



Triple Helix and Regional Innovation Systems: Knowledge Transfer in New South Wales

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Abstract

Imagine you could benchmark collaboration in research publications, spatially and over time, by research area, between university, industry, and government, look at international and domestic, inter- and intra-state; measure it relative to regional economic activity. In effect, measure knowledge spillovers and connections.

Measurement is essential for assessment of performance. Without measurements using a repeatable tool there is no ability to monitor change. The application of the triple helix to measuring university-industry-government collaboration allows assessment of performance in the research sector. Furthermore, with the integration of research partner (or individual organisation) locations, any relationship with the local economy can be identified.

This research was developed with a comprehensive, transparent, and repeatable methodology, drawing on over 30 years of existing research knowledge in bibliometric and scientometric analysis and using an even older mathematical formula. Patterns and trends of increasing (or decreasing) collaboration can be identified by examining university, industry, and government collaboration measured through author affiliations.

The novelty is the application to New South Wales, Australia and the accessibility of the code to perform the analysis. Using common coding tools such as R and data from the Web of Science ensures accessibility. The results for all research areas show changes in government, that the publication increase as reporting periods approach, and that there has been an overall trend of declining collaboration. However, agricultural-related research has bucked the trend. Although the collaboration is of a lower magnitude, the trend since 2015 has been an increase in collaboration.

Ultimately, there are policy implications for organisations looking for research partners and opportunities.

Understanding how the triple helix of university–industry–government translates to existing and future industry-level behaviours and trends will enable the emergence of stronger, more resilient industries and economies. As regional economies change, the historical drivers of economic growth in regional Australia are shifting from agriculture, fishing, forestry, and extractive industries to knowledge-based industries. The triple helix and industry specialisation combination has rarely been applied to an Australian agri-food and agricultural context where research organisations can operate in spatially large ecosystems, sometimes away from highly specialised areas.

Applications of the triple helix in Australia have focused on metropolitan and capital cities as opposed to regional areas. Understanding where concentrations of both research and industry are located will inform decisions on possible locations where any competitive advantage exists due to specialisation.

New South Wales exhibits different behaviours for different research sectors, demonstrated by differences between all research fields and seven agriculture-related areas. Whilst all fields of research exhibited decreasing collaborations, agriculture-related countered this with increasing collaboration.

These measurements allow targeted policies to enhance collaboration and improve research activities by increasing awareness of the nature and location of collaboration.

Intended to improve the transfer of knowledge from research organisations to industry, this research enables specific spatial areas to be targeted for agri-food, agri-business, and general agricultural research areas. Identifying where there are strong research bases and industry

specialisation will allow for learning to be shared between different agents. Conversely, identification of weaknesses will allow for structured action (potentially government led – the third pillar of the triple helix) to be undertaken to build the resilient communities needed. The occurrence of mismatched triple helix and industry specialisation may reflect workforce skills shortages or under-skilling, and thus the need for extension to be undertaken to build these areas can be implemented. Using an industry specialisation metric to reflect theoretical demand, the future engagement of industry will enable improved research outcomes as it matches the needs in the differing regions. Organisations ranging from CRCs to university and research organisation incubators and accelerators will benefit from this increased knowledge and the role they can play in the ecosystem.

Certification

I certify that the ideas, experimental work, results, analyses, software, and conclusions reported in this thesis are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.



Candidate Name

25th August 2023

Date

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When tackling a scientometric approach to analysis, the data source is key. Fundamental to this were the librarians at the University of New England (both current and past) who have helped me navigate the databases and methodologies required, as well as introducing me to the world of open access publications and to methodologies from other disciplines that I would never have found.

Alongside me all the time has been my wife Daniella Fleming, and for her support, encouragement, and tolerance in the time it has taken I am eternally grateful. To my family far and wide, thank you all for your support and encouragement, especially those who believed in the project, but will not see it to fruition.

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Chapter 1: Introduction

The identification of research opportunities starts with the question, then the examination of the existing literature and finally the forming of the hypotheses to be tested.

1.1 Background to the Research Problem

In 2020 the Australian Federal Government formally announced a target for the agricultural sector to be \$100 billion in 2030 (House of Representatives Standing Committee on Agriculture and Water Resources, 2020). This has subsequently become known as Ag2030. To do this, and following the white paper from the National Farmers Federation in 2019 (National Farmers Federation, 2019), the government funded Cooperative Research Centres (CRCs) to accelerate the expansion to a \$100 billion industry.

Theoretically, the agricultural sector is not a city-dominated research landscape. Universities such as the University of New England (Armidale, NSW), Southern Cross University (Lismore and North Coast of NSW), and Charles Sturt University (Wagga Wagga and Central West NSW) have strong connections to the land or sea. However, the University of New South Wales and the University of Sydney also have satellite research centres located in regional or peri-urban locations. State and federal bodies also undertake research with agencies such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO), which operates at a federal level, and the NSW Department of Primary Industry (NSW DPI), all of which have active research centres located in regional areas. Lastly, commercial organisations participate in research, testing new innovative solutions or applying these as test cases. This is often in conjunction with the above organisations.

With this background, it is therefore pertinent to understand further the NSW research landscape as a proof of concept using a replicable and scalable methodology and approach to

data collection and categorisation. The data used can be viewed as both time series and spatial data. Building on Leydesdorff and Etzkowitz's triple helix and examining the relationships from a collaboration perspective, the relationship trends between collaborative partners in universities, government, and industries can be explored.

As an evaluation framework, the data collection and categorisation approach can be varied as required. Importantly, this has allowed for analysis of the total landscape as well as the agricultural fields of research. Without analysis of the total landscape – all fields of research – the ability to compare or understand change is reduced. While it can be easy to look at trends and assume they encompass all fields, the landscape is complex and, therefore, will be broken apart.

1.1.1 Statement of Problem

Economics is fundamentally about the allocation of finite resources. Research funding and resources (capital), as well as knowledge (again, a form of human capital), can be allocated with better information. This information will have the capacity to inform research managers, interested industry organisations, and those involved in economic development as to where potential collaboration synergies may exist at a meso-economic level. Driving this information is the adoption of a transparent methodology that is scalable and replicable. Furthermore, the integration of the concepts of knowledge-based economies (and the subsequent opportunities for economic development and growth) can be used to enable economic development.

1.1.2 Significance of the Problem

Changes in research collaboration at a wide scale and at a smaller scale focused on specific research fields are possible. This scalable approach allows for the detailed analysis of

different fields of research related to agriculture and changes that can be observed in research during the period studied. Political changes and organisational requirements can all be seen in the changes in collaborations, as well as the (full) arrival of the publish or perish era of research. The implications of relating (at a funding body level) funding and publications were identified before the start of the study period by Butler (2003), who discusses this further.

With the analysis of the research collaboration by organisations at a granular level, identification of possible research partners is possible. At a geospatial level, the ability to identify these opportunities may lead to an increase in local collaboration, further accelerating the economic development through the knowledge economy. Integration with an economic specialisation measurement will further support the identification of economic development opportunities which comprise the specialisation profile, and the contribution made by selected industries of a local government area (LGA) in three census periods (2006, 2011 and 2016).

1.2 Research Questions

Two questions will be addressed in this thesis. First, whether the bibliometric indicators derived from the triple helix concept using replicable data extracted from the Web of Science could be used to measure trends in and strengths of collaboration within New South Wales research activity (a) across all fields of research and (b) across agriculture-related fields. Second whether the university, industry, and government collaborations shown in the agriculture-related fields are related to regional economic specialisation and activity by Local Government Area.

With the knowledge surrounding the existing measurement tools that can be used, as well as the preliminary questions, the development of the final research questions and subsequent hypotheses can be identified. However, the original questions were ordered in a wide to

narrow focus. With the knowledge gained through the literature review and the methods examination, the questions can be reordered and consolidated into three distinct questions, that are bounded geospatially. The original intention was to address the measurement of university, industry, and government organisational collaboration for Australia. When confronted by the volume of data required and the accessibility of the data, this was found to be impractical. Instead, the question was bounded geographically by concentrating on research outputs with at least one author from New South Wales.

These questions can be addressed with an overarching frame of a geographical and research subset. The funding support of the Food Agility CRC has defined the research subset.

