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ORIGINAL ARTICLE

Inter-sectoral economic linkages in the Australian mining industry: Analysis using partial hypothetical extraction method

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Abstract

The mining industry is not only one of Australia's main economic sectors but also one that the country is considered to have managed well. However, little is known about the industry's potential to contribute to the structural change of Australia's economy. We use the national input–output (IO) tables and apply the partial hypothetical extraction method (P-HEM) within both the Leontief and Gosh IO frameworks to examine the inter-sectoral linkages of the Australian mining and quarrying sector. Ee find that this sector demonstrates strong backward linkages (BL), but forward linkages (FL) appear to be weak, and they mainly involve non-metallic materials. The mining and quarrying sector appears to generate linkages with the business services sector and the construction sector, which can potentially contribute to diversifying the economy. Such linkages may be realised via skilling and reallocating skilled labour and technical supplier capacity as well as via developing physical infrastructure that supports existing and new economic sectors. We find that the identified linkage pathways via the construction sector are tied to energy-intensive but coal-dependent sectors. Thus, these pathways are vulnerable because of the climate-related need to move away from combusting coal and invest in cleaner sources of energy.

KEYWORDS

economic transformation, industrialisation, productivity, renewable energy, steel

JEL CLASSIFICATION

Q32, L16, D57, O14, O25

1 | INTRODUCTION

Economic development hinges on the ability of an economy to efficiently utilise its resource endowments. Different schools of thought envisage continuous economic development as a process of economic transformation characterised by structural changes to production and employment (Schlogl & Sumner, 2020). Economic transformation occurs when the reallocation of resources increases productivity and induces industrialisation and diversification (Elhiraika et al., 2019). Part of this process is inter-sectoral linkages—the demand and supply of intermediate products between different industries (Sposi, 2019). According to Hirschman (1958), this concept is premised on the potential of industries to procure inputs (backward linkages (BL)) and sell outputs (forward linkages (FL)) to other industries, which generates multiplier effects in the wider economy. To understand how inter-sectoral linkages might contribute to economic diversification, it is necessary to conceptualise resource endowments very broadly, considering natural resources, human capital and technological and institutional capabilities (Weldegiorgis et al., 2021). This paper analyses inter-sectoral linkages with the mining industry within the overall Australian economy, as one part of several factors that could potentially contribute to economic transformation through diversification.

The industrial mining sector with its large-scale capital-intensive investments often dominates national exports while also substantially contributing to fiscal income and, to a much lesser extent, also to employment. Empirical work conducted in developing countries has found that countries with a large share of raw material exports typically experience limited productivity-enhancing structural change (McMillan et al., 2014). This finding also reflects experiences of many Latin American countries where the mining sector has grown but inter-sectoral linkages have been limited (Olvera & Foster-McGregor, 2018). Similarly, countries in Africa have experienced structural changes in their economies because resources have been reallocated from agriculture to non-manufacturing industries. But this change has not helped to move away from exporting primary commodities, especially because the mines can be operated as enclaves in isolation from the rest of the economy (Carmignani & Mandeville, 2014). Therefore, it can be conjectured that whether and how the mining sector links to the broader economy matters for economic diversification and ultimately structural transformation.

Resource-rich countries in Latin America and Africa have been looking towards Australia as a country that has done well on the back of its mining industry. Against this backdrop, we undertake an analysis of inter-sectoral linkages in the Australian economy to investigate the extent to which Australia has done well in leveraging the mining sector to develop other economic sectors. Australia is endowed with a broad range of mineral resources and ranks among the top 10 countries in the world in terms of deposit and/or production of 36 commodities (Senior et al., 2021). For example, Geoscience Australia (GOA, 2023) reports that in 2021 Australia was the largest global producer of lithium (with 53% share of global production), iron ore (36%), rutile (26%), bauxite (27%) and zircon (30%), the second largest producer of lead (11%) and gold (10%); and the third largest producer of manganese ore (11%), Black coal (8%), zinc (10%) and cobalt (3%). The mining sector attracts the largest proportion of foreign direct investment (FDI) into the country, having generated AUD 360.4 billion worth of FDI (35% of total) in 2020 (DFAT, 2021). Currently, more than 55 companies exploit the various resources in about 350 operational mines (MCA, 2021). The Australian quarry industry has 2200 quarries producing 200 million tonnes of rock, limestone, gravel and sand, which goes to the production of 12.5 million tonnes of cement and 29 million metre cube of concrete per year (CCAA, 2023). The industry accounts for 30,000 direct and 80,000 indirect employments and AUD 15 billion in annual revenue (CCAA, 2023).

The Australian Bureau of Statistics (ABS) defines the mining sector to include coal, metallic minerals, non-metallic minerals, exploration and other mining support services, and oil and gas extraction. In 2020/21, this sector accounted for a share of 9.9% of GDP and was the second most dominant economic sector behind the services sector, which contributed a share of 60.7% to GDP (DISER, 2021a). The mining sector also generated direct employment for an average total of 219,108 persons over the period 2007–2021 (ABS, 2021). Excluding non-metallic minerals, the sector is largely export-oriented: A dominant share of the minerals produced leave the country to be used as production inputs elsewhere (Schandl et al., 2008). For example, Australia's export of unprocessed raw bauxite has grown by 50% between 2010 and 2019, costing the country an estimated AUD 2660 per tonne in lost value added (Stanford, 2020). In 2018/19, primary (unprocessed) mineral exports made up 69% of total mining-related exports, with the share rising to 76% when processed minerals excluding manufactured products are taken into account (DFAT, 2020). The large proportion of unprocessed mineral exports can be seen as a lost opportunity in terms of value addition and development of technology and innovation that could potentially have been achieved through downstream processing and manufacturing.

High energy and labour costs and currency appreciation due to an increase in resource export earnings have undermined the country's international competitiveness in downstream processing and manufacturing. Nonetheless, in 2020/21 the country generated significant export earnings from the sector, which, excluding petroleum products, amounted to approximately AUD 228 billion (DISER, 2021a). This accounted for 58% of total merchandise and 50% of total goods and services export values. Iron ore, as the top mineral export earner, provided up to 67% of the mining sector's export earnings. The sector has also been a major source of government revenues through fiscal and consumption linkages. According to the Minerals Council of Australia (MCA, 2022), the mining industry paid AUD 132 billion in company taxes, AUD 106 billion in royalties and AUD 246 billion in wages from 2010/11 to 2019/20. Mining taxation revenues accounted for 6% (AUD 39 billion) of total Australian taxation revenues (AUD 683 billion) in 2021/22, and a total royalty payment of AUD 24 billion, of which AUD 13.8 billion (58%) came from fossil fuels (Buckley, 2022; Ernst & Young, 2023). This revenue stream is expected to grow as demand for Australian minerals is poised to increase, including for fossil fuels (at least in the next decade or so) and potentially critical minerals.

Compared with other jurisdictions, Australia's stable policies and regulatory conditions and several sector-focussed government initiatives and public–private partnerships make it a preferred trading partner, not least because geopolitical developments have given rise to security of supply concerns, especially among those countries that are concerned about supply dependence on Russia and China. In addition, Australia has an advanced upstream supplier base supported by the Mining Equipment, Technologies and Services (METS) sector, which consists of (1) *specialised* suppliers, which provide services such as mine construction, geological survey services and the manufacturing of mine-specific equipment, and (2) *non-specialised* suppliers, which provide other goods and services used in the mining supply chain, such as financial, travel and accommodation services, that are not only specific to mining but also used by other sectors (METS Ignited, 2019). The METS sector has become crucial to leveraging mining for economic development, in addition to policies and programs that have aimed at developing a highly skilled labour force, supporting innovation and boosting local content and other industry development initiatives.

