

'[t]his pandemic…exposed a Grand Canyon size fault in our supply chain' and that government recovery efforts 'should include new measures to bring critical supply chains back to this country from China and elsewhere' (Hawley, 2020).

Some have pushed back on these concerns, however. On 11 October 2020, John Denton and Damien Bruckard of the International Chamber of Commerce wrote (Denton and Bruckard, 2020):

> *COVID-19 indeed exposed serious vulnerabilities, but that should not automatically lead to the conclusion that global supply chains are systemically fragile or that vulnerabilities require correction by governments.*

On 2 June 2020, Damien Ma, Director of the Paulson Institute's MacroPolo think-tank, made the case that, while supply chain disruptions had 'become a central political argument in justifying economic 'decoupling,'' with China, 'the concentration of supply chains in East Asia…has turned out to be a major silver lining' because those economies – including China – resumed production earliest (Ma, 2020).

2.2 Global initiatives to reroute supply chains away from China

Of the countries that have begun implementing multi- and unilateral rerouting initiatives, the most prominent is the US and its ongoing imposition of tariffs on Chinese imports, explicitly intended to reduce US companies' incentive to base supply chains in China. Responding specifically to cybersecurity concerns, the US government has also initiated the Clean Technology Infrastructure Network, described by then-US Secretary of State Pompeo as a 'comprehensive approach to guarding our citizens' privacy and our companies' most sensitive information from aggressive intrusions by malign actors, such as the Chinese Communist Party' (Pompeo, 2020b).

Another illustrative case is that of Japan, which in April 2020 allocated US$2 billion to subsidise Japanese firms' onshoring from China and a further US$222 million to promote supply chain rerouting to southeast Asia (Tajitsu et al., 2020).

The Australian government, in implementing its own supply chain resilience initiatives, has tended to avoid specifically naming China and has focused on shifting supply chains onshore rather than toward other economies. On 1 October 2020, Australian Prime Minister Scott Morrison announced a A$1.5 billion 'Modern

Manufacturing Strategy' with A$107 million allocated to a 'Supply Chain Resilience Initiative', aimed at supporting domestic manufacturing in six priority areas: resources technology and critical minerals processing, food and beverages, medical products, recycling and clean energy, defence, and space (Morrison and Andrews, 2020).

Of these, two supply chains have been subject to particular attention. The first is the rare earth mineral supply. China maintains a near-monopoly on the production of rare earth minerals, which are essential inputs for technologies in a range of strategically important industries. China's restriction of rare earth mineral exports to Japan in 2010 following bilateral political tensions over a territorial dispute has sharpened fears that China could 'weaponise' its near-monopoly against other states (Wilson, 2018). The second is medical protection equipment. Amid the COVID-19 pandemic, medical products have been a natural focal point for concerns around supply chain resilience. In addition to concerns around lack of transparency in personal protective equipment (Pournader, 2020), a May 2020 report by the Institute for Integrated Economic Research Australia found that 'Australia is dangerously dependent on imported medicine', and that '[t]he coronavirus is an example of a situation…that could significantly impact the global medicine supply chain given the global dependencies on China's pharmaceutical industry' (Borzycki, Quilty and Blackburn, 2020).

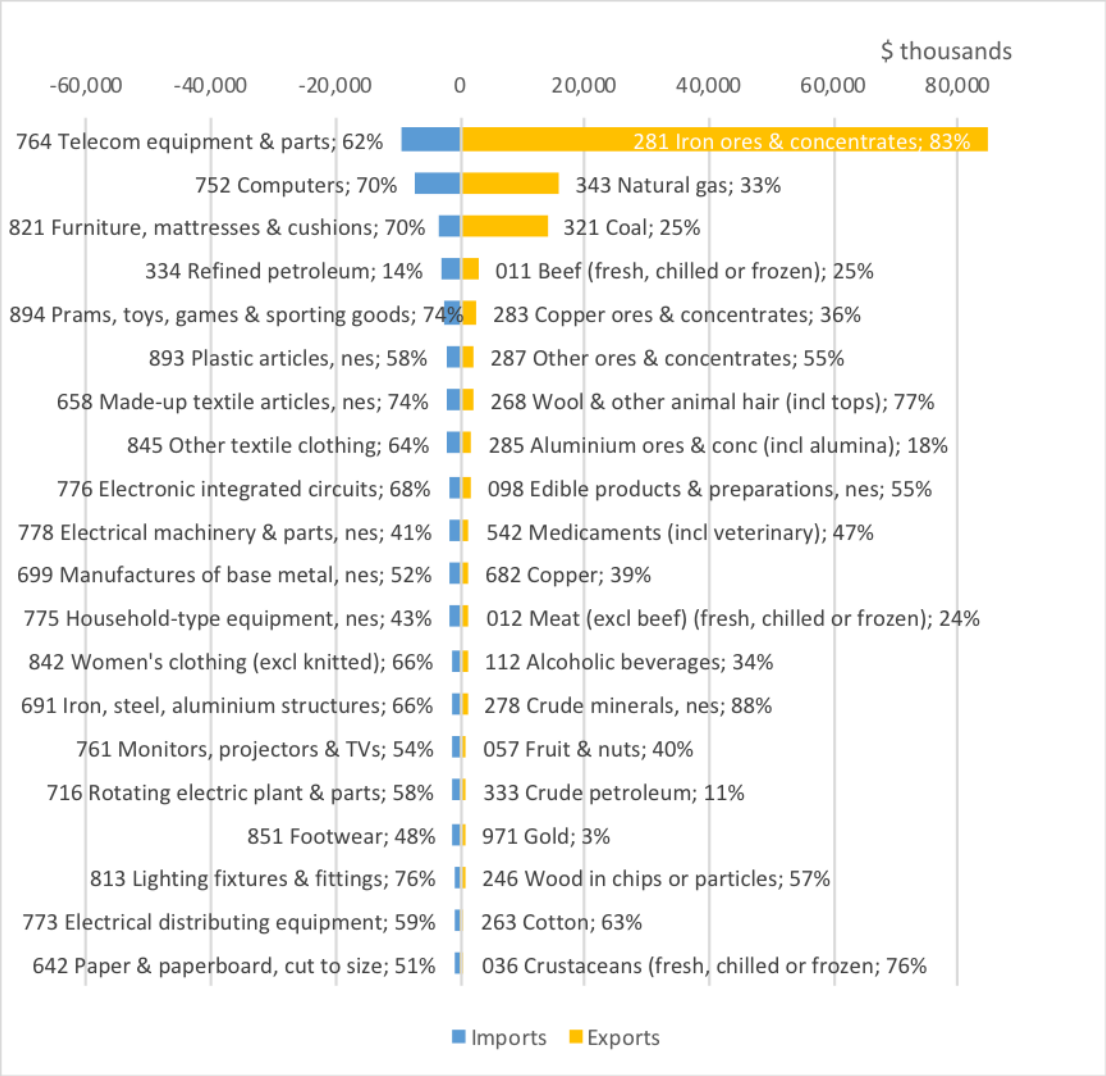
Australia, Japan and India are also moving towards multilateral cooperation on supply chain resilience. On 1 September 2020, Australia's Trade Minister Simon Birmingham released a joint statement with his Indian and Japanese government counterparts, 'recognising the pressing need for regional cooperation on supply chain resilience' and 'called for other countries in the region…to participate in the initiative' (Birmingham et al., 2020). This has since expanded to include the US, the fourth member of the group (Payne, 2020).

2.3 Australia–China dependence and debates

Australia's trade with China has grown rapidly over the last 2 decades. Goods exports to China grew from A$6.0 billion in 2000 to A$149 billion in 2019, accounting for 38.2% of Australia's total exports in 2019, while goods imports from China grew from A$9.1 billion to A$79.5 billion over the same period, accounting for 24.7% of total imports (Australian Government Department of Foreign Affairs and

Trade, 2020). Figure 1 highlights the largest component of these per sector and their respective shares of Australia's total exports and imports for each good.

Figure 1. Key Trading Sectors between Australia and China



nes: not elsewhere specified.
Note: '%' refers to imports from or exports to CN/total AU imports or exports.
Source: Australian Government Department of Foreign Affairs and Trade (2020).

Australia's trade surplus with China, which reached A$69 billion in 2019–20 (Australian Bureau of Statistics, 2020), has meant debates around trade dependence on China have tended to focus on exports rather than imports. On this front, there have long been calls for Australia to reroute exports towards markets other than China (Laurenceson and Zhou, 2020). More recently, Chinese import measures affecting Australian exports have prompted increased international attention. For instance, both the Trump and Biden administrations in the US are reported to have raised the

possibility of collective action in response (Greber, 2020).

Also gaining influence, however, were reports of pandemic-induced supply shortages in sectors as wide-ranging as construction, healthcare, agriculture and retail (Bleby, 2020; Robertson, 2020; Thompson, 2020; Wiggins et al., 2020), which prompted an increase in attention given to supply chain resilience and the extent of Australia's dependence on imports.

On 27 April 2020, Shadow Foreign Minister Penny Wong made the case that Australia 'should be considering how to secure key supply chains and greater diversification, without being dismissive of the reality of China's economic weight' (Wong, 2020). In a 20 May 2020 speech, Minister for Industry, Science and Technology Karen Andrews said that 'we can't just rely on foreign supply chains for the essential items we need in a crisis', and that the pandemic had 'laid bare our need to secure economic sovereignty' (Karp, 2020; Riley, 2020).

Some commentators explicitly framed concerns around supply chain dependence in terms of national security. On 31 March 2020, Chris Uhlmann, political editor for Nine News, asserted 'we should deliberately diversify our suppliers away from China', (Uhlmann, 2020), elaborating a month later that '[r]esuming business as usual where supply chains and income streams rely too heavily on a nation that views both as political weapons is to invite the next catastrophe' (Uhlmann, 2020). On 18 April 2020, Peter Jennings, the executive director of ASPI, wrote that a 'stronger national security perspective must be brought to how we manage the supply of fuel, food, medical equipment, information technology and critical infrastructure' (Jennings, 2020). And in May 2020, the Henry Jackson Society published a report finding that Australia was 'strategically dependent' on China in 141 of 1,244 HS 4-digit categories of goods (Rogers et al., 2020). In a contribution to the report, Liberal MP Andrew Hastie said that '[o]ur strategic dependency on critical imports makes us vulnerable to not only economic coercion, but also supply chain warfare' (Hastie, 2020).