1.3 The Position of this Study within the Economics Literature

The inclusion of economic specialisation contrasted against research organisations and activity provides the economic literature with new implementations of existing theories and concepts for the Australian, and in particular New South Wales, economic development. Positioned across economic disciplines, the thesis includes concepts from economic development, economic innovation, and economic geography. Examining the national and regional innovation system, the thesis provides insights into the estimated impacts of collaboration within the triple helix.

1.4 Structure

The questions and challenges are addressed through the following chapters. Chapter Two addresses the existing literature, the context this work takes within the current knowledge, and the definitions of key terms of reference. Furthermore, Chapter Two addresses the nature of knowledge-based economies on a global scale as parts of the regional economic development landscape. Chapters Three and Four discuss the approach to the measurement of

collaboration, as well as the method used for data collection, which is an intrinsic part of the approach adopted. Chapters Five and Six focus on the measurement and algorithms, firstly the organisation categorisation process and, secondly, the calculation of the triple helix index and specialisation. Chapters Seven and Eight comprise the analysis of the triple helix results, firstly for all research sectors and secondly for the agricultural-related fields. Chapters Nine and Ten address the measurement of specialisation and New South Wales's economic geography, particularly the actors' location within the triple helix models. Chapter Eleven brings these elements together. Chapter Twelve contains policy recommendations and final conclusions.

The appendices contain background information on the triple helix calculations, including the changes made to Leydesdorff and colleagues' (2013) `th4.exe` between the first and second versions, both in the software and in the calculation, and examples of the R code used for the calculations.

1.5 Researcher Positioning

Or how an economist became a youth worker – before becoming an economist again.

In 2000/2001, I examined sustainable development from an environmental economics perspective. The role of capital in that context – that of natural, financial, technological, and human (knowledge) capital – has remained present in much of my career since then. Whilst thematically disjointed, a thread that retains sustainable development through individuals and community to organisations and their role within a community can be traced.

An inquisitive mind, which some would recognise over many years, with an overwhelming desire to understand how things work, why they work, and how they could be made to work better, has shaped my career. As a youth and community worker, I predominantly worked with young people, building new human capital through supporting them with their learning

and enabling personal development – providing new opportunities for them, and building a sustainable community from the perspective of young people entering the adult workforce in a meaningful manner.

When I returned to economics in 2012/2013, I chose to study somewhere that was close to areas I was interested in, specifically agricultural and resource economics – the relationship with natural resources. This brought me to the University of New England, whereupon Armidale became my home.

Since then, I have worked within influential economic sectors in Australia: tourism, education, and manufacturing. These sectors provide opportunities for sustainable economic development and activity, particularly emphasised by work in the start-up and scale-up ecosystem, as well as research and development in manufacturing (technological capital). However, there are challenges associated with the sustainable development of a regional economy. In an area where there is a human capital endowment – that is, the University of New England – can the research relationship between universities, local industry, and government be measured through collaborative research output? The challenge of a regionally relevant research measurement became a passion project of intellectual curiosity, which then became a formal research project with a focus on fields of research with a connection to agriculture once it was pitched to and adopted by the Food Agility Cooperative Research Centre.

Chapter 2: Literature Review

In a three-stage approach, this literature review explores the background narrative. Then it explores the triple helix and knowledge economy, followed by the role of regional economics and development.

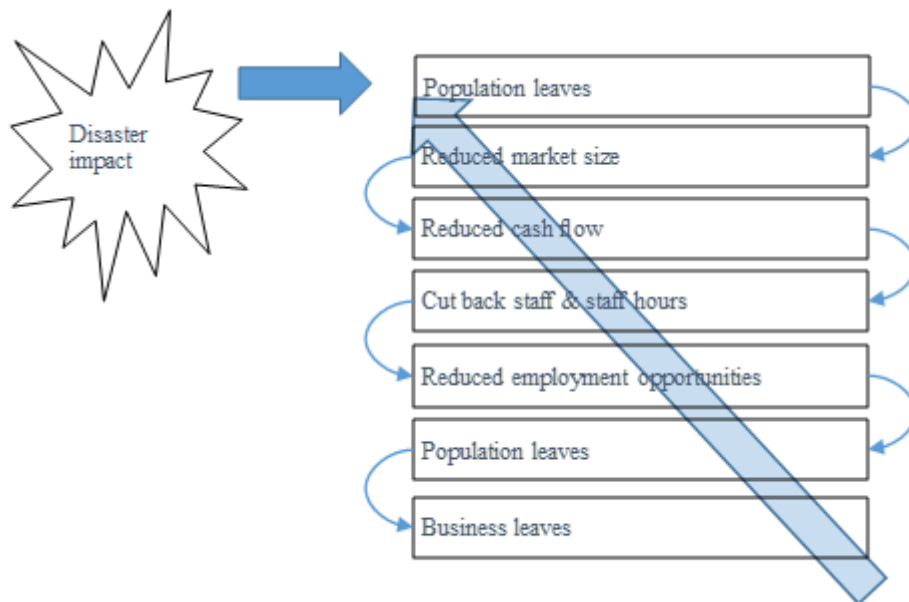
2.1 Background

Australian regional economies and communities are changing due to many influences. These changes motivate those interested in the Australian economy (economic geographers in this case) “...to explore new social and economic processes as they have emerged and reconfigured the spatial distribution of economic activity in this nation” (Beer, 2012, p. 270).

Firstly, agricultural economic activity is changing. For example, the Australian Bureau of Agricultural and Resource Economics and Sciences (2018, p. 216) data shows prices are increasing in some sectors (livestock) and declining in others (grains and crops) over a 5-year period. Secondly, the industrial base in regional economies is changing; examples include McFarlane et al. (2016) who examine the shift in employment from agriculture to mining and the impact on a specific region’s economy. Thirdly, the population base has changed – Alston (2004, p. 41) states that many residents in rural (defined as non-metropolitan areas) Australia moved to less rural areas such as regional cities, coastal regions, or capital cities. Lastly, the median age of the population is higher in regional areas – examples from Australian Bureau of Statistics (2018a) data for New South Wales show a median age of 42 years outside of the Greater Sydney area and a median age of 35.8 years for the Greater Sydney area, supporting Alston (2004), who stated that rural residents in the 15 to 24 age bracket are most likely to leave. Combined, these influences, along with others, have impacted regional economies.

Regional economies are at risk of the contracting adaption spiral that Drennan et al. (2016, p. 82) present – albeit in the context of a business adapting to the effect of a natural disaster.

Figure 2-1: The Negative Adaption Spiral



Adapted from Drennan et al. (2016).

Although focused on the effect of a disaster, this scenario can be seen in many regional areas after the departure of a dominant employer or industry (the changing industrial base) and the departure of young people (the changing population base).

Whilst the literature above is from the last two decades, the question around economic performance has been running for much longer. For example, Kerr (1970, pp. 359-360) asks questions about the competition between six of the Australian capital cities, as well as other regions, for growth industries.

At a macroeconomic and international level, Australia has been a large exporter of commodities. As Watkins (1963, p. 148) stated, many colonies were production facilities for their old world colonists. Prior to the 1960s, Australian exports were dominated by exports to the United Kingdom. However, the market for Australian exports has changed and moved to nearer destination markets, with Japan, and then China becoming the largest single

destination market (Department of Foreign Affairs and Trade, 2016). This demand has also led to structural changes in the Australian economy since the mineral booms of the late 1990s. Synergies can be seen in the evaluation that Ross (1999) undertook into the literature surrounding resource curses. The resource curse is seen in many economies – often synonymous with Dutch Disease – as evidenced in studies covering Canada (Dubé & Polèse, 2015) and Australia (Fleming et al., 2015; Ivanova, 2014) of particular interest. Furthermore, Beer (2012) discusses the evolution of the Australian economy from one protected through tariffs and trade barriers to one openly trading and experiencing changes in much of the economy compared to the booming mineral sector (Beer, 2012, p. 273).

While the identification of possible influences is straightforward, quantifying the magnitude of influences is more challenging for several reasons. Firstly, these influences cannot be measured easily in a single measure within readily available data. Often readily available data does not provide sufficiently disaggregate detail, and when it does, there is often disruption to the data (e.g., census data in Australia is at 5-year intervals). Secondly, and perhaps most importantly, changes in methods of data recording through boundary changes in the Australian context lead to incompatible data sets over time. The adoption of the Australian Statistical Geographical Standard (ASGS) from the 2011 census limits the availability of comparable data. Likewise, boundary adjustments and council amalgamations in LGAs lead to data incompatibility within these measurement units. However, these changes add to the conversation and discussion around regions and their associated definitions.