This paper addresses three research questions, namely: (i) how is the mining and quarrying sector (M&Q, hereafter) interlinked within the Australian economy; and which are the economic sectors that M&Q interacts with most? (ii) what is the extent of the sector's interdependence with the most significant other economic sectors? And (iii) are the sector's inter-sectoral linkages contributing to economic diversification, and if so how? The paper is structured as follows: Section 2 describes the methodological background and model specification applied to measure inter-sectoral linkages. Section 3 presents the results and highlights the key findings. Section 4 discusses the results and the potential pathways for economic diversification. Section 5 concludes and provides some recommendations for future research.

2 | METHODOLOGY

An input–output (IO) analysis is a commonly used method to understand inter-sectoral linkages. Earlier work has drawn on the basic IO method with a focus on the sector's direct and total (direct and indirect) input requirements as well as its gross value-added requirements. For example, Ivanova (2014) used this method with reference to coal mining to identify key sectors within three regions in Queensland, based on a 38-sector aggregation using the 2006/07 IO tables. Around the same time, in a discussion paper published by the Reserve Bank of Australia (RBA), Rayner and Bishop (2013) applied the basic method using five of the Australian IO tables (until 2008/2009) to analyse the economic impact of the 2000s' resource boom. The drawback of the RBA's work is that it used an aggregated definition of the country's resource sector. Building on the RBA paper, Deloitte Access Economics (2017) compiled a report for the Minerals Council of Australia to estimate the economic contribution of mining using the 2012–13 Australian IO tables. More recently, Sánchez et al. (2019) applied the basic IO method using the World IO Database (WIOD) tables for 2009 to analyse the relationship between economic sectors and greenhouse gas (GHG) emissions.

This paper moves beyond the basic IO method and applies the hypothetical extraction method (HEM) to measure the inter-sectoral linkages between M&Q and the broader Australian economy. The HEM provides a more refined measure of linkages by accounting for exogenous shocks and effects on intermediate outputs instead of just the final demand and primary input (Dietzenbacher & Lahr, 2013). In the original HEM (Paelinck et al., 1965), the loss in total output resulting from a hypothetical nullification of one of the sectors (industries) in an economy (i.e. eliminating the sector's connections with the rest of the economy) indicates the total linkage of that sector with the rest of the economy. Valadkhani (2003) applied the original HEM using the 1996–97 IO table and calculated sectoral employment multipliers and elasticities to identify high employment-generating industries. However, since hypothetically nullifying an entire sector from an economic system is excessive, further refinements to HEM have provided various decompositions of total linkages into different components, including an internal effect, a mixed effect and net BL and net FL (Duarte et al., 2002; Temurshoev & Oosterhaven, 2014).

Here, we apply the partial hypothetical extraction method (P-HEM) based on Dietzenbacher & Van der Linden (1997) and distinctly measure the BL and FL based on the Leontief and Gosh models, respectively. In P-HEM, the inputs required for a sector's production (and respectively, the outputs produced) are partially extracted to measure BL (and respectively, FL), and this should reflect the respective sector's dependence on inputs (and respectively, the sale of its outputs) from the rest of the economy. This allows us to identify economic sectors that have the greatest potential to stimulate the broader economy as well as to examine inter-sectoral linkages. To the best of our knowledge, this paper is the first to apply HEM-based Leontief and Ghosh models to measure the BL and FL of M&Q and its potential to increase economic diversification. Compared with earlier mining-related research which has typically only considered BL, that is from the perspective of industries purchasing outputs of other industries, our work provides a more complete insight into the structure of the Australian economy by assessing FL seen from the perspective of industries selling outputs to other industries. This can support the development of informed and forward-looking economic policies and strategic plans.

Overall, there has been limited application of the IO method especially in the case of Australia, which could be due to the lack of data for application at the sub-national level and the method's assumption of perfect elasticity of supply (Fleming & Measham, 2014). The method only enables the identification of sectors based on the mere significance of their output-based BL and FL with the rest of the economy. As we want our analysis to go further, we first isolate those sectors that are highly linked with M&Q and analyse five of these sectors in more detail to understand the extent of these interlinkages. We then zoom out to consider the broader Australian economy and explore how these important interlinking sectors function and how they could potentially be developed to increase diversification. Another limitation relates to the concern that the Gosh model may not be an accurate measure of output-based FL as results may reflect changes in prices of primary inputs rather than changes in output (Dietzenbacher & Van der Linden, 1997). However, it is also argued that 'primary input price sensitivities are transmitted in a downstream fashion or forwardly' (Miller & Lahr, 2001: 422). There has been a debate in the literature as to how and whether the implausibility of the supply-driven Gosh model can be corrected (Guerra & Sancho, 2011; Oosterhaven, 2012). Thus, in this paper, we cautiously interpret findings related to FL.

2.1 | Model specification

We begin with an input–output model by considering n sectors of an economy, which is described by the equation $\mathrm{x} = \mathrm{Ax} + \mathrm{f}$, where $\mathrm{x} = x_i$ represents the production vector of gross output of n sectors, $\mathrm{f} = f_i$ is the vector of final demand, and $\mathrm{A} = a_{ij} \forall i, j = 1, 2, 3, \ldots, n.$ is the technology matrix (also known as input–output coefficient or direct input coefficient) denoting the output that is required in industry i as an input to produce one unit of its output. In other words, the vectorAx represents the total intermediate demand for the output of industry i. The reduced form of the model can be represented as $x = (I - A)^{-1} f$. Let $L = \left(b_{ij}\right)_{i,j} = (I - A)^{-1}$ where $(I - A)^{-1}$ is the Leontief inverse or the total requirement matrix and I is the identity matrix. The basic Leontief model is used to measure the total (direct and indirect) BL of a sector (Miller & Lahr, 2001). For instance, the element b_{ij} of the Leontief inverse represents the amount of output of industry i that is required to meet one unit of final demand in industry j, where $p'_0 = e'L$ represents the row vector of output multipliers and e' denotes the summation vector of ones (1 s).

The basic Ghosh model is used to measure direct and indirect (or total) FL (Miller & Lahr, 2001). It is expressed as $x' = v'(I - B)^{-1}$ and delivers a column with *total input multipliers Ge*, where x' is a row with total input by sector, v' is a row with total primary inputs (including imports) by sector, B is a direct output coefficient matrix (calculated as $(x)^{-1} Z$), and G is the Ghosh inverse matrix $(I - B)^{-1}$ (Temurshoev & Oosterhaven, 2014).

Therefore, the *total BL* and *total FL* can be written as, respectively:

$$BL(t)_i = \sum_{i=1}^{n} l_{ij} \quad \text{and} \quad FL(t)_i = \sum_{i=1}^{n} g_{ij} \tag{1}$$

where t refers to total (direct and indirect) linkages of sector i.

As mentioned above, since the basic IO method only accounts for effects on final demand and primary input, the hypothetical extraction approach is needed to also account for effects on intermediate output changes by isolating or exogenously specifying the elements of the sector measured to generate a relatively accurate economic linkage measure. We consider the application by Dietzenbacher and van der Linden (1997) and apply P-HEM using the closed-form analytical expressions derived in Temurshoev and Oosterhaven (2014). In this case, the column for sector i in the input coefficient matrix, denoted by A_c^{-i}, and the row for sector i in the output coefficient matrix, denoted by B_r^{-i}, are nullified. Then, using the Leontief model to estimate the backward (upstream) linkages and the Ghosh model to estimate the forward (downstream) linkages, the *corresponding absolute impacts* of the extraction of sector i equal $e'x - e'x_c^{-i}$ and $x'e - \left(x_r^{-1}\right)'e$, respectively, where $x_c^{-i} = \left(I - A_c^{-i}\right)^{-1} f$ and $\left(x_r^{-1}\right)' = v'\left(I - B_r^{-i}\right)^{-1}$. The *normalised BL* and *FL* of the *partial extraction* of sector i are then expressed as:

$$LPE_i = \frac{e'x - e'x_c^{-i}}{x_i} \times 100 \quad and \quad GSE_i = \frac{x'e - \left(x_r^{-1}\right)'e}{x_i} \times 100 \tag{2}$$

where, for simplicity, the term LPE (Leontief Power of Extraction) is used to refer to indices from the Leontief IO model based on P-HEM; and the term GSE (Ghosh Sensitivity of Extraction) is used to refer to the indices from the Ghosh IO model.