As noted in Laurenceson and Zhou (2020), however, the potential for a single good's inputs and stages of production to be distributed across multiple regions means that simply focusing on reducing dependence on one part of that supply chain is an inadequate approach for managing risk. Shiro Armstrong, director of the East Asian Bureau of Economic Research, further contends (Armstrong, 2020): 'The best insurance…is openness to supply from producers all around the world. The key is to

manage supply chain risk, not to avoid it'.

On medical imports specifically, Medicines Australia stated in a 29 June 2020 submission to the Joint Standing Committee on Foreign Affairs, Defence and Trade that, '[a]ny concerns about disruptions (strategic or otherwise) to the production active pharmaceutical ingredients and subsequent medicines in China and India were largely unfounded' (Medicines Australia, 2020).

3. Methodology and scenarios

The research will rank Australia's exports to and imports from China by sector. We simulate stopping the exports and imports of each sector by using a CGE model that will estimate the economic and emission consequences of shutting down the bilateral trade for each sector. The economic losses will be ranked in descending order. We then report the economy-wide impact of removing the five top-ranked sectors in ASEAN/India by taking relocation and investment into consideration.

3.1 Hypothetical extraction method

In most studies, a trade sector is assessed using imports as a measurement of interdependence. However, this approach is insufficient as 70% of global trade is in intermediate goods (OECD et al., 2014), meaning that finished goods may have supply chains beyond where they are assembled.

The importance of each sector in bilateral imports and exports is more appropriately be ranked by HEM, which is an application of an input–output (I/O) approach that was first initiated by (Schultz, 1977) and further improved by (Cella, 1984) and (Duarte et al., 2002). In recent years, HEM was extended to identify the key sectors in terms of emissions (Liao et al., 2017; Zhang et al., 2018; Zhao et al., 2015).

HEM measures a sector by estimating the economic loss when it is hypothetically extracted. The difference in gross domestic product (GDP) between this hypothetical scenario and the baseline scenario is the economic effect or 'value' of this sector. By estimating the value one-by-one, we get a ranking for Australia's I/O balance from China.

The basic concept of HEM, as shown by Huang and Tian (2021), is as follows: Assume the economy has two sectors: $\mathbf{B}_S$ represents a block of target sectors in the

economy, while $\mathbf{B}_{-S}$ represents the remaining blocks. The economy can be re-described as:

$$\begin{bmatrix} \mathbf{X}_S \\ \mathbf{X}_{-S} \end{bmatrix} = \begin{bmatrix} \mathbf{\Delta}_{S,S} & \mathbf{\Delta}_{S,-S} \\ \mathbf{\Delta}_{-S,S} & \mathbf{\Delta}_{-S,-S} \end{bmatrix} \begin{bmatrix} \mathbf{Y}_S \\ \mathbf{Y}_{-S} \end{bmatrix} \quad (1)$$

Where $\mathbf{X} = \begin{bmatrix} \mathbf{X}_S \\ \mathbf{X}_{-S} \end{bmatrix}$ denotes the total output, $\mathbf{Y} = \begin{bmatrix} \mathbf{Y}_S \\ \mathbf{Y}_{-S} \end{bmatrix}$ denotes the final demand, and $\mathbf{L} = \begin{bmatrix} \mathbf{\Delta}_{S,S} & \mathbf{\Delta}_{S,-S} \\ \mathbf{\Delta}_{-S,S} & \mathbf{\Delta}_{-S,-S} \end{bmatrix}$ is the Leontief inverse matrix.

In the hypothetical economy, block $\mathbf{B}_S$ neither buys from nor sells to other sectors, and the hypothetical economic relationship can be described as:

$$\begin{bmatrix} \boldsymbol{X}_S^* \\ \boldsymbol{X}_{-S}^* \end{bmatrix} = \begin{bmatrix} \boldsymbol{A}_{S,S} & 0 \\ 0 & \boldsymbol{A}_{-S,-S} \end{bmatrix} \begin{bmatrix} \boldsymbol{X}_S^* \\ \boldsymbol{X}_{-S}^* \end{bmatrix} + \begin{bmatrix} \boldsymbol{Y}_S \\ \boldsymbol{Y}_{-S} \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} \boldsymbol{X}_S^* \\ \boldsymbol{X}_{-S}^* \end{bmatrix} = \begin{bmatrix} (\boldsymbol{I} - \boldsymbol{A}_{S,S})^{-1} & 0 \\ 0 & (\boldsymbol{I} - \boldsymbol{A}_{-S,-S})^{-1} \end{bmatrix} \begin{bmatrix} \boldsymbol{Y}_S \\ \boldsymbol{Y}_{-S} \end{bmatrix} \quad (2)$$

The economic impact of the block $\mathbf{B}_S$ on the total output can be expressed as follows:

$$\mathbf{X} - \mathbf{X}^* = \begin{bmatrix} \mathbf{X}_S - \mathbf{X}_S^* \\ \mathbf{X}_{-S} - \mathbf{X}_{-S}^* \end{bmatrix} =$$

$$\begin{bmatrix} \mathbf{\Delta}_{S,S} - (\mathbf{I} - \mathbf{A}_{S,S})^{-1} & \mathbf{\Delta}_{S,-S} \\ \mathbf{\Delta}_{-S,S} & \mathbf{\Delta}_{-S,-S} - (\mathbf{I} - \mathbf{A}_{-S,-S})^{-1} \end{bmatrix} \begin{bmatrix} \mathbf{Y}_S \\ \mathbf{Y}_{-S} \end{bmatrix} = \begin{bmatrix} \mathbf{C}_{S,S} & \mathbf{C}_{S,-S} \\ \mathbf{C}_{-S,S} & \mathbf{C}_{-S,-S} \end{bmatrix} \begin{bmatrix} \mathbf{Y}_S \\ \mathbf{Y}_{-S} \end{bmatrix} \quad (3)$$

The effect of block S on CO_2 emissions can be expressed as Equation (5):

$$\mathbf{F} - \mathbf{F}^* = \begin{bmatrix} \mathbf{f}_S & 0 \\ 0 & \mathbf{f}_{-S} \end{bmatrix} \begin{bmatrix} \mathbf{C}_{S,S} & \mathbf{C}_{S,-S} \\ \mathbf{C}_{-S,S} & \mathbf{C}_{-S,-S} \end{bmatrix} \begin{bmatrix} \mathbf{Y}_S \\ \mathbf{Y}_{-S} \end{bmatrix} = \begin{bmatrix} \mathbf{\Omega}_{S,S} & \mathbf{\Omega}_{S,-S} \\ \mathbf{\Omega}_{-S,S} & \mathbf{\Omega}_{-S,-S} \end{bmatrix} \begin{bmatrix} \mathbf{Y}_S \\ \mathbf{Y}_{-S} \end{bmatrix} \quad (4)$$

Where $\begin{bmatrix} \mathbf{f}_S & 0 \\ 0 & \mathbf{f}_{-S} \end{bmatrix}$ indicates the sectoral CO_2 emissions per unit of output of block S and block $-S$.

3.2 The Computable General Equilibrium model

Traditionally, HEM estimation is concluded in an I/O model, which has several limitations, such as a lack of constraints in the supply side and budget for households and governments, fixed prices in the model and no response of consumers to price changes; further, the ratios for intermediate inputs and outputs are fixed. These assumptions are therefore unreasonable and could lead to misleading results.

In this paper, we replace traditional I/O analysis with the global trade and analysis (GTAP) model. GTAP is a multi-region, multi-sector CGE model that assumes perfect competition and constant returns to scale. We use the current model (version 7) (Corong et al., 2017) with the most updated database (version 10) that is based on the world economy in 2014 (Aguiar et al., 2019). Compared with the original HEM I/O analysis, the CGE model can better reflect reality.

The standard GTAP model reports result in the term of GDP, welfare, and trade by each of the 141 countries/regions. The GTAP-E database further provides information on CO_2 emissions by assuming an average coefficient for each fuel that is constant across all sectors of the economy, as well as across different regions (Burniaux and Truong, 2002).

In the database, there are 65 sectors, as shown in the Appendix. Since our interest is to rank the importance of each sector, we will not aggregate the sectors. Amongst the 65 sectors, one is Dwellings that does not involve trade and thus we ignore it.

We aggregate regions into 13 regions. Apart from Australia and China, other independent regions include Hong Kong and the US. Hong Kong is separated because some trade from China might be rerouted through it. The US is separated because of its size and ongoing tension with China. ASEAN and India are highlighted as they are likely to be the destination for trade relocated from China. The European Union is separated as they are likely to have different policies from East and Central Europe (Table 1).

Table 1. Country Groups

Region	Country or country group
Asia (5)	ASEAN, India, China, Hong Kong, Developed Asia (Japan, Republic of Korea, Taiwan), Developing Asia
The Pacific (1)	Australia
North America (2)	US, Other North America
Africa (1)	Africa
Central–South America (1)	Central–South America
Europe (2)	European Union, Other European countries
Others (1)	Rest of the world

ASEAN = Association of Southeast Asian Nations, US = United States.
Source: Authors' own estimation.

3.3 Shortlist key sectors for detailed analysis

Based on the I/O ranking of the 65 sectors, respectively, we will decide the key sectors from Australia's perspective. The ranking itself is a reference, but not the only determinant. Other sectors that are not at the top of the ranking, such as medical supply, would be considered key due to their prominence during the pandemic period. To estimate the impact of the supply chain relocation effect, we do not arbitrarily determine how much trade should relocate to each region other than China, but instead let the model decide the relocation based on its substitution mechanism. This redistribution of trade amongst regions will be its most optimal allocation. We then further check how much capital investment has been changed in each region. In GTAP, normal investment is determined endogenously. This change is the amount that should be invested to deliver the optimal distribution of trade amongst other regions.

4. Simulations results

We select GDP change as the key indicator. Our estimation suggests that a total trade cut between Australia and China will cause economic loss and lead to an increase in carbon emissions for both countries and the world as a whole though some countries may benefit from the trade cut. Although part of the reduction in bilateral trade can be diversified to other regions, the costs to both countries and the global community remains significant. Furthermore, even though many countries can gain their share in Australia's market after China is excluded, many of these countries may still register a loss in GDP. This is because China is the world's second-largest economy; if it suffers economic loss, then this will reduce consumption, which may reduce imports.

4.1. Economic and environmental impacts of reducing Australia's trade with China

Overall, it is found that, in the case of Australia's imports from China, when trade is cut off (value forced to zero), Australia will lose.

4.1.1 Impact of cutting off the flow of Australian exports to China

Table 2 illustrates the effect on Australian exports to China in each sector, with sectors displayed in column (1). These are ranked by the changes to Australia's GDP resulting from the cessation of trade in each sector, which are shown in column (2).