Moreover, the study of regional economies has fallen under several separate groups and themes in the last hundred years. Many paths led to regional economics or regional development when examining the history of the concept. Historically, in the first half of the 20th century, work was focused on the location of businesses and competition as methods of economic development. Examples (in English) include Hoover (1933), North (1955) and

Moses (1958), whilst Alfred Weber's 'Theory Of The Location Of Industry' was published in German in 1909 (and in English in 1929). These studies underpin much of the later work in location-based examination of industry, starting with the regional advantages and then moving to the clustering of industries. Bunker (1989) identifies Douglass North, Albert Hirschman and Harold Innis as key authors in the space of regional economic development, whilst it is widely recognised that Porter (1998) is one of the leaders in clustering and regional competitiveness.

Reflecting the evolution from regional development (focusing on location theory), this move to the triple helix is only part of the underpinning. There was still a concern that historical advantage was present for many organisations. Both Etzkowitz (1994) and Etzkowitz and Leydesdorff (1995) drew on observations of areas such as the surrounds of the Massachusetts Institute of Technology (MIT), the area surrounding Silicon Valley in the US, and Cambridge in the UK.

However, in this evaluation, much of the academic research has been concentrated in Europe and the US. Examples include Kitson et al. (2004), who broadly cover the research in regional competitiveness. Enright and Roberts (2001) detail the global regional cluster research undertaken and state that very little had been published on Australian industry clusters. When research is undertaken to examine Australian clusters, it is often part of a sustained regional development strategy. Examples from Enright and Roberts (2001) include studies on the Hunter region of New South Wales, southeast Queensland, Melbourne and Adelaide. Research covering clustering and regional advantages as tools to enable regional economic development in an Australian context commonly originates from state or federal governments (e.g., the work of the New South Wales Department of Premier and Cabinet's report on regional economies published by the Centre for Economic and Regional Development in 2017).

Research on Australian industrial clustering often focuses on a finite number of industries. Examples include Roberts and Enright (2004), Aylward and Zanko (2006) and Henderson et al. (2010), who all examine clustering to varying degrees of specialisation. Roberts and Enright (2004) take a broad overview of clustering throughout Australia, whereas both Aylward and Zanko (2006) and Henderson et al. (2010) examine the wine industry in Australia, with Henderson et al. (2010) focusing on the Hunter Valley. In contrast Beer and Clower (2009) detail the evolving nature of regional cities in Australia, such as the changes in clusters that can be observed in the census data. Contextualising this line of research work in regional economies has also been concentrated overseas. Authors such as Martin, Leydesdorff, Cooke and Sunley have focused on economies in Europe and the US. Work on Australian regional economies is less common. Examples include work by Argent, Plummer, and Tonts, who have examined regional recovery and resilience, whilst McFarlane et al. (2016) have looked at the economic transition of regions in post-mining areas. Steiner, Cleary, and Atterton have undertaken other research into Australian small businesses and resilience. Steiner and Cleary (2014) focused on rural businesses, whilst Steiner and Atterton (2015) examined resilience across disciplines.

However, whilst many of these studies and researchers take the boundary of the region as a given, it is unclear how a region is defined or what makes a region.

2.2 The Triple Helix and Knowledge Economy

Since the 1990s, development policies have changed with their view on the role of universities in economic development. In Etzkowitz (1994, p. 139), the role of new knowledge generated by universities as a tool for economic development is tied to national technical and scientific research policies. Furthermore, these policies influence university, industry, and government relations.

In the mid-1990s, Leydesdorff and Etzkowitz were leading figures in introducing the concept of the interlinking between university, economy/industry, and government. This was coined the triple helix (Etzkowitz & Leydesdorff, 1995, p. 9) after the earlier work introduced in Etzkowitz (1994).

Evolving in this period, Etzkowitz's work foreshadowed a new approach to regions – that is, the relationship between research, industry, and government. A focus on the political and social aspects within the context of economic development underpinned the suggestion of a new way for achieving economic growth. Drawing on the research of the latter half of the 20th century – which had not finished at the time Etzkowitz wrote this piece – there was the recognition that economists "...view[ed] land, labour and capital as the primary sources of economic productivity" (Etzkowitz, 1994, p. 140). A historical review of the role of technological change outside of those primary sources began to observe relationships forming between research and development expenditure and technological change: the beginnings of the use of research and development expenditure as an indicator of technical change.

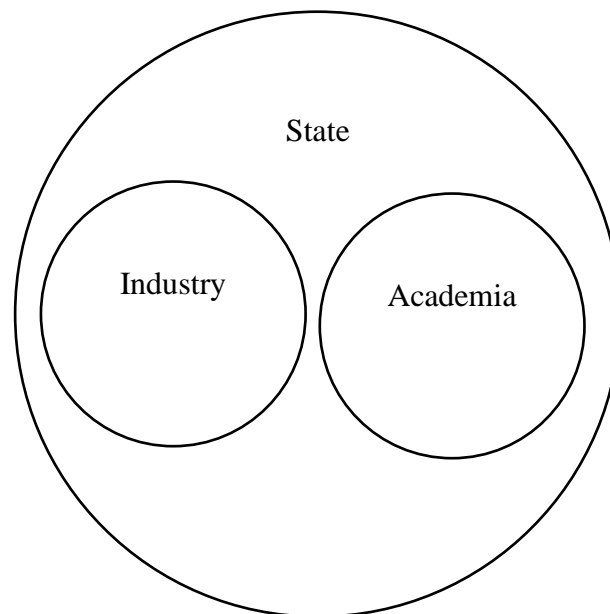
With this insight into how Etzkowitz saw both the role of measurement and the need to understand the linkages between universities and industry in the context of economic development. Importantly, Etzkowitz remained focused on the sociological aspects of these collaborations and their role in economic development. Over a short period, this concept turned into the triple helix as Etzkowitz and Leydesdorff's (1995) work saw the emergence of a new economic development framework and innovation ecosystem involving the university, industry and government. Whilst these appear as stand-alone concepts, they are underpinned by the idea that a national (or regional) innovation system can be measured.

Broadly, the triple helix model has been identified as being of different types. Exploring the role of the triple helix on knowledge, Leydesdorff and Etzkowitz (1998) state that three forms

of triple helix were observed: Triple Helix I, Triple Helix II and Triple Helix III. Each of these behaved or enabled different behaviours in a manner often represented by three institutional spheres – university, industry, and government.

Illustrated in Etzkowitz and Leydesdorff (2000), the different approaches to national innovation system management can be seen in the structures set out. Where historically there has been strong government intervention, the state (for example, the former Soviet Union or other command economies) has encompassed industry and academia, directing their interoperation.

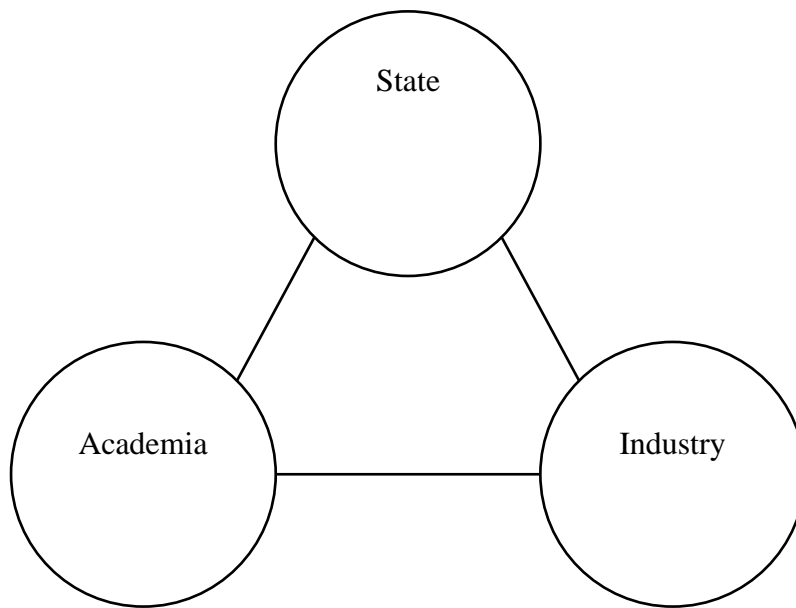
Figure 2-2: Triple helix Mode I



Triple helix Mode I, from Etzkowitz and Leydesdorff (2000, p. 111)

In contrast, a laissez-faire model of interoperation (more representative of Western democratic economies) is a more open approach, with links between actors. However, what is implicit in this model is the borders that are in place surrounding the actors; whilst there are ties or connections, there are also (implicit) borders that retain knowledge within silos.