We then apply *Normalisation relative to the average* to identify the economic sectors classified as *key* sectors after partially extracting each of the sectors. In the subsequent sections, we use sector classifications according to their BL and FL strengths as indicated in Table 1. The index value of 1 (unity) is widely used as the average of the relative linkage of all sectors in a normalised form (Miller & Lahr, 2001). This stems from Hirschman's (1958) early assertion that sectors have the potential to induce economy-wide growth when they have above-average inter-sectoral linkages. Accordingly, a sector is considered *key* to the broader economy (or specific sector) when its normalised BL and FL after P-HEM are above average (>1).

2.2 | Data description

We use 10 national IO tables obtained from the ABS to analyse the linkages. These IO tables have been consistently published from 2007/08 to 2018/19, except for 2010/11 and 2011/12. The available tables are based on the Australian and New Zealand Standard Industrial Classification (ANZSIC) and cover yearly flow of intermediate inputs among 114 sectors. We defined 10 industry classifications and aggregated the 114 sectors into 42 sector groups based on ANZSIC and the classification used by the WIOD. These sector groups are coded and presented in Appendix S1, alongside the corresponding specific sectors in the ABS IO table. The literature recommends deriving an adequate aggregation of sectors because too high a degree of aggregation runs the risk that a sub-sector that is of critical importance may not be singled out, while too low a degree of aggregation means that the analysis will suffer from dealing with a lot of homogenous goods (Cabrer et al., 1991; Su et al., 2010). The consolidation of 114 sectors in 42 groups still provides a sufficient disaggregation for a robust analysis of linkages in the Australian economy.

Different from the ABS tables, we single out energy resources, namely: coal and oil and gas. On this basis, we coded 'Coal mining' as B, 'Oil and gas extraction' as C and 'M&Q' as D. M&Q comprises iron ore mining, non-ferrous metal ore mining, non-metallic mineral mining, and exploration and mining support services. Drawing on a classification that Deloitte Access Economics used based on Australia's METS sector, we isolated key M&Q-related industries for our targeted analysis aimed at discerning mining-specific linkages. These METS-related sub-sectors are underlined in Appendix S1 under 'sectors' column, where we also added an '*'

TABLE 1 Classification of sectors by their BL and FL strengths.

		GSE Index	
		Low (<1)	**High (>1)**
LPE Index	Low (<1)	Weak sectors	Strong forward linkages (selling) sectors
	High (>1)	Strong backward linkages (buying) sectors	Key sectors

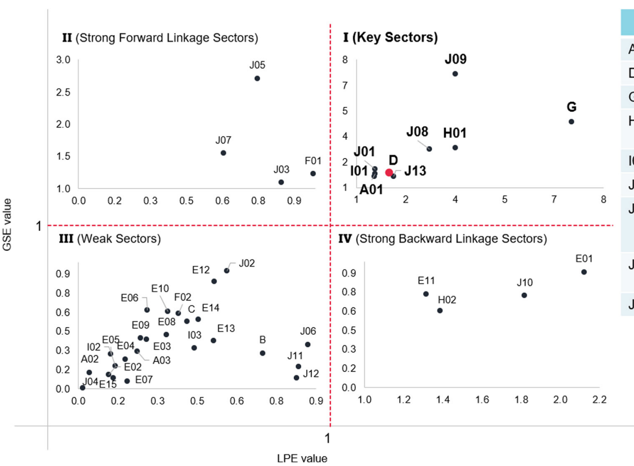
to the respective codes. Consideration of the METS sector-based classification enabled us to take full stock of (a) sectors that are specific to mineral extraction and (b) sector-related activities such as engineering and other services, as well as exploration, construction, transportation and manufacturing-related activities, including mineral processing.

3 | RESULTS

3.1 | 'Key' sectors of the economy

Our first level of analysis seeks to identify the *key* sectors to the economy based on the results of the P-HEM on each of our 42 economic sectors in turn. Identified as *key* sectors are those whose monetary input change (and respectively, output change) can cause an above-average change in output of all the upstream sectors (and, respectively, input of all the downstream sectors). If hypothetically and partially removed, these sectors can cause the highest level of disruption to the economic system, because they are either highly sensitive to or cause significant changes in other sectors. Identifying such *key* sectors underlines their policy relevance: This can inform the evaluation of economic performance *ex post*, and/or it can guide the development and implementation of national economic strategies, industrial policies and investment decisions.

Figure 1 (Quadrant I) depicts the nine sectors that are *key* to the overall economy, which are stimulated by the overall industrial production and consumption and they in turn stimulate national economic growth, more than other sectors. The four *key* sectors that stand out most in that quadrant are 'Professional, technical, scientific, and other support services' (J09); 'Real estate activities, renting and hiring of equipment & machinery and other business activities' (J08); 'Wholesale and retail trade and repair of motor vehicles and motorcycles' (H01); and Construction (G). From a BL and FL perspective, Construction (G) and 'Professional, technical, scientific, and other support services' (J09), respectively, appear to be the most important *key* sectors for the economy. While the analysis period coincides with the spikes in mining-related construction, other sectors such as real estate and transport infrastructure also have



Key Sectors	
A01	Crop and animal production
D	Mining and quarrying
G	Construction
H01	Wholesale and retail trade and repair of motor vehicles and motorcycles
I01	Land transport
J01	Postal, courier and warehouse activities
J08	Real estate activities, renting and hiring of equipment & machinery and other business activities
J09	Professional, technical, scientific, and other support services
J13	Other community, social and personal services

FIGURE 1 Most linked Australian economic sectors (2007–2019). GSE refers to Ghosh Sensitivity of Extraction (level of FL) and LPE is Leontief Power of Extraction (level of BL). There are nine *Key* sectors to the economy (with high (>1) GSE value and high (>1) LPE value); *Weak* sectors are those with low (>1) GSE value and low (>1) LPE value; *Selling* sectors are those with high (>1) GSE value and low (<1) LPE value; and *Buying* sectors are those with high (>1) LPE value and low (<1) GSE value. [Colour figure can be viewed at wileyonlinelibrary.com]

grown in that period, as discussed in Subsection 4.1. M&Q (marked 'orange' in Quadrant I) can also be considered as a *key* sector, albeit to a lesser extent than the above-mentioned *key* sectors.

The sectors in Quadrant III are those that would cause the least disruption to other sectors if they were partially removed from the national economy. Interestingly, 'Coal mining' (B) and 'Oil and gas extraction' (C) are some of the sectors with weak links to other economic sectors. This is despite these sectors providing most of the country's energy inputs as discussed in Subsection 4.3. The reason could be that the calculations of LPE and GSE values consider a sector's strength of linkages with all other sectors in aggregation, in which case sectors such as M&Q are identified as *key* because their linkages are greater than the 'Coal mining' and 'Oil and gas extraction'. The composition of sectors as defined by the ABS could also have an impact on these results, such as the inclusion of exploration and mining support services in M&Q but not in the 'Coal mining' and 'Oil and gas extraction'.