Column (3) displays the resultant GDP changes for China. Column (4) lists the net GDP change globally. Negative values in columns (2), (3) and (4) indicate GDP losses, while positive values indicate GDP gains. Columns (5), (6) and (7) display each sector's emissions change in three regions, namely, Australia, China and the world, following cessation of trade. Negative values in these columns indicate emissions reductions, while positive values indicate emissions increases.

As expected, the largest GDP losses for Australia are incurred when the largest goods exports are cut off. For example, cutting off exports of Ores, which includes Australia's largest export, iron ore, results in a GDP reduction of A$6.17 billion. Cutting off Coal induces a A$733 million GDP loss, while cutting off Non-Ferrous Metals results in a loss of A$418 million.

However, the GDP loss for China in almost all sectors is substantially larger. Returning to the Ores sector, the absence of trade causes a A$151 billion loss for China's GDP, 24.5 times larger than the GDP loss for Australia. A similar effect is seen in agricultural sectors such as Other Grains (including maize and barley), where a loss of A$58.0 million to Australia's GDP corresponds with a 23.4 times larger loss of A$1.36 billion to China's GDP, and in Miscellaneous Animal Products, where China's A$790 million loss is 20.1 times larger than Australia's at A$39.4 million. And in Petroleum and Coke Products and Beverages and Tobacco Products, cutting off Australian exports results in an Australian GDP gain of A$6.5 million and A$7.5 million respectively, in contrast to a respective A$82.4 million and A$261 million GDP loss for China.

At the aggregate global level, cutting off trade in the top four sectors – Ores, Coal, Non-Ferrous Metals and Other Grains – each cause a net GDP loss of over A$1 billion. Cutting off Ores causes a net A$130 billion loss globally, substantially more than the next largest sector, Coal, which results in a A$5.16 billion loss.

There are no sectors where Australia's losses exceed China's. In 61 of 63 sectors, China's GDP contracts more than Australia's when trade is cut off. However, given the larger size of China's economy, the relative impact to China may be much smaller in many sectors. At the global level, blocking trade in any sector would cause a net GDP contraction.

When it comes to the environmental impacts of cutting off trade, Table 2 shows that emissions changes are again concentrated in Australia's mineral exports to China. Most notably, cutting off Ores exports would benefit China significantly more than

Australia, increasing Australian emissions of CO_2 by 12.8 MT, while decreasing China's emissions by 123 MT. Cutting off Coal, on the other hand, causes an emissions increase in both economies, but an increase of 54.2 MT in China compared to 4.0 MT in Australia, thereby implying that the increase is much larger in China than Australia. And cutting off Australian exports of Non-Ferrous Metals results in a 3.1 MT emissions reduction in Australia, while China would see a 0.6 MT increase.

Cutting off exports in other sectors would cause somewhat less significant changes in emissions, with the exception of Air Transport, which would lead to a 0.9 MT emissions reduction in Australia and a 0.1 MT increase in China. As with changes in GDP, Australia experiences a larger emissions reduction than China in most of the sectors.

At the global level, cutting off Ores results in a net emissions reduction of 24.7 MT. Cutting off Coal, however, causes a net emissions increase of 73.2 MT globally. For other sectors, the emissions impact is much lower, with a maximum emissions change of 0.2 MT.

Table 2 GDP and Emissions Impact of Trade Cut-Off per Sector, Australia Exports to China

Sector	AU ΔGDP	CN ΔGDP ($ millions)	Global ΔGDP ($ millions)	AU ΔCO_2 (MT)	CN ΔCO_2 (MT)	Global ΔCO_2 (MT)
Ores	–6,173.9	–151,296.0	–130,115.7	12.8	–123.8	–24.7
Coal	–732.6	–5,522.6	–5,162.5	4.0	54.2	73.2
Non–ferrous metals	–417.6	–1,104.6	–1,389.3	–3.1	0.6	–0.2
Other grains	–58.0	–1,358.6	–1,468.9	–0.2	–0.2	0.2
Land and pipeline transport	–56.2	–415.7	–461.5	–0.3	–0.2	0.0
Fibres crops	–54.2	–424.8	–579.6	–0.4	–0.1	0.2
Meat of ruminants	–50.8	–419.0	–440.9	–0.1	–0.2	–0.1
Recreation services	–47.2	–367.7	–385.5	0.0	–0.3	0.0
Animal fibres	–42.5	–319.8	–990.0	–0.3	–0.2	–0.1

Air transport	–39.7	–347.2	–317.3	–0.9	0.1	0.1
Miscellaneous animal products	–39.4	–789.8	–802.2	–0.1	–0.2	0.0
Motor vehicle services	–31.6	–250.3	–257.5	–0.1	–0.4	–0.1
Hospitality services	–28.3	–219.4	–226.8	0.0	–0.2	–0.1
Medicinal products	–24.7	–119.8	–135.8	0.0	0.0	0.0
Prepared and preserved food products	–21.8	–176.8	–196.6	0.0	–0.1	0.0
Financial intermediation	–20.9	–83.2	–87.0	0.0	–0.2	–0.1
Dairy products	–20.6	–107.3	–121.8	0.0	0.0	0.0
Real estate activities	–18.9	–63.3	–70.6	0.0	–0.1	0.0
Paper and paper products	–18.2	–77.7	–84.0	0.0	0.0	0.1
Chemicals and chemical products	–18.0	–100.4	–106.9	–0.1	0.0	0.1
Human health and social work	–17.7	–288.7	–312.7	0.0	–0.1	0.0
Forestry products	–16.3	–114.1	–117.2	–0.1	–0.1	–0.1
Insurance	–16.1	–109.3	–105.7	0.0	–0.1	0.0
Other business services	–15.1	–143.3	–151.4	0.0	–0.2	–0.1
Information and communication	–13.4	–96.8	–103.7	0.0	–0.1	0.0
Water transport	–12.8	–76.4	–89.2	–0.1	0.0	0.0
Electronic and optical products	–12.2	–76.2	–80.4	0.0	0.0	0.0
Warehousing and support activities	–11.5	–61.7	–70.0	0.0	–0.1	0.0
Oil seeds	–11.1	–140.7	–142.4	0.0	0.0	0.0
Wheat	–10.3	–112.8	–119.6	0.0	0.0	0.0

Government services	–10.0	–84.6	–94.1	0.0	0.0	0.0
Machinery and equipment	–9.3	–71.3	–75.3	0.0	0.0	0.0
Education	–8.9	–227.2	–239.8	0.0	–0.1	0.0
Other manufactures	–6.8	–50.8	–54.9	0.0	0.0	0.0
Forestry and forestry services	–5.2	–116.9	–108.1	–0.1	–0.1	–0.2
Water management	–5.1	–18.8	–21.8	0.0	0.0	0.0
Motor vehicles	–4.9	–42.5	–42.7	0.0	0.0	0.0
Rubber and plastic products	–4.5	–39.6	–42.1	0.0	0.0	0.0
Vegetable oils	–4.5	–22.3	–27.8	0.0	0.0	0.0
Electrical equipment	–4.0	–26.0	–28.4	0.0	0.0	0.0
Sugar	–3.9	–32.8	–37.7	0.0	0.0	0.0
Cattle	–3.9	–171.2	–173.0	0.0	–0.1	–0.1
Fishing services	–2.9	–64.0	–65.8	0.0	0.0	0.0
Vegetables and fruits	–2.8	–56.1	–56.2	0.0	0.0	0.0
Leather products	–2.3	–12.5	–13.9	0.0	0.0	0.0
Fabricated metal products	–2.3	–13.6	–14.9	0.0	0.0	0.0
Textiles	–1.9	–11.6	–14.3	0.0	0.0	0.0
Ferrous metals	–1.5	–6.4	–7.2	0.0	0.0	0.0
Apparel	–1.3	–9.0	–10.0	0.0	0.0	0.0
Stimulant and aromatic crops	–1.2	–17.0	–17.7	0.0	0.0	0.0
Non–metallic minerals	–0.9	–5.2	–5.6	0.0	0.0	0.0
Gas and gas extraction	–0.5	–3.3	–11.0	0.0	0.0	0.0
Transport equipment	–0.5	–8.4	–8.3	0.0	0.0	0.0

Construction and dwellings	–0.4	–2.2	–2.3	0.0	0.0	0.0
Other meat	–0.2	–1.4	–1.7	0.0	0.0	0.0
Processed rice	0.0	–0.1	0.0	0.0	0.0	0.0
Milk	0.0	–0.1	–0.1	0.0	0.0	0.0
Electricity	0.0	0.0	–0.1	0.0	0.0	0.0
Rice	0.0	0.0	0.0	0.0	0.0	0.0
Sugar crops	0.0	0.0	0.0	0.0	0.0	0.0
Oil and oil extraction	0.0	–0.3	–0.3	0.0	0.0	0.0
Petroleum and coke products	6.5	–82.4	–72.6	0.0	–0.1	–0.1
Beverages and tobacco products	7.5	–261.4	–239.7	0.0	–0.1	0.0

AU = Australia, CN = China.
Source: Authors' own estimation.

4.1.2 Impact of cutting off the flow of imports from China to Australia

Table 3 illustrates the effect of cutting off the flow of imports from China to Australia on GDP and emissions in Australia, China and the world. As with Table 2, column (1) lists each sector in descending order ranked by the size of Australian GDP change arising from stopping trade, as shown in column (2). Column (3) displays the corresponding GDP change in China and column (4) displays the net GDP change for the whole world. Columns (4) and (5) list the emissions change resulting from ceasing trade in each sector in Australia and China, respectively. Column (6) lists the net emissions change in the world.

In contrast to Table 2, there are no sectors in which Australia sees increased GDP following trade cessation. Column (2) lists three sectors in which Australian GDP decreases by more than A$1 billion: Electronic and Optical Products, reducing GDP by A$3.52 billion; Apparel, reducing GDP by A$2.23 billion; and Electrical Equipment, reducing GDP by A$1.04 billion. These manufactures correspond to the largest flows of products from China to Australia.

In 60 of 63 sectors, Australian GDP contracts by more than Chinese GDP. When exports of Chinese oil and oil extraction are stopped, China loses A$0.311 million, whereas Australia loses A$0.233 million. China's GDP losses are A$837 million when

Electronic and Optical Products exports are stopped, A$196 million for Apparel and A$269 million for Electrical Equipment. In these sectors, the GDP loss for China is 4.20, 11.4 and 3.88 times smaller than the GDP loss for Australia, respectively. There are also several sectors where China sees GDP increases following stopped trade, most notably including Land and Pipeline Transport, where China gains A$7.7 million while Australia loses A$156 million.