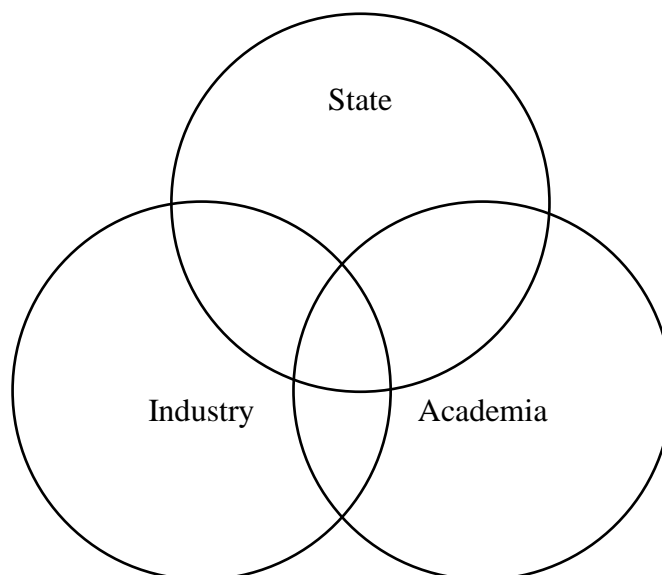
Figure 2-3: Triple helix Mode II



Triple helix Mode II, from Etzkowitz and Leydesdorff (2000, p. 111)

The final option proposed was that of a mixed approach, where all would take on the role of the other. That is, universities have become increasingly entrepreneurial whilst hybrid organisations emerge.

Figure 2-4: Triple helix Mode III



Triple helix Mode III, from Etzkowitz and Leydesdorff (2000, p. 111)

With the intersection of the spheres of influence, the role of hybridised organisations is clear. They are now acting as spin-offs from government or academia entering the industrial sector, but commercial research partnerships are also occurring. Notably, the hybridised

organisations expected these new collaborations to result in new commercial entities: spin-offs and start-ups. With these models of the triple helix, the context of the innovation systems is clear, and the subsequent work was undertaken to observe both national and regional innovation systems.

As with many researchers, Etzkowitz (1994) focuses on the US model of university–industry relations. Whilst focused, there are parallels with other countries as efforts to emulate the success of institutions such as MIT in developing nascent technologies are transnational. Emerging from this evolution of the university and research institutions are the beginnings of the technology transfer model – the movement of research into a commercial entity (Etzkowitz, 1994, p. 149). Some of the most important distinctions made by Etzkowitz (1994) are the differences in the genesis of research and technological opportunity. Etzkowitz (1994, p. 142) introduces a model where there is a move from a nascent technology to a discipline; that is, an industrial problem drives the emergence of an academic discipline. Countering this is a model where academic research leads to opportunity – the commercialisation of research outcomes.

Leydesdorff's later work, including Leydesdorff and Meyer (2006, p. 1442), expanded on the underpinning theories of the triple helix model, including the university's role in the process of research commercialisation. The triple helix is part of the advantage that a region is able to command over other regions. Cooke and Leydesdorff (2006, p. 10) identify the triple helix as a constructed advantage in the same way that endowments and enablers form part of the ecosystem.

Even in recent years, the triple helix has assessed regional performance; research and publications include:

1. Gunasekara (2006) explores the challenges universities face in maintaining regional engagement and defining the region.
2. Hira and Aylward (2013) examine the triple helix's role in the growth of the Australian wine sector.
3. Massey et al. (2014) examine the town and gown relationship and the part the triple helix plays in the relationship.
4. Jackson et al. (2018) address the innovation connections of firms and universities, as well as between firms.
5. Kriz et al. (2018) explore the theoretical triple helix's development in Tasmania – the pure relationship between university, industry, and government – how it evolves, grows, and changes over time.
6. Oplakanskaia et al. (2019) explicitly explore the triple helix within the context of Bristol and Sheffield (United Kingdom) and Novosibirsk and Tomsk (Russia), as well as the role that the development of connections between all actors can play in economic and social development

Management of the research connections with the community is becoming a crucial revenue stream for universities. This ranges from contract research to the commercialisation of research and the corresponding revenue stream from royalties. Wright et al. (2008) examine the role of research commercialisation on 'mid-range universities' in Europe, including the need to build relations with industry through contracted research. This contracted research model was also examined by Gál and Ptaček (2011) and can be seen within Australia in the links to the CRCs. The CRCs typify the relationship that Cai and Etzkowitz (2020, p. 7) identify. This incentivisation of projects to contain university, industry, and government partners enables the active development of industrial and social innovation – even if those involved are unaware of the triple helix as a concept or enabler.

Within the Australian context, the role of the university within the triple helix is typified by the CRC model. The CRC program started in 1990. Since then, over 200 CRC programs have operated (Department of Industry Innovation and Science, 2018a, p. 2), with a further four launched in the first six months of 2018 (Department of Industry Innovation and Science, 2018b, p. 2). The explicit aim of the CRC program, as outlined by the Department of Industry Innovation and Science (2018a, p. 10; 2018b, p. 11), is to maximise innovation through engaging the following:

1. Universities and research organisations.
2. A wide range of businesses – from small and medium enterprises (SMEs) to large multinationals.
3. Federal, state, and local governments.
4. Partners from overseas.
5. Industry-specific organisations, community groups, and the not-for-profit sector.

These aims can align with the purpose of the triple helix – the interaction between government, university, and industry is clearly set out. Leydesdorff and Sun (2009, p. 786) suggest that the measurement of internationalised research and diffusion systems, or national and sub-national research and diffusion systems, can be achieved with the transmission calculation within the triple helix – further capturing the aims of the CRC system identified above.

The Research and Development Corporations are often found alongside CRCs – such as the Grain Research and Development Corporation (GRDC). They are a mixture of five statutory bodies (established under legislation) and ten that are industry-led to provide economic, environmental, and social benefits to the rural regions. This is achieved by ensuring there is an investment in the transfer of technology from research to users, as well as the adoption of technologies (Rural R&D Corporations, n.d.).

Aligning with this and recognising the importance of new knowledge generation, Tödtling and Trippl (2005) state that the role of knowledge (the university), learning (the university again) and innovation (industry) is recognised in academic literature as one of the crucial elements in building competitive nations, regions and firms, often through economic development.

2.2.1 Triple helix model and the triple helix index (T-value)

Whilst the triple helix model represents the framework that collaboration can occur and be incentivised, the calculation of the triple helix index and the subsequent derivation of the transmission value (T-value) quantify the transmission of information. The work of Leydesdorff in the measurement of the mutual information shared within the triple helix model creates the triple helix index. Examples and explanations can be found in Leydesdorff and Sun (2009, p. 779), where the derivation of the mutual information using the work of Shannon (1948) is explained in more detail.

As the reduction of uncertainty tends towards zero and negative values, the T-value also reflects the increase in synergy – that is, the collaboration that occurs within a triple helix model that is influenced by policy intervention. Importantly Leydesdorff (2012) identified that to expand beyond a triple helix model or index, additional helix inclusion in the model and subsequent index must be carried out step by step. The development of the solution will be undertaken in this manner.

Subsequently, references to the triple (or n-tuple) helix refer to the model of collaboration and contribution, whilst the triple (or n-tuple) helix index refers to the calculated T-value.

2.3 Regional Economics and Development

If the triple helix can be a measurement of new knowledge generation and the subsequent building of competitive nations, regions, and firms, then this may be quantified in the economy of a region. From the start, there is a need to address the language of regional development, economics, and associated fields where terminology can be ambiguous, with an extensive range of definitions for region. The need to define the following terms drives this section, with each taken in turn.