The sectors shown in Quadrant II have strong FL (high sales of outputs to other sectors) but weak BL (low purchases of inputs from other sectors). They include 'Financial service activities, except insurance and pension funding' (J05); 'Activities auxiliary to financial services and insurance activities' (J07); and Telecommunications (J03). Meanwhile, the sectors in Quadrant IV have strong BL but weak FL. Those that experience important BL among these sectors include 'The manufacture of food products, beverages, and tobacco products' (E01); 'Public administration and defence, compulsory social security' (J10); 'Accommodation and food service activities' (H02); and 'The manufacture of basic metals' (E11).

3.2 | Inter-sectoral linkages of mining and quarrying

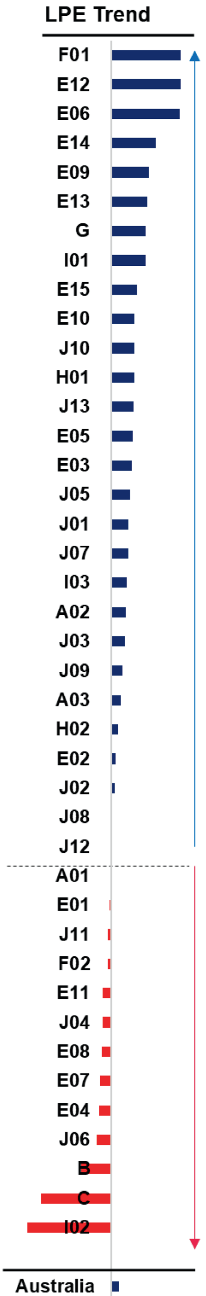
Our second level of P-HEM analysis focusses on the inter-sectoral linkages of M&Q with each of the other economic sectors over the 10-year period in consideration. Figure 2 presents the ranking of the inter-sectoral linkages of M&Q (D) with each of the other sectors based on the BL (indicating LPE values) and FL (indicating GSE values). In addition to the sector rankings, we calculated the slopes for each sector over the period in consideration to show the extent of the increasing and decreasing trends in inter-sectoral linkages (the graphs are shown in Figure 2). The top five sectors that sell inputs to M&Q (i.e. sectors with which M&Q has strong BL) include 'The manufacture of coke and refined petroleum products' (E06), 8%[1]; 'The manufacture of fabricated metal products, except machinery and equipment' (E12), 7%; 'Electricity, gas, steam, and air conditioning supply' (F01), 6%; 'Professional, technical, scientific, and other support services' (J09), 5%; and 'The manufacture of chemicals and chemical products' (E08), 5%.

The top five sectors that buy inputs from M&Q (i.e. sectors with which M&Q has strong FL) are 'The manufacture of basic metals' (E11), 48%; 'The manufacture of other non-metallic mineral products' (E10), 10%; 'Coal mining' (B) 9%; 'The manufacture of fabricated metal products, except machinery and equipment' (E12), 7%; and 'The manufacture of furniture, other manufacturing' (E15), 4%. These sectors, especially 'Coal mining', are ranked as important FL sectors largely due to their interlinkages with 'mining exploration and mining support services', which in this paper are treated as a sub-sector of M&Q. A noteworthy finding is that 'The manufacture of basic metals' (E11) is the top destination of M&Q's domestic sales: 48% of this sector's activities would suffer if M&Q were to be partially removed. However, the FL between 'The manufacture of basic metals' and M&Q

[1]The value indicates a percentage decrease in total economic activity (or total output) of the mentioned sectors (e.g. sector E06 in this case) following partial extraction of M&Q.

Backward Linkages

Rank	Sector	LPE
1	E06	8.07%
2	E12	6.48%
3	F01	5.72%
4	J09	4.61%
5	E08	4.51%
6	J07	4.34%
7	E14	4.10%
8	B	3.94%
9	I02	3.52%
10	C	3.35%
11	E10	3.32%
12	J05	2.89%
13	E05	2.81%
14	J01	2.80%
15	G	2.68%
16	E09	2.59%
17	E03	2.58%
18	I01	2.41%
19	A03	2.34%
20	A02	2.29%
21	F02	2.09%
22	E11	1.84%
23	H01	1.84%
24	J13	1.79%
25	E04	1.79%
26	J02	1.77%
27	I03	1.63%
28	J03	1.59%
29	J08	1.41%
30	E13	1.37%
31	E02	1.19%
32	H02	1.06%
33	E15	0.99%
34	J10	0.86%
35	J06	0.78%
36	E07	0.75%
37	E01	0.59%
38	A01	0.56%
39	J11	0.20%
40	J04	0.15%
41	J12	0.04%
Australia		2.49%



Forward Linkages

Rank	Sector	GSE
1	E11	48.39%
2	E10	10.13%
3	B	9.34%
4	E12	7.27%
5	E15	3.84%
6	E14	3.00%
7	E13	2.84%
8	E08	2.78%
9	G	2.68%
10	C	1.99%
11	F01	1.15%
12	E04	1.04%
13	E09	1.02%
14	E03	1.00%
15	E07	0.95%
16	E01	0.83%
17	A03	0.76%
18	J09	0.73%
19	H01	0.72%
20	J01	0.71%
21	F02	0.71%
22	I01	0.70%
23	J03	0.69%
24	E06	0.64%
25	E05	0.63%
26	A01	0.59%
27	I03	0.59%
28	J10	0.57%
29	I02	0.56%
30	J13	0.51%
31	E02	0.49%
32	H02	0.49%
33	J07	0.42%
34	J02	0.38%
35	J08	0.38%
36	A02	0.37%
37	J12	0.33%
38	J06	0.31%
39	J11	0.29%
40	J04	0.24%
41	J05	0.12%
Australia		2.33%

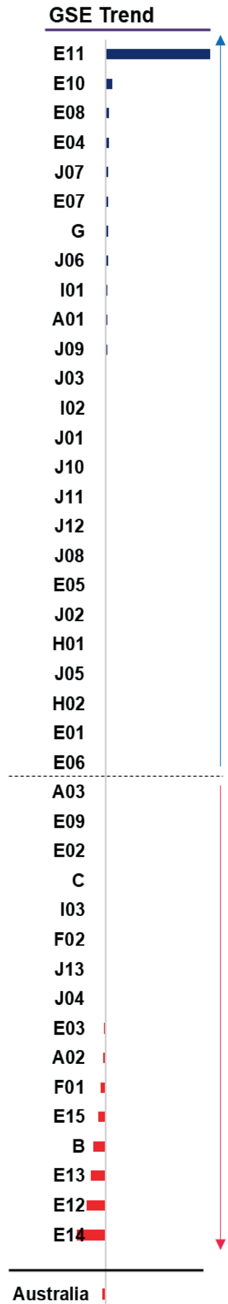


FIGURE 2 Ranking and trends of inter-sectoral BL (LPE) and FL (GSE) of the Australian M&Q (2007–2019). The values indicate a percentage decrease in total economic output of the respective sectors following partial extraction of the M&Q. So, if we consider the LPE values in the left diagram (the BL), it means only the columns are extracted to indicate the extent of the M&Q's dependency on domestic inputs. Upward-pointing blue arrows indicate increasing trend, and downward-pointing red arrows decreasing trend. [Colour figure can be viewed at wileyonlinelibrary.com]

is large only in relative terms, because about 98% of the iron ore production is exported (DISER, 2021a).

Overall, if M&Q were to be partially removed, the sectors that are most linked with it would suffer a decrease of between 5% and 9% in their activities from the perspectives of both supply (FL) and demand (BL)—except for 'The manufacture of basic metals' (E11). While this entails some dependency of individual sectors on M&Q, the dependency is low when the economy 'as a whole' is considered. Figure 2 indicates that partial removal of M&Q (D) would cause a 2.5% and 2.3% reduction in total economic output from the perspective of BL and FL, respectively. This indicates that the Australian economy 'as a whole' is not critically reliant on the Mining and quarrying sector, at least from the viewpoint of production linkages.