Table 3 GDP and Emissions Impact of Trade Cut-Off per sector, China Exports to Australia

Sector	AU ΔGDP ($ millions)	CN ΔGDP ($ millions)	Global ΔGDP ($ millions)	AU ΔCO_2 (MT)	CN ΔCO_2 (MT)	Global ΔCO_2 (MT)
Electronic and optical products	–3,516.4	–837.3	–3,711.1	–0.5	0.7	1.9
Apparel	–2,232.9	–196.4	–2,142.5	–0.1	0.3	0.3
Electrical equipment	–1,044.4	–269.0	–1,045.9	–0.2	–0.2	0.1
Machinery and equipment	–950.4	–286.7	–994.3	–0.1	–0.1	0.4
Other manufactures	–885.9	–192.3	–903.1	0.0	0.2	0.4
Rubber and plastic products	–696.8	–190.0	–747.3	0.0	–0.2	0.0
Fabricated metal products	–653.0	–178.6	–690.0	0.0	–0.3	–0.1
Chemicals and chemical products	–545.7	–199.7	–601.5	0.0	–0.9	–0.8
Petroleum and coke products	–492.1	–94.9	–527.7	–1.0	0.1	–1.1
Leather products	–483.1	–65.5	–431.0	–0.1	0.1	0.2
Textiles	–412.8	–73.1	–405.5	0.0	–0.1	0.0

Non–metallic minerals	–335.3	–91.4	–358.5	0.2	–0.8	–0.3
Paper and paper products	–310.1	–78.0	–333.7	0.0	–0.1	0.0
Prepared and preserved food products	–307.8	–19.6	–292.5	0.0	0.1	0.1
Ferrous metals	–220.0	–58.3	–224.6	0.0	–0.5	–0.1
Non–ferrous metals	–203.2	–77.2	–237.7	0.0	–0.3	–0.1
Motor vehicles	–186.8	–80.5	–205.7	0.0	0.0	0.1
Transport equipment	–183.3	–56.4	–192.9	0.0	0.0	0.1
Land and pipeline transport	–155.5	7.7	–115.6	0.1	0.0	0.2
Medicinal products	–144.1	–50.0	–157.4	0.0	0.1	0.1
Other business services	–138.2	–0.4	–116.4	0.0	0.1	0.1
Beverages and tobacco products	–133.6	–2.6	–135.6	0.0	0.0	0.0
Forestry products	–102.0	–27.9	–112.2	0.0	0.0	0.0
Air transport	–95.5	–14.7	–84.3	0.1	–0.1	0.1
Human health and social work	–61.1	–5.9	–55.2	0.0	0.0	0.0
Motor vehicle services	–54.7	8.5	–38.5	0.0	0.1	0.1
Recreation services	–51.3	–0.8	–43.9	0.0	0.0	0.0
Hospitality services	–47.7	0.4	–41.2	0.0	0.0	0.0
Information	–43.1	–2.3	–37.2	0.0	0.0	0.0

and communicatio n						
Ores	–42.2	–2.4	–40.9	–0.1	0.0	0.0
Education	–41.0	–1.0	–34.5	0.0	0.0	0.0
Vegetables and fruits	–21.9	0.0	–24.5	0.0	0.0	0.0
Miscellaneous animal products	–21.5	–0.2	–22.3	0.0	0.0	0.0
Real estate activities	–20.3	0.4	–16.3	0.0	0.0	0.0
Water transport	–12.2	–1.6	–10.1	0.0	0.0	0.0
Insurance	–12.0	–0.1	–9.6	0.0	0.0	0.0
Stimulant and aromatic crops	–9.1	1.3	–8.0	0.0	0.0	0.0
Sugar	–6.6	–0.8	–6.7	0.0	0.0	0.0
Fishing services	–5.7	–0.1	–5.6	0.0	0.0	0.0
Warehousing and support activities	–4.5	–0.2	–3.9	0.0	0.0	0.0
Vegetable oils	–3.7	–1.4	-4.3	0.0	0.0	0.0
Construction and dwellings	–3.7	–0.2	–3.0	0.0	0.0	0.0
Financial intermediation	–3.5	0.5	–2.6	0.0	0.0	0.0
Animal fibres	–3.4	–0.3	–7.8	0.0	0.0	0.0
Processed rice	–3.3	–0.4	–3.7	0.0	0.0	0.0
Government services	–2.5	–0.1	–2.1	0.0	0.0	0.0
Oil seeds	–2.1	–0.3	–2.5	0.0	0.0	0.0
Dairy products	–1.6	–0.5	–1.8	0.0	0.0	0.0
Water management	–1.1	0.2	–0.9	0.0	0.0	0.0
Other grains	–1.0	0.0	–1.0	0.0	0.0	0.0

Other meat	–0.9	–0.1	–0.8	0.0	0.0	0.0
Forestry and forestry services	–0.8	0.0	–0.8	0.0	0.0	0.0
Meat of ruminants	–0.8	–0.2	–1.1	0.0	0.0	0.0
Cattle	–0.3	0.0	–0.3	0.0	0.0	0.0
Oil and oil extraction	–0.2	–0.3	–0.6	0.0	0.0	0.0
Milk	–0.2	0.0	–0.2	0.0	0.0	0.0
Rice	–0.2	0.1	–0.1	–0.6	0.0	–0.6
Gas and gas extraction	–0.2	0.1	0.3	0.0	0.1	0.1
Coal	–0.1	0.0	–0.1	0.0	0.0	0.0
Wheat	–0.1	0.0	–0.1	0.0	0.0	0.0
Fibres crops	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	0.0	0.0	0.0	0.0	0.0	0.0
Sugar crops	0.0	0.0	0.0	0.0	0.0	0.0

Source: Authors' own estimation.

GDP changes at the global level generally exceed those of Australia. In the top three sectors, the global GDP loss is A$195 million larger, A$90.4 million smaller and A$1.5 million larger than the Australian GDP loss in Electronic and Optical Products, Apparel and Electrical Equipment, respectively.

The emissions impact of stopping Chinese exports to Australia is also considerably less significant than that of stopping Australian exports to China. As columns (5) and (6) show, no sector accounts for an emissions change greater than 1 MT in either Australia or China, with the majority of sectors recording emissions changes of less than 0.05 MT. The maximum of a 1 MT reduction in Australia comes from stopping Chinese exports of Petroleum and Coke Products. This corresponds with an emissions increase of 0.1 MT in China.

In several other sectors, cutting off Chinese imports to Australia also results in significantly larger emission increases in China than in Australia. For instance, cutting off Electronic and Optical Products causes Australian emissions to decrease by 0.5 MT, while increasing by 0.7 MT in China. In Apparel, the disparity is smaller, with a

0.1 MT reduction in Australia in contrast to a 0.3 MT increase in China. An opposite effect is observed in Non-Metallic Minerals, where Australian emissions increase by 0.2 MT, while Chinese emissions decrease by 0.8 MT.

When the emission changes for all sectors are combined, Australia sees an overall emissions reduction of 2.3 MT, while China's emissions reduce by 1.5 MT. Taking Table 2 into account, Australia is more likely to see emissions benefits by cutting off trade with China in both imports and exports. Such emissions reductions, however, should be carefully correlated with the decline in GDP.

At the global level, cutting off trade also results in net emissions changes lower than 0.05 MT for most sectors. The largest emissions change comes in Electronic and Optical Products, with a 1.9 MT increase.

4.2 Trade, economic and environmental impacts of alternative markets for Australia

4.2.1 Impact on trade from cutting of Australia's exports to China

Table 4 shows the effect on the proportion of total Australian exports going to each region, in each of six key sectors. Column (1) lists the destination regions for Australian exports. Columns (3) to (20) list each region's absolute value and percentage share of exports before and after cutting off trade with China in that sector. The final row lists Australia's total exports in each sector, in US$ millions.

Overall, export growth to ASEAN and India tends to lag other established markets such as the European Union (EU) and UK, Developed Asia, and the US. In these key sectors, the results indicate that ASEAN and India are unlikely to 'leapfrog' these markets to compensate for the loss of the Chinese market.

The largest changes in both absolute values and percentage shares are seen in Ores, where cutting off the Chinese market equates to eliminating A$51.7 billion in demand. Developed Asia subsequently grows from 23.7% of total Australian Ores exports to become the largest source of demand, accounting for 75.3% of the total. This is a larger proportion of demand than that of China prior to the cut-off, but at A$32.1 billion in absolute terms, this market share is 62.1% of China's pre-cut-off demand. No other markets, including ASEAN and India, account for more than 8.5% of the total. The total absolute value of Australian Ores exports thus decreases to 58.2% of the pre-cut-off level.

Large changes in export market share are also seen for Animal Fibres, with the total absolute value of Australian Animal Fibres exports dropping to 52.2% of the pre-cut-off level, a larger drop than for Ores. ASEAN and India account for a combined A$157 million increase in demand, a figure exceeded by the EU and UK's A$199 million increase. Rather than ASEAN or India, the EU and UK move from the second-largest combined market (the destination for 11.5% of exports) to become the largest (at 39.5%), followed by Developed Asia. The collective increase in demand from non-China markets – A$476 million – is outweighed more than three times over by the loss of the Chinese market, which otherwise accounted for A$1.52 billion.

Similar changes are observed in Other Grains. Total Australian exports in this sector fall to 45.2% of pre-cut-off levels, larger than the fall for Ores and Animal Fibres. For Other Grains exports from Australia, the rest of the world collectively become the largest source of demand, accounting for 50.6% of export demand. Developed Asia is the next largest market, accounting for 36.9% of exports, with no other markets accounting for more than 4.6% of the total. Although the rest of the world and Developed Asia combined purchase an additional A$180 million worth of Australian Other Grains exports, this figure represents just 14.5% of the value of the Chinese market.