1. **Region.** Defining region shapes many of the issues. If the region is too large, changes can be lost; if it is too small, changes can have too much influence – highlighted by Dwyer et al. (2016, p. 356) examining the impact of tourism events on differing levels of the economy (and the associated decision holders).
2. **Ecosystem.** The need to define ecosystem is driven by the use of the ecosystem analogy in business (including the entrepreneurial ecosystem) or economic analysis, which differs from the language used conventionally when examining economies. The use of the ecosystem as a metaphor for a regional economy reflects the many agents and organisations that are interlinked; for example, Spigel (2017, pp. 49-50) identifies the factors that combine to provide an environment (ecosystem) that supports innovation-driven economic activity. In contrast, Cavallo et al. (2018) developed a set of guidelines for enabling the construction of an entrepreneurial ecosystem.
3. **Resilience:** The definition of resilience also becomes a factor, particularly within the ecosystem and regional development contexts. Often resilience refers to a region's ability to recover to the point before an exogenous shock and establish a growth path the same or greater.
4. **Specialisation and diversification .** Defining specialisation is interlinked with the work of many authors who have examined the competitive and comparative advantages of nations and regions.

2.3.1 Regions

The definition of a region can vary depending on the characteristic of concern(Eversole, 2017, p. 306). The language surrounding this in Australia has been changing. McManus and Pritchard (2000) reflect on the emergence of the (then) new discourse surrounding rural and regional Australia and the need to encompass several disciplines. This continuing change in language can be seen in Parr (2015), who states that there has been a move from urban and

rural to city and regional. This increasing use of region in lieu of rural has the potential to be attributed to any one of several reasons – this, however, is beyond the scope here; rather, the distinction and definition of ‘region’ is key. Godden’s (2001, p. 34) comment is related to this discussion. He states that there was a tendency for politicians to bundle all non-metropolitan areas into a generic group – as opposed to the regional, rural, and remote groupings that others use.

Enright and Roberts (2001) define a region as sub-national as opposed to a supranational region (such as South East Asia); Eversole (2017, p. 306) proposes a region that has shared characteristics, large enough to influence the greater economy but small enough that interactions and connections occur between those resident there. Cooke and Leydesdorff (2006) state a region can be defined as:

1. an administrative division of a nation.
2. a unit for geographical, functional, social, or cultural reasons.
3. a large, indefinite, and continuous area or space.
4. nested beneath the level of nation but above the local or municipal level.

Cooke and Leydesdorff (2006) further elaborate on the definition of a region by examining the linguistic root, stating that, ‘Region has its origin in the Latin *regio* which stems from *regere*, meaning “to govern”’. With this linguistic root identified, the relationship when applied to local government areas becomes quite explicit and clear. In contrast, Paasi and Metzger (2017, p. 20) state that the concept of a region has been an evolving definition in recent years, with many new concepts appearing in the vernacular. Examples identified include:

1. city-region
2. mega-region
3. learning region
4. creative region

5. competitive region
6. resilient region
7. bioregion

In the Australian context of discussion on what makes a region is widespread. The states and territories are the dominant sub-federal administration areas but are not the only regions.

Thus, defining the regions is a multi-level process in the Australian context:

1. Australia – The overarching Commonwealth of Australia
2. State/Territory – 6 states and 3 territories of the Australian Commonwealth
3. Regions – within each state/territory are subdivisions that are referred to as regions
4. Council areas and suburbs – exist within regions and may cross over regions. These are the smallest administrative unit within Australia.

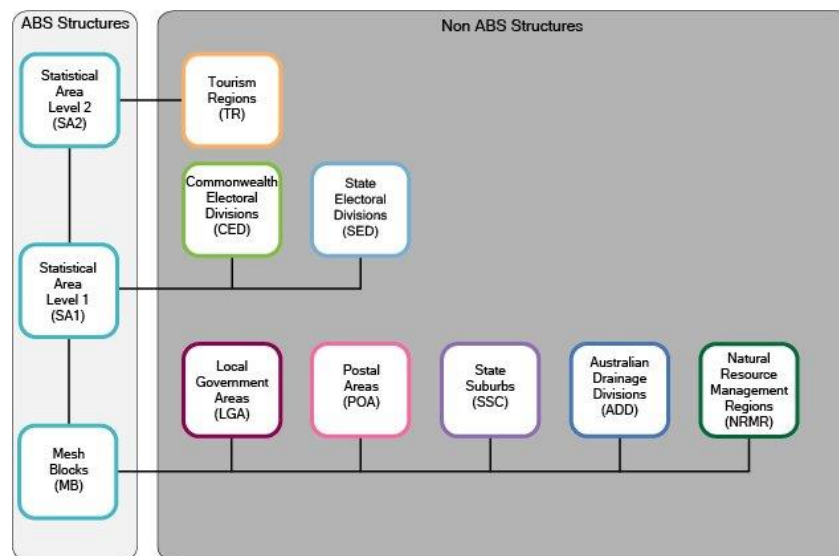
In Australia, ‘regional’ is often used to describe an area outside of the main cities. Examples of this include Beer and Clower (2009), who state that regional cities are those outside the main cities with a population greater than 100,000. In contrast, Charters et al. (2011) state that many characteristics make regional Australia, including the diversity of landscape and economic activity, which relates to Paasi and Metzger (2017) with the different region types. Eversole (2017, p. 307) discusses the differing definitions of a region, including the use of measures of economic interaction between areas or the administrative regions separate from government structures. However, it is of interest that the definition of a region can be a definition of what it is not, and the implications associated with this approach. Included in this is the notion that by being outside of the capital city (what a region is not), the region is not experiencing the same economic growth.

The Productivity Commission (2017, p. 6) identifies that regions will vary depending on the analysis context. Example regions are given as those dependent on one industry or commodity, local administrative areas, or large-scale areas that share environmental impacts

(in the example case, the Murray-Darling Basin). Ultimately though, the report adopts the ABS' ASGS.

The ABS breaks Australia into several smaller units for measurement purposes in the ASGS, with two different versions existing. Firstly, there is a framework for non-ABS structures of regions that reflect a more functional type of region, such as LGAs.

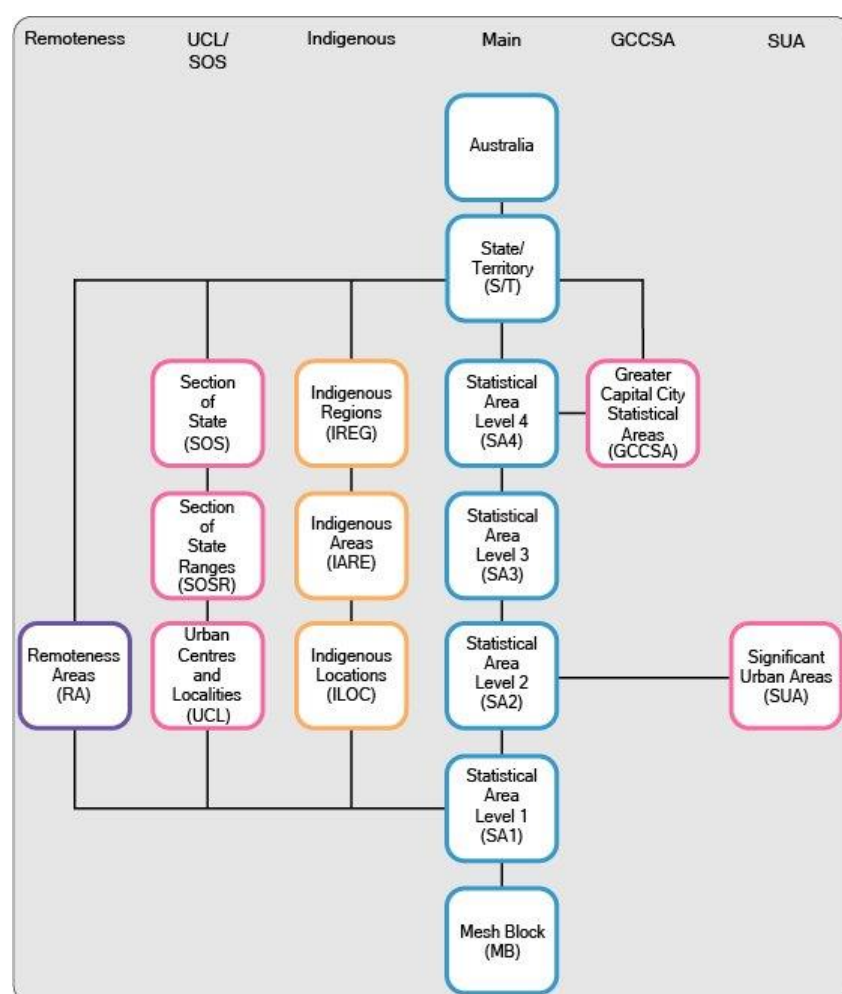
Figure 2-5: Non-ABS structures



Non-ABS Structures (Australian Bureau of Statistics, 2017b)

Secondly, the ABS statistical structures result in a breakdown that is illustrated in Figure 2-6 below. Intended to be more comparative than the non-ABS structure, these areas are defined at a federal level through the ASGS Structure.