Figure 2 also illustrates the trend of linkages over the 10-year period of analysis. It shows that M&Q (D) experienced an increasing BL trend with 29 sectors (see blue lines with upward arrow) and a declining BL trend with the remaining 13 sectors (red lines with downward arrow). As Figure 3 shows, there has been a relatively significant increase in M&Q's purchases of inputs from 'Electricity, gas, steam, and air conditioning supply' (F01); 'The manufacture of fabricated metal products, except machinery and equipment' (E12); 'The manufacture of coke and refined petroleum products' (E06); and 'The manufacture of computer, electronic and optical products, electrical equipment, machinery and equipment' (E14), see tables of trends for all sectors in Appendix S2. Much of the increase occurred in the early 2010s before the mining downturn hit around mid-2010s, which stabilised afterwards. When the economy 'as a whole' is considered, M&Q's BL show an increasing trend. This could be due to growing mineral production requiring more domestic supply of goods and services from sectors such as those mentioned above.

For FL, M&Q (D) experienced a decreasing trend of sales to 17 sectors (see red lines with downward arrow in Figure 2) and an increasing trend of sales to the remaining 25 sectors (blue lines with upward arrow). As shown in Figure 3 (and Appendix S2), M&Q has had a relatively significant increasing trend in sales of its outputs to 'The manufacture of basic metals' (E11) and 'The manufacture of other non-metallic mineral products' (E10). The former reflects an increase in domestic and global demand for steel that resulted in the production of iron ore more than doubling in the past 10 years (Summerfield, 2020), while the latter indicates growing domestic demand for construction materials, including from M&Q which saw increased construction investments during the period of analysis. When the economy 'as a whole' is

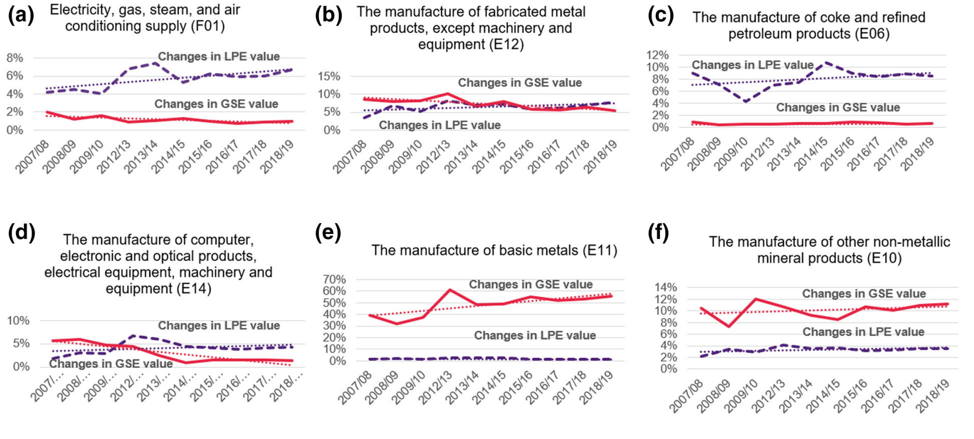


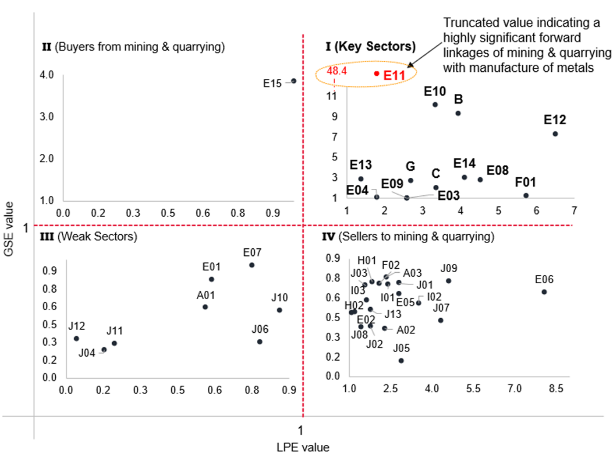
FIGURE 3 Changes in inter-sectoral BL (LPE) and FL (GSE) of the Australian M&Q with selected sectors (2007–2019). The values indicate a percentage decrease in total economic output of the respective sectors following partial extraction of M&Q. Purple broken lines indicate BL (LPE), red lines are FL (GSE), and dotted lines are trends. [Colour figure can be viewed at wileyonlinelibrary.com]

considered, M&Q has generally experienced a declining FL trend. This may be due to rising exportation of raw minerals; for example, iron ore volumes increased steadily from about 380 m tonnes in 2010/11 to about 880 m tonnes in 2020/21 (DISER, 2021b) and the effect of export earnings on currency appreciation which undermined domestic processing.

Based on the inter-sectoral linkage results shown in Figures 2 and 4 presents a classification of sectors by their level of linkages with M&Q. Focussing on Quadrant I only, there are 13 economic sectors that are *key* to M&Q with above-average (>1) GSE and LPE indices. To assess the extent to which there are interdependencies between M&Q and these sectors, we move on to analyse whether M&Q is, in turn, *key* to these sectors. We do this by selecting five of the 13 economic sectors and partially extracting each of them to analyse their linkages with other sectors, including M&Q. We select 'The manufacture of other non-metallic mineral products' (E10): 'The manufacture of basic metals' (E11); 'The manufacture of fabricated metal products, except machinery and equipment' (E12); and Construction (G) for analysis from a BL perspective, and 'Coal mining' (B) and 'The manufacture of other non-metallic mineral products' (E10) from a FL perspective.

Based on applying the P-HEM to each of the selected sectors, Figure 5a shows that M&Q (D) is the top source of the domestic inputs of 'The manufacture of basic metals' (E11). M&Q would experience a 23.7% reduction in its output if this sector were to be partially removed. 'The manufacture of fabricated metal products, except machinery and equipment' (E12) comes further up in the value chain which, based on its strong backward relationship with 'The manufacture of basic metals' (E11), has a significant indirect link, in addition to important direct link, with M&Q. Along this line, Figure 5b shows 'The manufacture of basic metals' (E11) and M&Q among the top three providers of inputs to 'The manufacture of fabricated metal products, except machinery and equipment' (E12). Similarly, Figure 5d shows that M&Q and 'The manufacture of fabricated metal products, except machinery and equipment' (E12) are among the top four input-providing sectors for 'The manufacture of other non-metallic mineral products' (E10).

While M&Q (D) is an important provider of direct inputs to Construction (G), Figure 5c,e show that it also has indirect links with Construction through 'The manufacture of other non-metallic mineral products' (E10) and 'The manufacture of fabricated metal products, except machinery and equipment' (E12). There is a strong interdependence to the extent that there would be an 80% decline in the output of 'The manufacture of other non-metallic mineral products' (E10) if Construction were to be partially removed. Meanwhile, 'The manufacture



Key Sectors	
B	Coal mining
C	Oil and gas extraction
E03	The manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
E04	The manufacture of paper and paper products
E08	The manufacture of chemicals and chemical products
E09	The manufacture of rubber and plastic products
E10	The manufacture of other non-metallic mineral products
E11	The manufacture of basic metals
E12	The manufacture of fabricated metal products, except machinery and equipment
E13	The manufacture of motor vehicles, trailers, semi-trailers, and other transport equipment
E14	The manufacture of computer, electronic and optical products; electrical equipment; machinery and equipment not elsewhere classified
F01	Electricity, gas, steam and air conditioning supply
G	Construction

FIGURE 4 Inter-sectoral linkages of the Australian M&Q (2007–2019). There are 13 *Key* sectors for M&Q in both BL and FL. [Colour figure can be viewed at wileyonlinelibrary.com]