Table 4. Australian Exports per Sector per Region pre- and post-trade cut-off with China,

(A$ millions and %)

		Other grains			Meat of ruminants			Animal fibres			Coal			Gas and gas extraction			Ores		
		Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ
China	(A$ mn)	1,247	0	–1,247	1,117	0	–1,117	1,521	0	-1,521	13,087	0	–13,087	70	0	–70	51,686	0	–51,686
	(%)	65.7	0.0	–65.7	11.1	0.0	–11.1	69.6	0.0	–69.6	23.4	0.0	–23.4	0.6	0.0	–0.6	70.6	0.0	–70.6
Hong Kong	(A$ mn)	0	0	0	223	241	18	0	0	0	57	81	24	17	17	0	0	0	0
	(%)	0.0	0.0	0.0	2.2	2.5	0.3	0.0	0.0	0.0	0.1	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0
ASEAN	(A$ mn)	23	31	7	879	942	63	85	142	57	1281	1739	458	62	62	0	1,051	2,409	1,359
	(%)	1.2	3.6	2.4	8.8	9.9	1.1	3.9	12.4	8.5	2.3	3.3	1.1	0.5	0.5	0.0	1.4	5.7	4.2
Developed Asia	(A$ mn)	239	316	77	3,061	3,231	170	86	148	62	28,848	33,556	4,708	11,148	11,211	62	17,326	32,117	14,791
	(%)	12.6	36.9	24.3	30.5	33.9	3.4	3.9	13.0	9.0	51.5	64.4	12.9	96.3	96.9	0.6	23.7	75.3	51.7
India	(A$ mn)	5	6	1	1	1	0	173	273	100	7,560	9,781	2,221	1	1	0	1,015	2,543	1,528
	(%)	0.2	0.7	0.4	0.0	0.0	0.0	7.9	23.9	16.0	13.5	18.8	5.3	0.0	0.0	0.0	1.4	6.0	4.6
South Asia	(A$ mn)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
US	(A$ mn)	1	2	0	2649	2825	177	9	16	7	1	1	0	38	38	0	231	586	354
	(%)	0.1	0.2	0.1	26.4	29.7	3.3	0.4	1.4	1.0	0.0	0.0	0.0	0.3	0.3	0.0	0.3	1.4	1.1
Canada	(A$ mn)	17	23	6	262	282	20	3	6	3	449	577	127	3	3	0	115	273	158
	(%)	0.9	2.7	1.8	2.6	3.0	0.4	0.2	0.5	0.4	0.8	1.1	0.3	0.0	0.0	0.0	0.2	0.6	0.5
Central and South America	(A$ mn)	0	1	0	108	118	10	1	1	1	943	1208	265	7	7	0	36	101	65
	(%)	0.0	0.1	0.0	1.1	1.2	0.2	0.0	0.1	0.1	1.7	2.3	0.6	0.1	0.1	0.0	0.0	0.2	0.2
EU + UK	(A$ mn)	4	6	1	381	414	33	252	451	199	2912	3939	1027	153	154	1	1384	3603	2219
	(%)	0.2	0.7	0.4	3.8	4.3	0.6	11.5	39.5	28.0	5.2	7.6	2.4	1.3	1.3	0.0	1.9	8.5	6.6
Non-EU Europe	(A$ mn)	0	0	0	116	126	10	0	1	0	95	138	43	32	32	0	19	50	31
	(%)	0.0	0.0	0.0	1.2	1.3	0.2	0.0	0.1	0.1	0.2	0.3	0.1	0.3	0.3	0.0	0.0	0.1	0.1
Africa	(A$ mn)	30	39	10	148	160	12	31	56	25	59	82	23	5	5	0	33	96	63
	(%)	1.6	4.6	3.0	1.5	1.7	0.2	1.4	4.9	3.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.2	0.2
Rest of world	(A$ mn)	330	434	104	1100	1186	86	26	47	22	748	1,039	291	38	38	0	343	858	516
	(%)	17.4	50.6	33.2	11.0	12.5	1.5	1.2	4.1	3.0	1.3	2.0	0.7	0.3	0.3	0.0	0.5	2.0	1.5
Total value of exports	(US$ mn)	1,896	857	–1,040	10,044	9,526	–518	2187	1,142	–1,045	56,041	52,142	–3,899	11,574	11,568	–5	73,238	42,637	–30,601

ASEAN = Association of Southeast Asian Nations, EU = European Union, UK = United Kingdom, US = United States.
NB: The size of current natural gas exports is not reflected in results because a large proportion of Australia's natural gas exports from the east coast did not exist in 2014.
Source: Authors' own estimation.

In contrast, for Coal and Meat of Ruminants, regions other than China can compensate for the loss of the Chinese market. In Coal, cutting off the Chinese market means India moves from the third-largest market to second-largest (18.8%) after Developed Asia (64.4%). Combined, the absolute increase in Coal imports by regions other than China equate to A$9.19 billion, or 70.2% of the value previously imported by China.

For Meat of Ruminants, ASEAN and India play a smaller role in picking up demand after cutting off Australia–China trade compared to the US, Developed Asia and the rest of the world. ASEAN and India's increased imports of Australian products in this sector are A$62.8 million, with India's imports growing by less than A$0.1 million. Lost Chinese demand is primarily compensated for by other regions, in which increased demand makes up for 53.6% of the lost Chinese market.

In these two sectors, however, China was the destination for a substantially smaller proportion of Australian exports prior to shutting down bilateral trade.

4.2.2 Economic and emission impacts of cutting of Australia's exports to China

Table 5 presents the GDP and CO_2 emissions impacts of relocating Australian exports in key sectors away from China. Column (1) lists the regions, while columns (2) to (7) list the GDP change per region following the relocation of trade away from China in each of six key sectors discussed in Table 4. Negative values indicate GDP losses, while positive values indicate GDP gains. Columns (8) to (13) list the CO_2 emissions changes following trade relocation in the same six sectors. Negative values indicate decreased CO_2 emissions, while positive values indicate increased CO_2 emissions.

Columns (2) to (7) show that the GDP impacts for countries other than Australia and China are mixed. For instance, ASEAN's GDP declines in four of six sectors when Australian exports to China are rerouted. India, meanwhile, sees GDP losses in five of six sectors. Where there are GDP gains, the largest tend to be in established markets such as Developed Asia, the US, or the EU and UK. In sectors such as Other Grains and Animal Fibres, diverting Australian exports away from China causes almost all regions to incur GDP losses.

Consistent with Table 2, the GDP impacts of relocating Australian exports of Ores away from China are the largest amongst the six sectors. Column (7) indicates that, aside from Australia and China, Hong Kong and India both lose A$7.9 million

and A$342 million in GDP, respectively. Of 14 regions, 10 experience GDP gains, including ASEAN (A$305 million), but these are vastly outweighed by China's A$151 billion GDP loss, which, on its own, causes world GDP to fall by a net A$130 billion. The largest GDP gains are made by the EU and UK (A$7.29 billion), Central and South America (A$5.30 billion), and the US (A$4.31 billion).

Column (5) lists the GDP changes associated with redirecting Australian Coal exports away from China. Here, nine of 14 regions see GDP growth, including ASEAN (A$11.8 million) and India (A$84.4 million). However, these are significantly smaller than GDP gains made by Developed Asia and the EU and UK, which see GDP growth of A$644 million and A$325 million, respectively.

In Other Grains (column [1]), redirecting Australia's exports away from China induces GDP contractions in all regions except the US, which grows its GDP by A$10.1 million. ASEAN loses A$3.5 million in GDP, while India loses A$5.7 million. Similarly, in Animal Fibres, the GDP impact tends to be negative for most regions, including ASEAN and India.

For Meat of Ruminants, Developed Asia, Central and South America, the EU and UK, and Africa see GDP gains of A$32.4 million, A$9.4 million, A$4.6 million and A$2.0 million, respectively. Hong Kong's GDP experiences no change, with the remaining regions all declining in GDP.

In terms of emissions, diversification of Australian exports has significant effects in Ores and Coal. Column (13) shows that while China's emissions decrease by 124 MT, all other regions' emissions increase by 0.1 MT (South Asia) to 16.3 MT (Developed Asia). The latter emissions change is the second-largest after China's. In Coal, all regions experience emissions increases, with the exception of ASEAN, Canada, non-EU European economies, and the rest of the world. Outside China, the only region with an emissions change in the double digits is Developed Asia. In other sectors, no regions outside Australia and China experience emissions changes greater than 0.25 MT, except for the US, which increases its emissions by 0.263 MT when Australian exports of Other Grains are redirected.

Table 5. Economic and Emissions Impact of Diversifying Australian Exports away from China

	ΔGDP (A$ millions/%)						ΔCO_2 (Mt)					
	Other grains	**Meat of ruminants**	**Animal fibres**	**Coal**	**Gas and gas extraction**	**Ores**	**Other grains**	**Meat of ruminants**	**Animal fibres**	**Coal**	**Gas and gas extraction**	**Ores**
Australia	–58.0	–50.8	–42.5	–732.6	–0.5	–6,173.9	–0.2	–0.1	–0.3	4.0	0.0	12.8
China	–1,358.6	–419.0	–319.8	–5,522.6	–3.3	–151,296.0	–0.2	–0.2	–0.2	54.2	0.0	–123.8
Hong Kong	–0.1	0.0	0.0	0.2	0.0	–7.9	0.0	0.0	0.0	0.0	0.0	0.7
ASEAN	–3.5	–0.8	–4.5	11.8	–0.2	305.0	0.0	0.0	0.0	–1.3	0.0	3.2
Developed Asia	–1.8	32.4	–10.7	644.1	–0.1	2,843.3	0.1	0.1	0.1	12.3	0.0	16.3
India	–5.7	–0.3	–9.0	84.4	0.0	–341.9	0.1	0.0	0.1	5.3	0.0	7.4
South Asia	–0.4	–0.1	–0.3	–0.5	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.1
US	10.1	–11.3	–12.7	30.7	0.0	4,305.6	0.3	0.0	0.0	1.3	0.0	8.6
Canada	–2.3	–2.6	–1.8	11.0	0.0	1,584.7	0.0	0.0	0.0	–0.1	0.0	2.5
Central and South America	–3.3	9.4	8.6	6.3	–0.1	5,295.1	0.0	0.0	0.1	0.4	0.0	14.1
EU + UK	–32.4	4.6	–596.4	324.5	–0.6	7,291.7	0.1	0.0	–0.1	1.6	0.0	3.0
Non-EU Europe	–7.0	–3.0	–15.5	–13.4	–6.9	1,640.6	0.0	0.0	0.0	–0.3	0.0	7.9
Africa	–1.2	2.0	11.9	–15.3	0.1	2,695.2	0.0	0.0	0.1	0.1	0.0	14.5
Rest of world	–4.6	–1.5	2.8	9.0	0.6	1,736.1	0.0	0.1	0.1	–4.3	0.0	8.1
World Total	**–1,468.9**	**–440.9**	**–990.0**	**–5,162.5**	**–11.0**	**–130,115.7**	**0.2**	**–0.1**	**–0.1**	**73.2**	**0.0**	**–24.7**

ASEAN = Association of Southeast Asian Nations, EU = European Union, GDP = gross domestic product, UK = United Kingdom, US = United States.
Source: Authors' own estimation.