Figure 2-6: ABS ASGS structures



ABS ASGS structures (Australian Bureau of Statistics, 2017b)

Both these structures can be aligned with Cooke and Leydesdorff's (2006) definitions, outlined in Table 2-1 below. Primarily, the functional reasons definition encapsulates the LGAs as well as the legislative layers of state/territory government.

Table 2-1: Definitions of regions - correspondence of definitions

Cooke and Leydesdorff (2006)	Australian Bureau of Statistics (2017b) non-ABS Structures	Australian Bureau of Statistics (2017b) ABS Structures
Geographical reasons	Natural Resource Management Regions Australian Drainage Divisions	Australia State/Territory
Functional reasons	State Suburbs Postal Areas Electoral Divisions Local Government Areas	Statistical Areas 1-4 Mesh Blocks
Social reasons	Tourism Regions	
Cultural reasons		Indigenous Locations, Areas, and Regions

Based on Cooke and Leydesdorff (2006) and the Australian Bureau of Statistics (2017b)

Due to constraints in data availability, this analysis uses the LGA data sets. Consistent data is available at this level from the 5-yearly census for three census periods (2006, 2011, and 2016) and allows for examination of the factors that can influence regional performance.

2.3.2 Ecosystems

The analogy of the economy as a biological environment is one that has gone through periods of popularity. Cavallo et al. (2018) identified early use of a natural environment analogy evolving from the biological economics of Alfred Marshall in the late 1800s – both Singer (1975) and Thomas (1991) reference the work of Marshall – to the ecosystem approach that was supported by Moore (1993). The ecosystem has become an analogous method of examination in business, economic, and innovation/entrepreneurial contexts. Adoption of the ecosystem analogy provides opportunities to refer to the elements and enablers (environmental conditions) and endowments (resources) that allow businesses (organisms) to grow, and for technological innovation (evolution) to occur and survive.

From these terms, ‘endowment’ and ‘enabler’ are more commonplace in regional development literature. Examples include McDonald and Maharaj (2015), who refer to the role that local endowment (such as a resource) has in regional development, whilst Argent et al. (2013) state that the endowment is a pre-existing attribute. Furthermore, McDonald and Maharaj (2015) refer to enabler as the opposite of a growth constraint. Detailed examination of the enablers for New South Wales regional economies were undertaken by the Centre for Economic and Regional Development (2017). In this context, enabling industries are the focal point – often those industries that have the potential to be large employment multipliers. These can interlink into several concepts, ranging from the triple helix (and the subsequent quadruple helix) that Leydesdorff and Meyer (2006) identified, to the role that these links between businesses and universities play in the role of regional development – examples

include Johnston and Huggins (2015), Strier (2010), Tomaney and Wray (2011), and Huggins and Johnston (2009). This leads to the need for further terminology to be defined.

2.3.3 Enablers

Examining enablers in the context of regional economies and regional development highlights how different approaches often reach the same end. Gunasekara (2006), when examining the role of industry–university links as part of the triple helix, identified that the university has become an enabler in regional development. When McDonald and Maharaj (2015) developed their approach to targeting economic growth, they examined the growth enablers (and, conversely, the constraints). The Centre for Economic and Regional Development (2017, p. 69) has identified three distinct categories of enablers:

1. Skills-related enablers.
2. Infrastructure-related enablers.
3. Regulatory enablers.

A longer-term strategic path can be identified by understanding the roles of enablers in a region's economic growth and activity.

Enablers, however, differ from endowments – endowments often fall into one of two categories: either built or natural (Centre for Economic and Regional Development, 2017, p. 70).

2.3.4 Endowments

Early references to endowments date back to the 1970s, and the term is still in use more recently. A cross-section of the use of endowments can be observed in:

- Singer (1975, pp. 378-379) references endowments as part of the comparative advantage.
- Porter (1996, p. 88) identifies that endowments play a role in cluster formation.
- Kitson et al. (2004, p. 992) state that national-level trade reflects the differing factor endowments.

- Centre for Economic and Regional Development (2017, p. 70) states that endowments form part of the reason why certain sectors flourish in a region.

The definition of an endowment, whilst broadly built or natural, includes the capital resources of a region. Cocklin and Dibden (2005, p. 4) detail five capitals – natural, human, social, institutional, and produced. In turn, this was cited by Beer (2012, p. 274) as four capitals: natural, human, social, and produced capital. This aligns with Singer (1975, p. 378), who identifies that factor endowments traditionally form part of the competitive advantage.

Examples include the abundance of labour leading to labour-intensive production. The role of the institutional endowment was highlighted by Wolfe (2010, p. 142) who stated that the relationship between the region, natural resources, and the capacity to build on the knowledge and skills of the region are part of the competitive success of a firm located in that region.

The inclusion or the consideration of endowments as part of the human and social capital narrative supports the measurement of the university, industry, and government collaboration.

2.3.5 Innovation

Innovation has long been recognised as a key driver in regional economic performance. For example, Enos (1962), identifies that innovation requires invention (and possibly inventions), whilst Markham (1962) explores the role governments have in this process.

Baptista and Swann (1998, pp. 528-529) examine the role of clusters in promoting competition between firms and how this drives innovation. Rather than relying solely on the university to provide research output that can be commercialised, the university is part of the commercialisation process due to specialised skills. The spillover of academic research is one of the components, along with the sharing of information.

More recently, research has focused on the effect that innovation can have on surrounding economies. Cooke (2001) examines the role of innovation in the new economy – a subset of

entrepreneurs who are engaging in new enterprises in reaction to the need for innovation. Studies such as Mueller (2006) examine the part that commercialised research from a university plays in the growth of an economy. This reflects the focus on building the connection between institutes.

The role of technology transfer has become an element that is increasingly under scrutiny; Wu et al. (2015, p. 14) state that university research patents can lead to technologies that are not mature enough to take to market, whilst Warren et al. (2008) explain that the idea of technology transfer was still novel for many universities, and possibly at odds with their primary purposes.

In Australia, Wise (2016) recognised the potential for universities to shape regional prosperity in *How regional universities drive regional innovation*. This report provides several strategies that can help regional economies:

1. Industry specialisation.
2. Providing a suitably skilled workforce for the local industries.
4. The use of teaching to drive innovation in the region.
5. The transfer of research into opportunities – the transfer of technology.
5. Industry clusters.

Furthermore, Etzkowitz (2002, p. 116) states that the role of transferring technology is an element in the incubation of new businesses within the triple helix model; that is, the ability to create new business enterprises that reflect the ties a university has within the home region, both formally and informally. This is closely related to concepts of academic entrepreneurship, most recently examined by Rippa and Secundo (2018), but also by others.

Commercialising research is not without challenges. In the United States, legislative change enabled the patenting of inventions produced with government funding through the Bayh-Dole Act. Further discussion on this topic can be seen in Friedman and Silberman (2003),

Fini et al. (2011), and Grimaldi et al. (2011) – who also discuss changes of a similar nature in other countries. Abreu and Grinevich (2013) illustrate the adoption of similar approaches in the United Kingdom over time, with the introduction of dedicated commercialisation offices. Importantly in the commercialisation landscape, Sheriff and Muffatto (2018) present a high value commercialisation opportunity with a barrier to competition: the ability to create a spin-off with a patent.

Expanding on this line of enquiry is Jefferson et al. (2018) who discuss the role of academic literature and research publication as part of the innovation and patent process. Their study examined the transfer of scholarly knowledge and output to economic outcomes (Jefferson et al., 2018, pp. 35-36). The identification that research output has a relationship with society, industry, and enterprise (Jefferson et al., 2018, pp. 35-36) is of particular interest – it is close to much of Etzkowitz and Leydesdorff's work on the triple helix model and index.