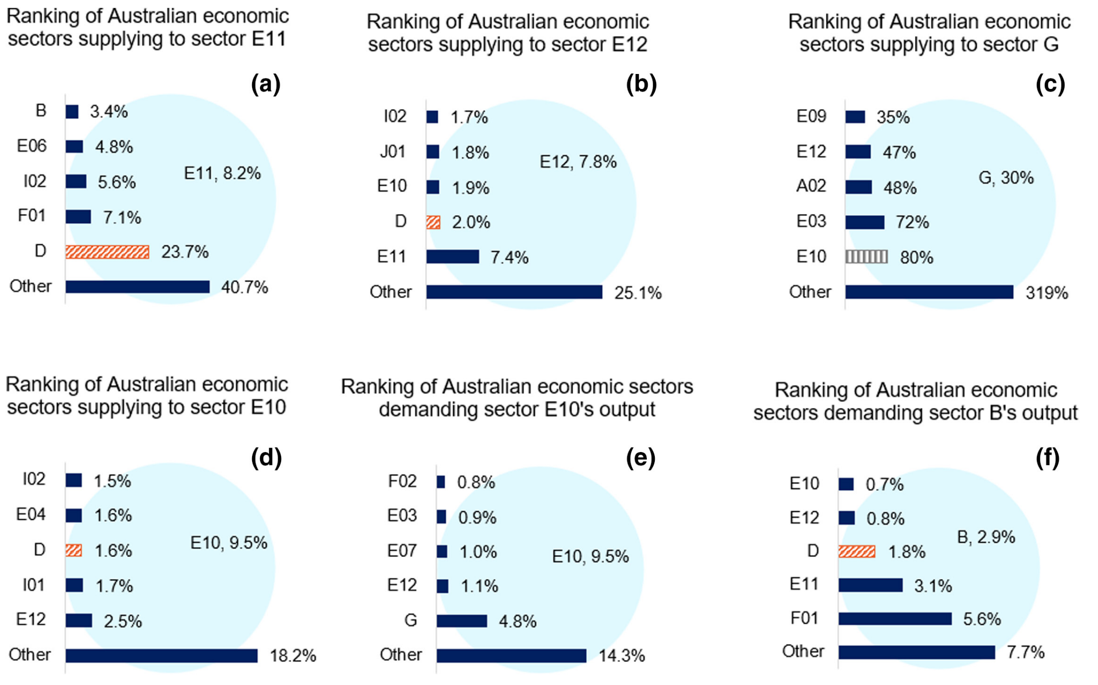
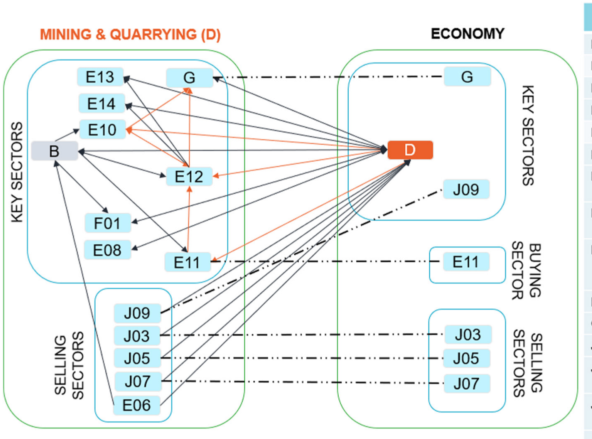


FIGURE 5 Ranking of Australian economic sectors by their linkages to selected sectors. P-HEM conducted on each of the five sectors, with the pale blue circles indicating linkage values of each of these extracted sectors with themselves. Columns indicate the linkage values of the other sectors with the extracted sector. Sectors E10 (The manufacture of other non-metallic mineral products), E11 (The manufacture of basic metals), E12 (The manufacture of fabricated metal products, except machinery and equipment) and G (Construction), B (Coal mining) and D (M&Q). [Colour figure can be viewed at wileyonlinelibrary.com]

of fabricated metal products, except machinery and equipment' (E12) is one of the top five providers of inputs to Construction, in addition to being the second important destination of sales from the 'The manufacture of other non-metallic mineral products' (E10). It would face a 47% reduction in output if Construction were to be partially removed. From a FL perspective, Figure 5f shows that these manufacturing sectors and M&Q are among the top five *key* sectors directly purchasing outputs from 'Coal mining' (B). In summary, M&Q has direct and indirect linkage importance to all five selected sectors.

4 | POTENTIAL PATHWAYS FOR ECONOMIC DIVERSIFICATION

The previous subsections demonstrated the linkages of M&Q (D) with other sectors and with the economy 'as a whole'. This discussion section drills down to investigate whether M&Q's inter-sectoral linkages could potentially provide a basis for increasing economic diversification. Based on the main findings presented in Figures 1, 4 and 5 and summarised in Figure 6, three notable results are examined below to (i) understand the extent of interdependence between the sectors that are identified as *key* to M&Q and those that are *key* to the overall economy and (ii) identify potential inter-sectoral linkage pathways towards increasing economic diversification. These pathways occur not only through the processing of metallic and non-metallic minerals and fossil fuel and the utilisation in manufacturing but also through the maximisation and utilisation of revenues, skills and technology that are generated through inter-sectoral linkages. For example, employment in mining is estimated to generate 4% and 2% increases in



Legend	
B	Coal mining
D	Mining and quarrying
E06	The manufacture of coke and refined petroleum products
E08	The manufacture of chemicals and chemical products
E10	The manufacture of other non-metallic mineral products
E11	The manufacture of basic metals
E12	The manufacture of fabricated metal products, except machinery and equipment
E13	The manufacture of motor vehicles, trailers, semi-trailers, and other transport equipment
E14	The manufacture of computer, electronic and optical products; electrical equipment; machinery and equipment not elsewhere classified
F01	Electricity, gas, steam and air conditioning supply
G	Construction
J03	Air transport
J05	Financial service activities, except insurance and pension funding
J07	Activities auxiliary to financial services and insurance activities
J09	Professional, technical, scientific, and other support services

FIGURE 6 Economic linkage pathways of M&Q. Figure shows how the select sectors that are *key* to both the economy and M&Q interact and what this means for leveraging M&Q for diversification. Three important sectors stand out: (1) Construction and (2) Steel sectors via the manufacture of metallic and non-metallic minerals and utilisation of coal; and (3) Service sectors. [Colour figure can be viewed at wileyonlinelibrary.com]

regional employment in other economic sectors and household income, respectively (Fleming et al., 2015). These are expected to have knock-on effects in other sectors through utilising diversification inputs such as financial capital and skills. While detailed exploration of how the different value chains across different commodities can be developed is beyond the scope of this paper, the following discussion highlights the opportunities and challenges present in the linkage dynamics of the sectors identified as *key*.

4.1 | Construction and service sectors as diversification pathways

The first result highlights that the most significant linkage channel of M&Q (D) with the broader economy is via its direct and indirect connections with Construction (G). Recall that we identified Construction as a *key* sector for M&Q as well as the overall economy. Moreover, the above discussion of Figure 5 rounds off the direct as well as indirect inter-sectoral linkages between these two sectors via inter-sectoral linkages with 'The manufacture of basic metals' (E11); 'The manufacture of fabricated metal products, except machinery and equipment' (E12); and 'The manufacture of other non-metallic mineral products' (E10). The orange lines in Figure 6 further demonstrate these interdependencies. Having established the direct and indirect linkages between M&Q and Construction, the next step is to assess how these linkages may contribute to increasing diversification.