4.2.3 Investment needed in the diversification of Australian exports

Table 6 lists the change in capital goods investment needed in each region to diversify Australian exports in each sector away from China. Column (1) lists the regions, and columns (2) to (7) list the change in investment required per region after cutting off trade with China in the key sectors outlined in Table 4. Positive values indicate increased investment requirements while negative values indicate decreased investment requirements.

The largest investment changes, predictably, are seen in Australia and China. In almost all sectors, rerouting Australian exports to markets other than China results in significant reductions in investment. This is particularly accentuated in the case of Ores, where China's investment decreases by A$30.0 billion and Australia's by A$3.27 billion. The size of China's investment decrease is also substantially larger than Australia's. The sole exception is in Animal Fibres, where redirecting Australian exports away from China results in a A$177 million investment reduction in Australia, but a A$236 million investment increase in China.

Table 6. Capital Goods Investment Change per Region after Cutting Off Exports to China

(A$ millions)

	Other grains	Meat of ruminants	Animal fibres	Coal	Gas and gas extraction	Ores
Australia	–167	–50	–177	–2,762	–3	–32,746
China	–1,083	–327	236	–7,017	–3	–299,907
Hong Kong	0	–4	0	6	0	336
ASEAN	–15	–24	7	278	0	3,615
Developed Asia	–43	–64	5	2,849	1	24,410
India	7	18	–9	765	0	–3,326
South Asia	–1	0	0	12	0	–2
US	850	–26	–132	1,240	2	55,259
Canada	15	0	–12	189	0	7,953
Central and South America	28	14	34	184	0	23,860
EU + UK	–59	454	7	1,428	–1	36,933
Non-EU Europe	0	–19	–1	108	0	8,113
Africa	6	40	–2	42	0	8,050
Rest of world	–4	–45	25	173	1	6,534

ASEAN = Association of Southeast Asian Nations, EU = European Union, UK = United Kingdom, US = United States.

Source: Authors' own estimation.

The picture is more mixed for other regions. Investment in ASEAN reduces by A$15 million and A$24 million, respectively, when Australian exports of Other Grains or Meat of Ruminants to China are blocked. However, ASEAN's demand for investment increases by A$7 million, A$278 million and A$3.62 billion, respectively, when Australian exports of Animal Fibres, Coal and Ores are rerouted away from China.

Investment requirements in India grow most substantially (A$765 million) when Australia–China trade in Coal is blocked, and, to a lesser extent, in the cases of Other Grains (A$7 million) and Meat of Ruminants (A$18 million). When Australia–China trade in Animal Fibres and Ores is cut off, Indian investment demand declines by A$9 million and A$3.33 billion, respectively. In Ores specifically, India's investment decline is exceeded only by Australia and China's.

Cutting off Australia–China trade in Ores results in especially large investment in the US (A$55.3 billion), the EU and UK (A$36.9 billion) and Developed Asia (A$24.4 billion). These regions also gain the most in the case of Coal trade cut-off. Central and South America would require increased investment in all cases where Australia–China trade in any of the six key sectors is cut off.

4.3. Trade, economic and environmental impacts of Australia's alternative supply chains

As COVID-19 has exposed Australia's dependence on China and the ongoing trade disputes undermine its trust, there have been significant discussions that it should reduce its dependence for suppliers including medical products. In this section, we investigate the changes of trade flow following key supplies from China being cut off. The trade flow changes will be the optimal alternative supply chains as computed by the model, and thus can provide pragmatic information on this issue. The corresponding trade flow changes in other countries and economic and emissions for all regions are also examined.

4.3.1. Trade changes after cutting off Australia's imports from China

Table 7 displays the effects of the HEM on the market share of Australia's key import sources after cutting off trade with China in each of five key sectors. The key sectors were selected based on their significance in Table 3 or prominence in debate around Australian strategic dependence on imported products. Column (1) lists the

source regions for imports to Australia. Columns (3) to (15) list the percentage share of imports from each region per sector prior to cutting off trade with China. Columns (7) to (11) list the percentage share per region per sector after cutting off trade with China. The final row lists the total value of Australian imports in each sector.

A point of disparity between Table 4 and Table 7 is evident in their final rows, indicating total exports and total imports per sector, respectively. Whereas Australia's total exports in each sector decline significantly following the stopping of trade (Table 4), Australia's total imports in each sector tend to increase by a much smaller margin, essentially maintaining existing levels of imports, with the exception of Electronic and Optical Products (Table 7). Common to both tables, however, is that after China's share of total exports or imports falls to zero, the distribution of market shares tends to reflect the pattern before the change, with regions retaining their market share positions relative to each other. Compared to Table 4, ASEAN plays a stronger role in compensating for redirected Chinese trade by becoming the top supplier in two of five key sectors. India, while also increasing its exports to Australia, plays a less dominant role by comparison.

In Table 7, Apparel experiences the greatest changes in regional market share, increasing by between 3.3 times and 3.5 times following trade cut-off with China. ASEAN becomes the leading exporter, supplying 26.1% of total Australian Apparel consumption compared to 7.6% previously. ASEAN, India, and South Asia's combined increase in Apparel exports is A$2.70 billion, or 55.6% of supply originally imported from China. The remaining slack in supply is primarily taken up by the EU and UK, the rest of the world and the US, which boost their exports by a further A$1.62 billion.

In Electronic and Optical Products, all regions boost their market share in Australia. ASEAN again becomes the leading supplier, with 31.3% of the Australian market, increasing its exports to Australia by A$4.47 billion. India's increase is around 10 times smaller at A$45 million. Combined, the increase in imports from regions other than China equates to 97.1% of the value previously imported from China.

In Electrical Equipment, all regions increase their market share. ASEAN accounts for 16.5% of the market, taking third place to the EU and UK and the US. The value of ASEAN and India's increased exports to Australia sum to A$817 million, equivalent to 18.8% of lost trade with China. A similar pattern is seen in Machinery

and Equipment.

In Medicinal Products – a sector prominent in strategic discourse – it is notable that, even prior to the stopping of trade, China supplied 8.3% of Australia's imports, worth A$653 million in absolute terms. The EU and UK, which, prior to trade cut-off, accounted for more than 50% of Medicinal Products imports, increases their shares greatly, equating to a A$414 million increase in absolute value. ASEAN and India's combined growth in exports amounts to A$43 million, around 10 times smaller than the EU and UK's.

Table 7. Amount (Share) of Australian Imports per Sector per Region before and after Trade Cut-Off with China

(%)

		Apparel			Medicinal products			Electronic and optical equipment			Electrical equipment			Machinery and equipment		
		Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ
China	(A$ mn)	4,847	0	–4,847	653	0	–653	14,750	0	–14,750	4,322	0	–4,322	4,020	0	–4,020
	(%)	70.7	0.0	–70.7	8.3	0.0	–8.3	54.4	0.0	–54.4	39.4	0.0	–39.4	19.0	0.0	–19.0
Hong Kong	(A$ mn)	19	66	47	5	6	0	14	30	16	1	1	1	2	2	0
	(%)	0.3	1.0	0.7	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
ASEAN	(A$ mn)	523	1,796	1,273	277	303	26	3,880	8,350	4,469	1,103	1,837	734	3,096	3,807	711
	(%)	7.6	26.1	18.4	3.5	3.9	0.3	14.3	31.3	17.0	10.1	16.5	6.5	14.6	18.0	3.4
Developed Asia	(A$ mn)	48	167	119	88	96	8	1,564	3,395	1,831	941	1,577	636	2,586	3,196	610
	(%)	0.7	2.4	1.7	1.1	1.2	0.1	5.8	12.7	6.9	8.6	14.2	5.6	12.2	15.1	2.9
India	(A$ mn)	169	585	415	180	196	17	38	84	45	123	206	83	125	154	30
	(%)	2.5	8.5	6.0	2.3	2.5	0.2	0.1	0.3	0.2	1.1	1.9	0.7	0.6	0.7	0.1
South Asia	(A$ mn)	429	1,437	1,008	0	0	0	0	0	0	0	0	0	0	0	0
	(%)	6.3	20.9	14.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
US	(A$ mn)	107	373	266	677	741	64	3,023	6,547	3,524	1,258	2,109	851	3,976	4,914	938
	(%)	1.6	5.4	3.8	8.6	9.4	0.8	11.2	24.5	13.4	11.5	19.0	7.5	18.8	23.2	4.4
Canada	(A$ mn)	24	82	58	74	82	7	474	1,026	552	229	384	155	496	613	117
	(%)	0.3	1.2	0.8	1.0	1.0	0.1	1.8	3.8	2.1	2.1	3.5	1.4	2.3	2.9	0.6
Central and South America	(A$ mn)	53	183	131	35	38	3	35	77	42	37	62	25	120	149	29
	(%)	0.8	2.7	1.9	0.4	0.5	0.0	0.1	0.3	0.2	0.3	0.6	0.2	0.6	0.7	0.1
EU + UK	(A$ mn)	283	980	697	4,427	4,841	414	2,695	5,832	3,137	2,410	4,036	1,626	5,924	7,320	1,396
	(%)	4.1	14.2	10.1	56.6	61.7	5.1	9.9	21.8	11.9	22.0	36.3	14.3	28.0	34.6	6.6

Non–EU	(A$ mn)	15	51	36	1,279	1,399	120	398	862	464	168	282	114	222	275	53
Europe	(%)	0.2	0.7	0.5	16.4	17.8	1.5	1.5	3.2	1.8	1.5	2.5	1.0	1.1	1.3	0.2
	(A$ mn)	67	234	166	22	24	2	22	47	25	23	39	16	62	76	15
Africa	(%)	1.0	3.4	2.4	0.3	0.3	0.0	0.1	0.2	0.1	0.2	0.3	0.1	0.3	0.4	0.1
	(A$ mn)	273	939	667	107	118	10	206	445	240	350	584	234	541	668	127
Rest of world	(%)	4.0	13.6	9.7	1.4	1.5	0.1	0.8	1.7	0.9	3.2	5.3	2.1	2.6	3.2	0.6
Total value of imports	(A$ mn)	6,857	6,892	36	7,824	7,843	20	27,101	26,696	–404	10,965	11,116	150	21,170	21,174	4

ASEAN = Association of Southeast Asian Nations, EU = European Union, UK = United Kingdom, US = United States.
Source: Authors' own estimation.

4.3.2. Economic and emission impacts after cutting off Australia's imports from China

Similar to Table 5, Table 8 presents the GDP and CO_2 emissions impacts of sourcing Australia's imports in key sectors from regions other than China. Column (1) lists the regions, and columns (2) to (6) list the GDP changes for each region in each of the five key sectors in Table 7. Positive values denote GDP increases, while negative denote GDP decreases. Columns (7) to (11) list the CO_2 emissions changes for each region in the five sectors, with positive values indicating increased emissions and negative values indicating decreased emissions.