Combining innovation with the triple helix model can be seen as part of building resilient communities that can absorb shocks, maintain economic performance, and enable new opportunities. Etzkowitz and Leydesdorff (2000) return to the question of how a university in the triple helix model can be responsible for economic development as well as teaching and research.

2.3.6 Resilience

Resilience may appear tangential in this economic development discussion, but it is fundamental to an evolving region. Wolfe (2010, p. 142) identifies a resilient region as one where firms can move out of declining industries by drawing upon the local knowledge endowment to enter new areas that have growth potential. This local knowledge endowment may be captured in triple helix (partial or complete) relationships. With this considered, it is,

therefore, appropriate to explore the role of resilience of a region and the opportunity for a region to embrace the local knowledge endowment activity within the triple helix.

Apparent in the study of regions is that there are distinct levels of performance; this often joins with the concept of resilience, as external and exogenous events can influence performance. Revisiting Figure 2-1, resilience can be considered as the ability of a region to manage the risk of the population leaving after an event that reduces economic opportunities (Drennan et al., 2016, p. 82). Conversely, a resilient region may be able to attract new opportunities and avoid the spiral.

Resilience within an economy has been defined as the ability for a shock, event, damage, or loss to be absorbed or cushioned – that is, for the economy to continue with minimal adverse effect. Using this definition, Rose (2004, p. 308) drew upon the environmental science literature, referring to Holling (1973, p. 14), crossing over again to the natural sciences to build an economic concept. Martin and Sunley (2015, p. 4) align with the definition given by Rose, as well as referencing Holling (1973):

Table 2-2: The three main types/definitions of resilience

Definition/type	Interpretation	Main fields of use
Resilience as ‘bounce back’ from shocks	System returns, ‘rebounds’, to pre-shock state or path emphasises speed and extent of recovery.	So-called ‘engineering resilience’, found in physical sciences, some versions of ecology; akin to ‘self-restoring equilibrium dynamics’ in mainstream economics?
Resilience as ‘ability to absorb’ shocks	Emphasises stability of system structure, function, and identity in the face of shocks. The size of shock tolerated before system moved to new state/form.	So-called ‘extended ecological resilience’, found in ecology and social ecology, akin to multiple equilibrium economics?
Resilience as ‘positive adaptability’ in anticipation of, or in response to, shocks	Capacity of a system to maintain core performances despite shocks by adapting its structure, functions, and organisation. Idea of ‘bounce forward’.	Found in psychological sciences and organisational theory; akin to ‘robustness’ in complex systems theory; can be linked with evolutionary economics?

Definitions and types of resilience from Martin and Sunley (2015, p. 4)

However, a different approach was applied by Singer (1950), who states that in underdeveloped countries ‘manufacturing industries ... provide the growing points for increased technical knowledge, urban education, the dynamism and resilience that goes with

urban civilisation...’. This was applied to the field of economic development, particularly to developing and underdeveloped economies.

In a rural context, Steiner and Cleary (2014) identify several characteristics that may help create resilient rural businesses. Recognising the role those rural businesses have in their local economy, the need for a rural business to be resilient to external negative influences and react to positive influences quickly is crucial to remaining as part of that economy.

Martin and Sunley (2015, p. 2) recognise that shocks, changes, and disruptions influence economic growth within economies. Whilst these often originate from the national (or macro) level, they are often felt more acutely at the local, regional, or community level. This is partly due to the impact it may have on an individual industrial sector. Recognising that the interest in resilience is akin to the interest in clusters and competitiveness, there is a resulting policymaker engagement that further increases the interest and the resulting policies that focus on making regions resilient (Martin & Sunley, 2015, pp. 2-3).

The introduction of clusters and competitiveness leads to a brief discussion on specialisation, diversification, and clusters.

2.3.7 Specialisation and Diversification

Regions often have a specialisation which can be due to the endowments or an enabler. Conversely, they can also be a diverse economy with a broad range of industries. Duranton and Puga (2000, p. 534) give a third option: an economy that is both diversified and specialised. This specialisation can be observed in the clustering of industries due to a perceived advantage in the location of that industry. Rodgers (1957) identifies that the reliance on specialisation is not without risk, highlighted in the depression of the 1930s, and countered between then and the publication of his work by a trend towards a diverse

economy. This diversity can provide a stabilised economy through the periods of the economic, business, and environmental cycles that can impact regional economies.

2.3.7.1 Clusters

Behind much of the work on endowments, regional economic development, and specialisation is the concept of clusters. Clustering can be defined as the agglomeration of firms often focused on a specific area due to competitive advantage – the most famous proponent is Porter, who, with the publication of *The Competitive Advantage of Nations* in 1990, has driven much of the research on clusters.

In contrast, since the middle of the 1990s, Andrew Beer has undertaken an occasional cluster analysis of Australian industry. Through infrequent revisits to the cluster groupings that the Department of Home Affairs and Environment (1983) presented, Beer analysed a region's changing differentiation and specialisation. This can be seen in Beer (1995, p. 40), Beer and Maude (1995, p. 144) and Beer and Clower (2009, p. 381). Of interest is that rather than the concentration of industry that Porter focuses on, the focal point is on which places are classified in the same groupings – and how these have changed over time. Beer (1995, p. 45) notes, however, that there are industry integrations in a regional context, as manufacturing and processing are vertically integrated in some industries and regions. Examples provided include the move of sugar refining from Sydney to Grafton and Cairns – both near sugar cropping areas (Beer, 1995, p. 45).

In the revised edition, published in 1998 with a new introduction, Porter states that the competitive advantage is not the result of a macroeconomic decision, nor an abundance of resources; rather, the focus moved from the whole nation to individual industries (Porter, 1998, p. 9) and then onto the more detailed location of those industries. Often the industries are located in one of a few cities or regions for a particular reason (Porter, 1998, p. 29).

Historically, Hoover (1933) examined the concentration of the shoe manufacturing industry in the United States before the 1930s and the changes that took place with the discussion encompassing factors of production, the changing sources of raw materials (hide and tanning), and changing consumer trends.

Whilst Porter is recognised as one of the influential writers in this space, others have explored the concept of industry clusters. Some focus on the role that a university plays in the cluster when examining innovation clusters; examples include Cooke (2001), Cooke (2005), and Cooke and Leydesdorff (2006). The part that a university plays in the triple helix model as the origin of knowledge in a cluster can be seen in Etzkowitz (1994), Etzkowitz and Klofsten (2005), and Etzkowitz and Leydesdorff (1995). However, Porter is often cited alongside Etzkowitz and Leydesdorff when examining the role of transfer of knowledge from university to a region – examples include Huggins and Johnston (2009) and Huggins et al. (2008).

At a policy level, the cluster strategies can be applied by many organisations, with guidance evolving over time. Examples include the production of *The Cluster Initiative Greenbook* in 2003, and the follow-up, *The Cluster Initiative Greenbook 2.0*, in 2012. Using applied research on clusters, the development of clusters can be observed, and similar approaches undertaken. In the original survey, Sölvell et al. (2003) approached cluster initiatives on a global level – that is, organisations that were explicitly attempting to increase and grow the competitive nature of a cluster within a region through working across firms, government, and research – with an explicit reference to the triple helix (Sölvell et al., 2003, pp. 31-32).

Revisiting this in 2012, Lindqvist et al. (2012, p. 3) identify another theme to the organisational level efforts to boost regions. This time, the role of innovation is integrated into the cluster initiative's purpose. Innovation, however, also can be the base of a cluster. In the early 2000s, Cooke was a proponent of this. Cooke (2001, p. 952) discusses the role of

the regional and national system innovation system. There is a capacity at the national level for funds to be disbursed to scientific objectives, research strategies, and university training. However, whilst this innovation and attraction of high-tech firms can be a successful short-term strategy, the high-tech firms will move away unless the innovation becomes ingrained in the region's fabric. Cooke (2001, pp. 956-957) contrasts the successful attraction of Japanese electronics firms undertaking manufacturing in Wales from the mid-1970s, where there was a low need for entrepreneurial activity, to that of Scotland and Ireland, which had developed a need for entrepreneurial activity – as such, a second market was fulfilled by the spillover of the high-tech industry.