It is important to note that Construction receives significant inputs from various economic sectors, but mainly from manufacturing and service sectors that have characterised structural change in Australia. One channel through which M&Q contributes to structural change is through the labour market which has experienced an increase in the share of value added by highly skilled labour (Timmer et al., 2014). In essence, labour that acquired skills in the construction sector has shifted into the mining and quarrying sector, mainly attracted by higher wages. This labour is likely to shift back to construction if/when minerals production shifts towards more automated processes (Commonwealth of Australia, 2015). The elasticity of factors such as labour and technology is generally high but more so now and into the future due to the demand for innovations as part of the energy transition.

In addition to the reallocation of skilled labour, particularly to construction engineering, there has been a shift of technical supplies from M&Q to Construction, and this also has the potential to contribute to economic diversification. For example, 'Perth-based start-up Pointerra's founders used their experience in the mining sector to become leading exponents of 3D data DaaS capability in construction' (Gruszka et al., 2017: 58). This reorganisation of activities and technologies along a lengthy supply chain of the construction sector has been made possible by the exponential increase in residential and non-residential infrastructure (discussed below), which more than offset the impact of the decline in mining-related engineering construction output. Another factor that made this possible is the catalysing role of the METS sector, whose important sub-sectors are related to construction, and professional and technical services.

The other channel for M&Q's contribution to economic diversification via Construction is through improved physical infrastructure, which has become the backbone of Australia's economic growth over the last few decades. Data show that the value of construction work done by the private sector for both the private and public sectors increased by 602% between 2000 and 2021 and by 960% between 2000 and 2013 when it peaked at AUD 30 billion before declining in the following years, and picking up again in 2021 (ABS, 2022b). This construction work includes roads, highways and subdivisions; bridges; railways; harbours; water storage and supply; sewerage and drainage; electricity generation, transmission and distribution; pipelines; recreation; telecommunications; oil, gas and other minerals; and other heavy industries. Similarly, the value of total residential and non-residential buildings rose by 98% between 2002 and 2018 when it peaked at $29 billion (ABS, 2022a). Industrial buildings which have increased by 229% in value over the past two decades are part of the stock of non-residential buildings, as are buildings used for commercial purposes, including warehousing, entertainment and recreation, retail and wholesale trade, and factories; as well as for providing services of agriculture and aquaculture, education and healthcare.

This exponential growth in physical infrastructure has formed the basis for the propulsion of some value-added economic sectors such as business services. The development of transport infrastructure is noteworthy, which has increased labour mobility and reduced geographic barriers to competition providing firms with better access to inputs from various parts of the country (Jones & Tee, 2017). Improvements in transport infrastructure played a role in the growth of industries with widely distributed services, and in turn, in the growth of cities and towns with increased economic activities across different geographic locations (Commonwealth of Australia, 2015). M&Q has indirectly contributed to this progress via its strong linkages with 'The manufacture of basic metals' (E11); 'The manufacture of fabricated metal products, except machinery and equipment' (E12); and 'The manufacture of other non-metallic mineral products' (E10). It has also contributed to government revenues and accounted for the greatest usage of roads and ports across Australia (Commonwealth of Australia, 2015). In addition to the financing and development of physical infrastructure, the expansion in transport technology has been one of the key factors behind some progress towards diversification in Australia (Connolly & Lewis, 2010). A lot of the infrastructure such as energy, however, requires clean energy transformation which, in turn, implies greater potential for structural transformation.

Also, the strong BL of M&Q with the 'Professional, technical, scientific, and other support services' (J09) suggest that M&Q's procurement of such services from the METS sector is significant. This and, to some degree, the BL with Telecommunications (J03) imply that M&Q has indirectly created an opportunity for the reported contribution of the METS sector to growth in value addition and employment (METS Ignited, 2019). Furthermore, strong linkages with 'Auxiliary Finance and Insurance Services' (J07) and Finance (J05) indicate the economic contribution of M&Q through these lateral service sectors.

All these sectors are part of the broad business services sector, which has been central to factor productivity growth over the past five decades (Adeney, 2018). As these sectors increasingly integrated into the supply chains of economic sectors, they have contributed to Australia's diversification. As shown in Figure 6, their growing linkages with M&Q indicate this sector's important role in the diversification of inputs, including business and management skills and financial assets. Such inputs are critical for these service sectors to grow, while flexibly adopting to emerging economic opportunities. Furthermore, these service sectors are not overly reliant on M&Q. Instead, they are so well diversified that if M&Q were to be removed, there would be minimal impact on the economic activities of 'Professional, technical, scientific, and other support services' (J09), a 4.6% reduction in output; 'Auxiliary Finance and Insurance Services' (J07), 4%; Finance (J05), 2.89%; and Telecommunications (J03), 1.6%. While these show M&Q's impact on the growth of the services sector, the same cannot be said about the manufacturing sector. Evidence suggests that limited progress has been made towards diversifying manufacturing (Harvard University, 2023; Ivanova, 2014). Our results indicate that there might be a potential to contribute to diversification via the manufacturing of steel and metal products, provided that the country's energy and labour costs can be reduced.

4.2 | Steel and metal products as diversification pathways

The second result highlights the potential impact on diversification via M&Q (D)'s strong interlinkages with 'The manufacture of basic metals' (E11), which is also a key receiver of inputs from the overall economy. Related linkage channels involve 'The manufacture of fabricated metal products, except machinery and equipment' (E12); 'The manufacture of motor vehicles, trailers, semi-trailers, and other transport equipment' (E13); and 'The manufacture of computer, electronic and optical products, electrical equipment, machinery and equipment' (E14), which, as shown in Figure 6, are *key* sectors to M&Q. However, METS Ignited (2019) estimates that the Australian mining sector depends largely (about 50%) on imports of capital goods, including specialised vehicles and equipment. More specifically, the Australian manufacturers of machinery, equipment, motor vehicles and electronic products largely rely on imported intermediate inputs that were produced elsewhere. This is evidenced by (i) the export-oriented sales of metallic ores and (ii) the declining trend in domestic demand by the above-mentioned manufacturing sectors for Australian mineral inputs (shown in Figure 2). In turn, a significant portion of domestically manufactured basic and technical equipment has been exported as part of the METS sector.

About two-thirds of domestic steel consumption is supplied by domestic steel production, with the remaining one-third of steel demand being met by imports (Smith, 2021). Australia's annual steel production is around 5 million tonnes, which amounts to only about 0.3% of global production (DIIS, 2016). Steel production has declined since 2000, although it stabilised somewhat over the past decade. In contrast, imports of steel have increased by 122% in value over the past two decades (ABS, 2022c). This suggests that there is a significant gap between the actual and potential value-add that could potentially be gained through increasing domestic manufacturing of steel and fabricated metals for domestic use and exports. However, it is known that domestic steel production has faced a reduction in demand because of a significant global over-supply of steel more efficiently produced elsewhere. This has resulted in cheaper steel being imported from abroad, putting pressure on Australian steel prices to the extent that domestic steel production has become commercially unsustainable (DIIS, 2016). This led Bluescope Steel to shut down one of its two blast furnaces and Arrium Australia to shed hundreds of its workers before it was acquired by British-owned GFG Alliance.

Therefore, Australia faces a dilemma in furthering economic diversification by means of leveraging the interlinkages of M&Q with 'The manufacture of basic metals' (E11). It involves the question of whether to develop Australia's steel manufacturing capacity despite its current globally unfavourable costs of production, but with the view to undertake major investments in seeking to produce steel in a more climate-friendly manner, or to continue exporting raw minerals and generate revenues, while importing intermediate inputs. According to Wood and Dundas (2020), raising Australia's steel production from the current 0.3% to 7% of global production would require investments of around $200 billion, but this would create an annual output valued at $65 billion as well as 25,000 jobs. Because of the current geopolitics and bilateral and multilateral arrangements such as carbon taxation, Australia may find a competitive edge to supply domestically produced steel to the domestic economy more broadly and especially the construction and manufacturing sectors.