In Table 8, a majority of regions (excepting Australia and China) see GDP gains after Australia–China supply chains are rerouted in each sector. In particular, ASEAN gains in four out of five sectors, while India gains in all five. Overall, however, India's GDP gains tend to be smaller than that of ASEAN or other, more established, suppliers.

As expected, GDP tends to increase in the regions from which Australia imports a larger proportion of the total in each sector after blocking Chinese exports. For instance, after diversifying Australia's imports of Electronic and Optical Goods away from China, the absolute value of US exports in this sector to Australia grows by A$3.52 billion and its GDP increases by A$202 million (column [4], Table 8).

Similarly, the EU and UK's combined GDP increases by A$114 million when it boosts it exports of Electrical Equipment to Australia by A$1.63 billion. And overall, no region's absolute GDP change exceeds that of Australia or China.

However, there are exceptions to this pattern. Despite growing its exports of Apparel to Australia by A$266 million, the US' GDP contracts by A$7.1 million overall. This phenomenon is particularly noticeable in the Medicinal Products sector, with four out of 12 regions registering a similar result. In particular, whereas India boosts both its GDP and exports to Australia (by A$1.8 million and A$17 million, respectively), ASEAN's GDP falls by A$0.4 million, despite increasing sectoral exports by A$26 million. Similarly, non-EU European economies' collective GDP declines by A$4.8 million, even as exports of Medicinal Products increase by A$120 million.

Table 8. Economic and Emissions Impact of Diversify Australian Imports away from China

	ΔGDP (A$ millions)					ΔCO_2 (Mt)				
	Apparel	**Medicinal products**	**Electronic and optical products**	**Electrical equipment**	**Machinery and equipment**	**Apparel**	**Medicinal products**	**Electronic and optical products**	**Electrical equipment**	**Machinery and equipment**
Australia	–2,232.9	–144.1	–3,516.4	–1,044.4	–950.4	–0.1	0.0	–0.5	–0.2	–0.1
China	–196.4	–50.0	–837.3	–269.0	–286.7	0.3	0.1	0.7	–0.2	–0.1
Hong Kong	0.0	0.0	–0.1	–0.1	0.0	0.0	0.0	0.0	0.0	0.0
ASEAN	35.5	–0.4	40.8	11.7	12.8	0.1	0.0	0.3	0.1	0.1
Developed Asia	13.9	–1.2	71.1	29.1	30.1	–0.1	0.0	0.4	0.1	0.1
India	16.7	1.8	4.2	11.3	6.6	0.0	0.0	0.2	0.0	0.1
South Asia	34.0	0.1	1.1	0.7	0.5	0.0	0.0	0.0	0.0	0.0
US	–7.1	10.8	201.8	45.6	42.2	0.0	0.0	0.6	0.1	0.2
Canada	14.4	1.1	39.1	11.5	9.5	0.0	0.0	0.1	0.0	0.0
Central and South America	15.6	–0.8	21.4	7.9	8.7	0.0	0.0	0.0	0.0	0.0
EU + UK	56.7	25.9	200.0	113.6	105.6	0.0	0.0	0.1	0.1	0.1
Non-EU	15.1	–4.8	1.4	0.1	0.4	0.0	0.0	0.0	0.0	0.0

Europe										
Africa	34.6	1.9	26.2	12.6	10.5	0.0	0.0	0.0	0.0	0.0
Rest of world	57.5	2.3	35.8	23.5	15.9	0.1	0.0	0.1	0.0	0.0
World Total	**–2,142.5**	**–157.4**	**–3,711.1**	**–1,045.9**	**–994.3**	**0.3**	**0.1**	**1.9**	**0.1**	**0.4**

ASEAN = Association of Southeast Asian Nations, EU = European Union, GDP == gross domestic product, UK = United Kingdom, US = United States.
Source: Authors' own estimation.

Columns (2) to (6) also indicate that the US, and the EU (with UK) regions tend to experience the largest GDP gains from Australia redirecting its supply chains away from China. In some sectors, this occurs even if they do not become the largest exporters in those sectors or have the largest increase in the absolute value of their exports in that sector. For example, in Electronic and Optical Goods, the US and the EU (with UK) regions increase the absolute value of their exports by A$3.52 billion and A$3.14 billion, respectively. These increases come in at second and third place to ASEAN's A$4.47 billion export growth in the same sector, but this is not reflected in changes to the regions' GDP. The US' GDP expands by A$202 million and the EU and UK's expands by A$200 million, but ASEAN's expands by a significantly smaller A$40.8 million.

In terms of emissions impacts, relocating supply chains to regions outside China tends to have relatively small effects. The largest emissions change outside China of a 0.6 MT increase occurs in the US when Electronic and Optical Goods imports from China are cut off, followed by a 0.4 MT increase in Developed Asia in the same sector.

4.3.3. Investment needed for Australia's alternative supply chains

Table 9 lists the change in capital goods investment needed in each region to meet the new trade pattern after the stopping of trade. Column (1) lists the regions. Columns (2) to (6) list the changes in investment demand per region after cutting off Chinese imports in each of five key sectors outlined in Table 7. Positive values indicate growth in investment demand while negative values indicate the opposite.

As with Table 6, Australia and China tend to see the largest changes in investment demand after breaking off bilateral trade in these key sectors, with Australia tending to lower investment by a greater amount than China. For example, in Electronic and Optical Products, Australia's investment falls by A$4.05 billion, compared to a 2.5 times smaller drop of A$1.63 billion for China. In Machinery and Equipment, the gap is even larger, with Australia's A$1.32 billion investment decrease outweighing China's by 3.7 times. Two exceptions are in Medicinal Products, where Australia's investment decrease is 160 times smaller than China's A$320 million, and Apparel, where Australia in fact increases investment by A$129 million, whereas China decreases investment by A$955 million.

Turning to other key regions, ASEAN and India, which are often seen as alternate supply chain bases to China, would both see increased investment demand in scenarios where any of the key import sectors are relocated away from China. Redirecting Apparel supply chains, for instance, would see ASEAN and India pick up an additional A$114 million and A$112 million in investment, respectively. Cross-referencing this with Table 7, it can be seen that ASEAN increases the value of its Apparel exports to Australia by close to three times as much as India. South Asia, while increasing investment by slightly more than India, also increases the value of its Apparel exports to Australia by more than double compared to India.

Table 9. Capital Goods Investment Change per Import Sector per Region after Trade Cut Off with China

(%)

	Apparel	**Medicinal products**	**Electronic and optical products**	**Electrical equipment**	**Machinery and equipment**
Australia	129	–2	–4,054	–1,256	–1,320
China	–955	–320	–1,630	–565	–357
Hong Kong	6	–1	12	8	6
ASEAN	114	1	340	72	56
Developed Asia	–77	–27	479	175	153
India	112	8	77	51	40
South Asia	138	–1	3	2	2
US	10	123	1,270	377	327
Canada	16	–6	175	44	31
Central and South America	17	–12	98	31	29
EU + UK	–28	131	519	236	186
Non–EU Europe	–2	6	60	11	8
Africa	32	–6	43	10	7
Rest of world	36	–16	79	28	23

ASEAN = Association of Southeast Asian Nations, EU = European Union, UK = United Kingdom, US = United States.
Source: Authors' own estimation.

Australia–China trade cut-offs in other sectors have mixed implications for ASEAN and India's capital goods investments. In the case of Medicinal products, ASEAN and India's combined investment increase is A$9 million. The US and the EU and UK, however, see investment growth of A$123 million and A$131 million, respectively. To a lesser extent, this pattern is also seen in Electrical Equipment and Machinery and Equipment. In Electronic and Optical Products, despite attracting a smaller increase in investment compared to Developed Asia, the US and the EU and UK, ASEAN sees the largest gain in exports to Australia in this sector (Table 7).

5. Discussion and implications for globalisation and regional economic integration

While our study focuses on the case of Australia–China trade, it has general implications for other countries, particularly those that have close economic relationships with China. One issue that can gain illumination from our study is globalisation and regional economic integration, which has been undermined by the US trade policy under the Trump administration and Brexit in the UK. While the Asia–Pacific region stood against this deglobalisation by signing the Regional Comprehensive Economic Partnership in November 2020, some countries may expect to benefit from trade frictions against China by competing for China's markets.

One survey of Indian businesses, for instance, found that 69% expected global manufacturing to shift from China to India (Federation of Indian Chambers of Commerce and Industry and Dhruva Advisors, 2020). In November 2020, the Indian government extended a A$6 billion Production-Linked Incentive (PLI) scheme to incentivise localised manufacturing in targeted sectors, including batteries, electronics, cars, pharmaceuticals, telecommunications, textiles, food, solar modules, white goods and steel (Press Information Bureau, 2020).

Government support efforts in some sectors are directly tied to shifting supply chains away from China. In December 2020, the Indian government's telecom and IT minister, Ravi Shankar Prasad, said that a goal of the PLI scheme would be to 'surpass China' in manufacturing mobile devices (Press Trust of India, 2020). The PLI scheme

has also extended further support worth A$1.3 billion for manufacturers of active pharmaceutical ingredients, reportedly in response to global perceptions of over-dependence on Chinese supply chains (The Pharma Letter, 2021).

ASEAN economies such as Thailand and Malaysia have also implemented policies incentivising rerouting of supply chains through their respective jurisdictions. Thailand's government introduced in April 2020 its Thailand Plus Package consisting of tax benefits for foreign manufacturers (KPMG, 2020). In 2019, Malaysia also implemented tax breaks and subsidies worth A$240 million targeting selected foreign manufacturers (Muramatsu, 2019).

Our study generates the following implications:

First, despite global supply chains being revealed to be vulnerable, deglobalisation is not a rational solution. The global supply chains can bring both economic and environmental benefits for the world overall and for the participating countries. This has also been demonstrated by the impacts of trade cuts between Australia and China. Even though the trade size is not comparable with that between China and ASEAN, or the EU and the US, the cut will bring significant economic and environmental losses for both countries and the world.

Second, ad hoc diversification of imports or exports may not be a rational solution. A deliberate diversification will work against world trade dynamics and thus will incur economic and environmental costs as our simulation suggests that, while some receiving countries may benefit from supply chain diversification, there is a dead-weight loss for the global community. This cost can be illustrated by the difference in technology, labour skills and industry cluster. It takes time for new suppliers to become as efficient as those that have honed their processes for decades. On the contrary, alternative suppliers may have lower levels in technology, skills and even environmental standards; thus, relocating supply chains will lead to lower economic and environmental performance. In the case of China, an ecosystem of suppliers and product designers with an extensive domestic workforce make it a global leader in sectors such as telecommunications and low-carbon technologies (Goldthau and Hughes, 2020).