Australia has the advantage that it may be able to compete in the global steel market as well as support its domestic value-added sectors. Potentially, it can produce 'green steel', if it were to succeed in substituting coal with hydrogen in the production of steel (Wood & Dundas, 2020). According to NERA (2020), Australia is favourably positioned and endowed with the natural resources to produce hydrogen from renewable sources of energy. However, there are some gaps in the revenue generation; for example, Australian states do not have equity share which, as in Norway's case, could have increased income from the extractive sector through profit shares. Australia's R&D expenditure to GDP has been declining from a high of 2.4% in 2008 to 1.8% in 2019 (World Bank, 2022). To address the potential impact of rising prices, especially energy prices, revenue maximisation could ensure that funding is available to invest in innovative R&D to progress on clean mining and clean production utilising green hydrogen.

4.3 | Coal mining and challenges for potential economic diversification

The third result relates to the role of 'Coal mining' (B) in the Australian economy through Coal's linkages with specific sectors (Figure 6). Although Coal does not show strong inter-sectoral linkages in the overall economy considered in Subsection 3.1, there are economic sectors that are significantly linked with Coal as shown in Figure 5f. For example, there would be a reduction of 5.6% in the output of 'Electricity, gas, steam, and air conditioning supply' (F01) if 'Coal mining' were partially removed from the economy. It also shows reductions in the output of 'The manufacture of basic metals' (E11), 3%; M&Q (D), 1.8%; 'The manufacture of fabricated metal products, except machinery and equipment' (E12), 0.8%; and 'The manufacture of other non-metallic mineral products' (E10), 0.7%. The actual impact of a reduction in coal supply could be significant, because the sectors to which 'Coal mining' is linked dominate in terms of their share in Australia's energy consumption, accounting for 13% (mining), 17% (manufacturing, of which the above-mentioned manufacturing sectors are a part) and 26% (electricity supply) in 2018/19 (DISER, 2020). Although coal's share in Australia's electricity generation fuel mix has decreased from 90% in 1993–1994 to 56% in 2019, it still remains a major source of energy for the overall economy as well as for the mining industry (DISER, 2020).

As shown in Figure 6, M&Q is one of the dominant consumers of domestically produced electricity, in addition to also being the third most dominant consumer of coal as a production input. The heavy reliance on 'Electricity, gas, steam, and air conditioning supply' (F01) on coal as an input, therefore, means that M&Q is even more reliant on coal indirectly and directly. Furthermore, the dependence of the three energy-intensive manufacturing sectors mentioned earlier on coal as an input is reflected in Figure 5f as well as Figure 6. This reliance on coal, in turn, implies that Construction (G), which our analysis has identified as one of the main linkage pathways with the broader economy, is heavily reliant on coal. This finding corresponds with a previous study that found coal to be one of the main emission contributors in Construction's supply chain which, in turn, means that Construction is one of Australia's GHG emitters (Yu et al., 2017). Emissions include those released in connection with the supply of electricity; the production of cement, concrete, plasterboard, limestone, brick and other ceramics; as well as the production of iron & steel and other minerals and metals.

The global climate change and energy transition debate and related policy proposals (including carbon pricing and carbon border adjustment mechanisms) have been putting pressure on Australia to phase out coal mining. Meanwhile, Australia's 'big four' banks as well as some of its mining companies have already committed to phasing out coal by 2030 in accordance with the 2015 Paris Agreement (Webb et al., 2020). A rising share of natural gas and renewable sources of energy in total energy consumption is an encouraging sign for Australia's progress towards achieving its climate commitments, provided that natural gas is replacing coal and investments in minimising gas flaring are undertaken (DISER, 2020). At the same time, the push for transitioning to cleaner energy, in the form of electricity as well as heat, signals a vulnerability risk for the Australian economy. In particular, the potential for economic diversification via the linkage pathways discussed above may be subjected to this risk due to the dependence of those linkage pathways on domestic coal consumption.

5 | CONCLUSION

Beyond measuring the extent of inter-sectoral linkages, this paper considered the potential of linkage pathways for economic diversification. The construction and business service sectors have driven Australia's productivity in the last few decades. Against this background, the paper investigated whether the significant interlinkages of Mining and quarrying with these sectors indicate its potential to contribute to economic diversification. The main diversification pathways to existing and new economic sectors via the linkages of Mining and quarrying with Construction may lie in the (i) upskilling and reallocation of skilled labour and technical supplier capacity, (ii) the development of green physical infrastructure and (iii) the manufacture of green steel and fabricated metallic products. While there is evidence backing the first two pathways, the feasibility of the third pathway remains unclear.

There are questions that need to be considered around the economics of the domestic steel and fabricated metals industry. These can be addressed looking forward, rather than looking back. Can Australia develop a comparative cost advantage to manufacture low-carbon steel and fabricated metals? Will developing such a capacity require a major change in the country's industrial policy and deliberate investments in relevant innovations? Does the domestic political context allow for this, and where does it currently stand? How may such potential efforts be negatively and positively impacted by distortions due to external factors, such as shifts in technology?

The potential of Mining and quarrying's impact on economic diversification via its strong interlinkages with Construction may also be vulnerable to climate policy and the transition away from coal as a source of energy. At present, mining and quarrying and the manufacturing of basic and fabricated metallic and non-metallic products remain significantly dependent on coal as an input. Australia's wealth of iron ore deposits and the natural resources to produce hydrogen and clean electricity may provide for a comparative advantage in the production of green steel. However, this potential lends itself to the question of whether it also requires a reinvention of Construction to become less energy-intensive with less carbon emissions. Furthermore, there is an ongoing debate as to whether renewable sources of energy can be produced at levels sufficient to meet the energy needs of the construction and other energy-intensive large-scale industries. It might be worth exploring whether Australia can maximise Mining and quarrying revenues to strategically invest in technology and innovative capabilities to enable cost-competitive manufacturing of capital goods that are currently imported. Furthermore, the potential to grow other economic sectors such as agribusiness could be explored as potential opportunities for economic diversification.

This paper applied P-HEM within both the Leontief and Gosh input–output frameworks on 10 input–output tables over the period from 2007/08 to 2018/19. In doing so, it sought to differentiate itself from previous work that used either the basic input–output method or the original extraction method. With some limitations of a scenario-based extraction method in mind, such as the inability to analyse the impact of changes in factors of production, the method helped establish the Australian economic structures from a production perspective and served as foundation for analysis of key sectors and diversification inputs that can be developed by leveraging the extractive sector.

Economic transformation is a long and complex process that is determined by multiple factors, including innovation and productivity, institutional and administrative capacity, coordination of policy and regulation, and collaboration with the private sector. Further research is warranted exploring these multiple factors across the value chain using a holistic approach, especially the political transformation component to achieve economic transformation, which are outside the scope of this paper. Data specific to the various inputs that are used in the production processes in each of the economic sectors are critical to discern what inputs are sourced locally and which are imported, and how minerals compare in their utilisation in the production process. Methods need to be identified that help deepen the analysis of the inter-sectoral linkages of the Mining and quarrying sector, not only in terms of temporal changes in output but also changes in prices, employment, factors of production, and income at global, national and sub-national levels.

The analysis is expected to inform decision-making with respect to major economic investments and the prioritisation of specific sectors for the purpose of encouraging the diversification and structural transformation of the Australian economy. While availability and consistency of data remain a challenge, future studies may consider conducting input–output analyses at sub-national and cross-country levels as a useful tool for economic policy and investment planning at those levels. Future studies could also conduct in-depth analyses of inter-sectoral linkages by applying other methods in addition to the HEM, with the objective to provide further and targeted nuances around how specific economic sectors function in relation to relevant parameters such as productivity.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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