Third, regional integration should be upheld rather than doubted. While the pandemic reveals the vulnerability of global supply chains, it also shows their resilience. Initial shortages were due to a reduction in production capacity and/or feedstocks.

Diversification from China will not solve these issues unless alternative supply chains are always safer than China, which is not necessarily true as the ongoing pandemic proves. Despite efforts to move supply chains away from China in early 2020, China has since emerged as one of the most reliable suppliers. Regional coordination could include the optimisation of regional production networks and safeguarding of environmental standards to avoid the shift of polluting industries within the region.

Last, a collaborative approach to preparing for pandemics and other disasters is desirable. Problems with supply chains can be mitigated by sharing of technologies, production capacity and even stocks. The COVID-19 vaccination development case demonstrates that deglobalisation is not appropriate. Most countries lack domestic capacity to produce vaccines and thus global coordination in vaccination distribution is widely welcomed. Our results suggest that East Asia should defend the rules-based trading regime and continuously promote regional economic integration, a view that was strongly proposed by trade economists such as Kimura (2019). Moreover, East Asian countries should join hands in defending the rule-based trading regime and associated international supply chains. Our results suggest that although all countries gain market share from China's absence in Australia's trade, their economic impact is mixed. For example, while Australia's exports to China are cut in each of the six key sectors, ASEAN's GDP contracts in four of the six sectoral-cut cases and India's GDP contracts in five of the six sectoral cases. This suggests that no countries should add fuel to the fire.

6. Conclusion and policy implications

The shocks from COVID-19, coupled with ongoing US–China tension, generated the issue of supply chain resilience with China at the centre of the storm. Many analysts and even governments are actively promoting the relocation of supply chains away from China. Such interventions in supply chains will undermine the global trade regime and the economic integration, in particular in East Asia, which has significantly benefited from integrated regional production networks. While advocators are optimistic about reorganising supply chains, the complexity of GVCs and integration of the global economy may suggest that the impact will be unexpected.

In this study, we examine debates on supply chain resilience, and the economic and emissions impact of rerouting supply chains using Australia and China trade as an example. We first identify the most vulnerable supply chains between Australia and China. It augments HEM by replacing traditional I/O analysis with a CGE analysis. We select GDP and emission changes as the key indicators in our analysis, and rank Australia's exports to China and imports from China to Australia sector by sector separately. The ranking provides an indication of the importance of each sector in the bilateral trade. It also studies the supply chain reorganisation in key Austria–China trading sectors when these trades are forced to cut off individually.

The estimation results demonstrate that, in both export and import cases, a trade embargo between Australia and China, despite being compensated by alternative supply chains, will cause GDP loss and emissions increases for both countries and the world total. The losses are diversified across the sectors due to reasons such as the size and substitution of the affected trade.

Further analysis of the GVC reorganisation after the Australia–China trade decoupling in the six key Australian export sectors and five key importing sectors found that although all other countries gain in the markets left by China, many of them suffer from overall GDP losses and emissions increases. The impact on trade flows is more significant for decoupling of Australia's exports than its imports. A total trade cut of Australia's exports to China by sector will result in a reduction of Australia's exports of each of these sectors by about 40%. This suggests that no other countries can replace the Chinese markets for Australia exports. In contrast, in the case of Australia's imports from China, a zero trade between Australia and China will not see much change in Australia's imports, which suggests that its imports from China can be substituted, despite the fact that prices may be higher. While Australian blocking of imports from China would result in the need for increased investment in most regions, including ASEAN and India, Australia's embargo of exports to China would have mixed effects on investment for most regions, including China and India. For example, ASEAN and India, which are expected to benefit from Australia's decoupling from China, would actually lose in four and five out of six, respectively, amongst the total six sectoral cases.

The results suggest that countries need to defend the rules-based trading regime and continuously promote regional economic integration. The finding that ASEAN and China may also suffer from Australia–China trade decoupling despite gains in trade volume suggests that no country should add fuel to the fire.

One caveat of our study is the reference year does not reflect the current situation. The current version of the GTAP model uses the global economic system in 2014 as the reference. Although it can predict the relative change and direction for various policy scenarios, it cannot represent the current situation. For example, since Australia's large proportion of liquefied natural gas exports only started in 2015, our estimation by sector will not capture the importance of gas trade. Future studies could further calibrate the key indicators to the year 2019 for more precise estimations.

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Appendix

List of sectors in the GTAP Database, v10

	Code	Description
1	pdr	Rice: seed, paddy (not husked)
2	wht	Wheat: seed, other
3	gro	Other Grains: maize (corn), sorghum, barley, rye, oats, millets, other cereals
4	v_f	Veg & Fruit: vegetables, fruit and nuts, edible roots and tubers, pulses
5	osd	Oil Seeds: oil seeds and oleaginous fruit
6	c_b	Cane & Beet: sugar crops
7	pfb	Fibres crops
8	ocr	Other Crops: stimulant; spice and aromatic crops; forage products; plants and parts of plants used primarily in perfumery, pharmacy, or for insecticidal, fungicidal or similar purposes; beet seeds (excluding sugar beet seeds) and seeds of forage plants; natural rubber in primary forms or in plates, sheets or strip, living plants; cut flowers and flower buds; flower seeds, unmanufactured tobacco; other raw vegetable materials n.e.c.
9	ctl	Cattle: bovine animals, live, other ruminants, horses and other equines, bovine semen
10	oap	Other Animal Products: swine; poultry; other live animals; eggs of hens or other birds in shell, fresh; reproductive materials of animals; natural honey; snails, fresh, chilled, frozen, dried, salted or in brine, except sea snails; edible products of animal origin n.e.c.; hides, skins and fur skins, raw; insect waxes and spermaceti, whether or not refined or coloured
11	rmk	Raw milk
12	wol	Wool: wool, silk, and other raw animal materials used in textile
13	frs	Forestry: forestry, logging and related service activities
14	fsh	Fishing: hunting, trapping and game propagation including related service activities, fishing, fish farms; service activities incidental to fishing
15	coa	Coal: mining and agglomeration of hard coal, lignite and peat
16	oil	Oil: extraction of crude petroleum, service activities incidental to oil and gas extraction excluding surveying (part)
17	gas	Gas: extraction of natural gas, service activities incidental to oil and gas

		extraction excluding surveying (part)
18	oxt	Other Mining Extraction (formerly omn): mining of metal ores; other mining and quarrying
19	cmt	Cattle Meat: fresh or chilled; meat of buffalo, fresh or chilled; meat of sheep, fresh or chilled; meat of goat, fresh or chilled; meat of camels and camelids, fresh or chilled; meat of horses and other equines, fresh or chilled; other meat of mammals, fresh or chilled; meat of mammals, frozen; edible offal of mammals, fresh, chilled or frozen
20	omt	Other Meat: meat of pigs, fresh or chilled; meat of rabbits and hares, fresh or chilled; meat of poultry, fresh or chilled; meat of poultry, frozen; edible offal of poultry, fresh, chilled or frozen; other meat and edible offal, fresh, chilled or frozen; preserves and preparations of meat, meat offal or blood; flours, meals and pellets of meat or meat offal, inedible; greaves
21	vol	Vegetable Oils: margarine and similar preparations; cotton linters; oil-cake and other residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; vegetable waxes, except triglycerides; degras; residues resulting from the treatment of fatty substances or animal or vegetable waxes; animal fats
22	mil	Milk: dairy products
23	pcr	Processed Rice: semi- or wholly milled, or husked
24	sgr	Sugar and molasses
25	ofd	Other Food: prepared and preserved fish, crustaceans, molluscs and other aquatic invertebrates; prepared and preserved vegetables, pulses and potatoes; prepared and preserved fruits and nuts; wheat and meslin flour; other cereal flours; groats, meal and pellets of wheat and other cereals; other cereal grain products (including corn flakes); other vegetable flours and meals; mixes and doughs for the preparation of bakers'wares; starches and starch products; sugars and sugar syrups n.e.c.; preparations used in animal feeding; lucerne (alfalfa) meal and pellets; bakery products; cocoa, chocolate and sugar confectionery; macaroni, noodles, couscous and similar farinaceous products; food products n.e.c.
26	b_t	Beverages and Tobacco products
27	tex	Manufacture of textiles
28	wap	Manufacture of wearing apparel

29	lea	Manufacture of leather and related products
30	lum	Lumber: manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
31	ppp	Paper & Paper Products: includes printing and reproduction of recorded media
32	p_c	Petroleum & Coke: manufacture of coke and refined petroleum products
33	chm	Manufacture of chemicals and chemical products
34	bph	Manufacture of pharmaceuticals, medicinal chemical and botanical products
35	rpp	Manufacture of rubber and plastics products
36	nmm	Manufacture of other non-metallic mineral products
37	i_s	Iron & Steel: basic production and casting
38	nfm	Non-Ferrous Metals: production and casting of copper, aluminium, zinc, lead, gold, and silver
39	fmp	Manufacture of fabricated metal products, except machinery and equipment
40	ele	Manufacture of computer, electronic and optical products
41	eeq	Manufacture of electrical equipment
42	ome	Manufacture of machinery and equipment n.e.c.
43	mvh	Manufacture of motor vehicles, trailers and semi-trailers
44	otn	Manufacture of other transport equipment
45	omf	Other Manufacturing: includes furniture
46	ely	Electricity; steam and air conditioning supply
47	gdt	Gas manufacture, distribution
48	wtr	Water supply; sewerage, waste management and remediation activities
49	cns	Construction: building houses factories offices and roads
50	trd	Wholesale and retail trade; repair of motor vehicles and motorcycles
51	afs	Accommodation, Food and service activities
52	otp	Land transport and transport via pipelines
53	wtp	Water transport
54	atp	Air transport
55	whs	Warehousing and support activities
56	cmn	Information and communication
57	ofi	Other Financial Intermediation: includes auxiliary activities but not insurance and pension funding

58	ins	Insurance (formerly isr): includes pension funding, except compulsory social security
59	rsa	Real estate activities
60	obs	Other Business Services nec
61	ros	Recreation & Other Services: recreational, cultural and sporting activities, other service activities; private households with employed persons (servants)
62	osg	Other Services (Government): public administration and defense; compulsory social security, activities of membership organisations n.e.c., extra-territorial organisations and bodies
63	edu	Education
64	hht	Human health and social work
65	dwe	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)

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