The role of Porter in strategy can be seen in many areas. Kitson et al. (2004, p. 996) discuss the influence that it has had on the United Kingdom's Department of Trade and Industry (DTI) and the approach adopted for regional performance measurement. This analysis was undertaken by Swords (2013, p. 375), who broke the rise of Porter's work down into component parts:

1. Changes in intervention policy – a move to lower-cost interventions such as technology and training.
2. A move to embed inward investment into regions – the challenge of promoting collaboration between large international firms and the smaller domestic incumbent firms.
3. A focus on vertical and horizontal groupings – the promoting research and development gains.
4. The creation of jobs for the proponents of cluster theory – a service industry providing guidance and support for cluster initiatives.
5. Porter's suggestions are generic and flexible, enabling them to be used in various places with the supplied tools to build the cluster.

Following the adoption of Porter's cluster theory by the Labour Party in the late 1990s and early 2000s, 154 clusters were identified in the United Kingdom. However, identified that changing political will at a regional level stymied the advance of clusters, combined with a

change in regional focus – a move from a region level to a city-region level, as referenced by Paasi and Metzger (2017, p. 20), these factors limited the further growth of clusters.

Beer and Maude (1995, p. 144) state that cities with a population of less than 10,000 can now be specialised. Whilst the increasing specialisation of a city can bring advantages, it can also bring risks. The dependence on a narrow industrial field increases the susceptibility to recessions.

2.3.7.2 Competitive and Comparative Advantages

Behind the work of Porter is the discussion on competitive and comparative advantages.

According to Porter (1998, pp. xxi, xxii), comparative advantage is focused on the input endowments available. In contrast, competitive advantage reflects the specialisation that (in the case of Porter's work) a nation has achieved.

Huggins (2003, p. 89) states that local and regional competitiveness is a measure of a region's sustainability – the ability of a region to offer sustainable growth at a level of wages that can enhance the standard of living. Examination of this has continued since Porter first proposed the differences. Examples include Eversole (2017, p. 310), who discusses the differences between competitive and comparative advantage in the regional development models and identifies that comparative advantage may lie in the physical attributes of a region that enable trade links or specific agricultural production. Terluin (2003) identifies transport links as one of the challenges in the growth of a region, allowing the trade of economic products.

Assessments surrounding competitive advantage have been undertaken by McDonald and Maharaj (2015), who used a competitive advantage framework to measure the ability of a region to grow, as well as any constraints to this growth. Complementing observations are found in Korsgaard et al. (2015). The competitive advantage of a place may ensure that

businesses remain there. Whilst many identify a physical attribute or a particular cluster of industry, Hira and Aylward (2013, p. 413) identify the consumer as a driver in a nation's competitive advantage.

Comparative advantage is often aligned with the natural resource sector. North (1955, p. 248) states that the comparative advantage begins with an exportable commodity due to the relative costs involved in producing and distributing that commodity. Following the commodity theme, Gunton (2003) examines the role that coal had in the development of British Columbia in Canada. This closely aligns with the staples theory that Watkins (1963) uses to examine the growth of the Canadian economy; the comparative advantage identified is the abundant labour available to extract the resource-intensive exports – or as Watkins (1963, p. 148) terms them, the staples.

North (1955) observes that the early comparative advantage that staples provide promotes the development of a distribution network of infrastructure to increase the competitiveness of their exports. This also drove the emergence of other supporting industries – like that observed by Cooke (2001) in Scotland – that support the growth of an economy external to the staples.

It is clear that there are many different approaches to the advantages that a region can have. The method of measuring this is the next step.

2.3.8 Key Works

Porter has already been discussed in the earlier section on clusters. However, there are other seminal authors in the research into regional economies, development economics, economic geography, and new economic geography.

2.3.8.1 Krugman – New Economic Geography

The rise of economic geography, and then the following new economic geography, can be charted through the work of Krugman. Economic geography has evolved. In the detailed account of the history of economic geography, Barnes (2011) describes it as a result of the Second World War. Both complementing and contrasting this, Amin and Thrift (2000, p. 4) describe economic geography starting as the study of the agglomeration of innovation, industry, and learning; it has become a valuable component in the analysis of economic activity. Krugman (1998) relates economic geography to spatial economics, tracing the history back to the 1820s and his earlier work in Krugman (1991).

Krugman (1991) states that economic geography aims to understand the part that location plays in economic analysis, particularly the concentration of industrial activity and development compared to those areas that have not incurred that development (Krugman, 1991, p. 485). Within this is the role of industrial concentration and the associated specialisation of labour, resources, and spillovers.

Krugman's examination of the pre-railway 19th century United States (1991, p. 486) is particularly interesting. At this time, the population was predominantly employed in agriculture, and there were high transport costs and a small commercial and manufacturing sector with limited economies of scale. This combination led to the needs being met by the regionally focused small towns, but the economy was not static. The evolution of technologies facilitated faster and cheaper transport (canals, railways, road transport) and thus the rise of certain regions over others.

Whilst this industry concentration can be explained, to some extent, by the changes in technologies, the role of the skilled (or suitably skilled) workforce is also involved. Krugman (1998, p. 8) uses the London financial sector as an example to explain that the pool of

individuals with the appropriate skills is concentrated there, and the prestige leads to many companies to locate in London. This becomes part of the underpinning framework for the new economic geography – understanding the linkages associated with market sizes combined with the immobile factors of production (Krugman, 1998, p. 9).

2.3.8.2 Martin – Regional Economies and Resilience

Since the early 2000s, Martin has worked extensively on regional economies, ranging from Kitson et al. (2004), which explored regional competitiveness, to Martin and Sunley (2015), which explores the ability of a region to be resilient. Encompassing the ability of regions to resist and respond to shocks, much of the work focuses on resilient communities and economies. Examples include Simmie and Martin (2010) examining the resilience of different types of economies and Fingleton et al. (2012) examining the long-term employment resilience of regions. Martin (2011, p. 3) explores the concentrated disruption that regional economies can suffer from when exposed to shocks and the ability to recover from these shocks. The differences exposed in the reaction (both disruption and recovery) that the economies exhibit are particularly important; that is, the degree of resilience to the shock events.

This interest in resilience is a recurring theme. As Martin (2011) identifies, many are working on this topic. A 2010 special edition of the Cambridge Journal of Regions, Economy and Society covers the constructions of the resilience concept and metaphor with papers such as Pendall et al. (2009) and Hassink (2010) that examine the concept and the application of the concept to regional economies. Many of the methods developed in measuring regional economic resilience can be applied to Australian regional resilience.

2.4 Metrics for measuring innovation and collaboration

Data can be collected from different sources to quantify the existence of the triple helix in the model form, where the results can be integrated subsequently into a triple helix model. For example, Lundberg et al. (2006, p. 576) state that bibliometric data was a dominant source of collaboration and adopted in part due to the inexpensive nature of its collection. Other methods, such as funding agreements (an example given in Lundberg et al. (2006) demonstrates the accessibility of this data in Sweden) can also provide insights into the nature of industrial funding of research. Lundberg et al. (2006) subsequently compared the bibliometric measurement with that of the funding arrangements as metrics of collaboration. The use of funding arrangements requires detailed, consistent, and accessible data in a standardised format over the study period.

Other metrics that can provide insights into collaboration within the triple helix model include patents, case studies and surveys. Subsequently patented knowledge or the intellectual property generated in the pursuit of patented knowledge, may result in financial reward for the university through royalties. However, when there are low rates of patents within academia (a risk that Abramo et al. (2011) revisited from their earlier work (in Italian)), there is limited advantage to adopting this method. The use of publications rather than patents as the measurement for academic performance, as identified in Leydesdorff and Park (2014), encourages collaboration and co-authorship both domestically and internationally. However, analyses still value patents, and have explored the nature of the triple helix model within the context of patents. Examples include Zhuang et al. (2021) that apply the triple helix model to intra- and inter- regional activity through the measurement of patent applications.

Whilst many researchers examine the university-industry collaborations through bibliometric methods, Ramos-Vielba et al. (2010) undertook in-person surveys to build the dataset required for their analysis. They present a valid alternative, albeit not a repeatable or scalable approach for future measurements.

The quantification of innovation can be captured by measuring patents and trademarks. Acs et al. (2002) used the number of patents combined with the innovation count to understand the role of innovation in the United States. Huggins (2003) identified this role of innovation as one of the metrics that can be used to assess innovation in a region (or nation). University-level innovation commercialisation can be captured in financial reports of universities; examples include the University of New England (2018, p. 36) where the income from royalties, trademarks, and licences was \$145,000. In contrast, the University of New South Wales received \$5,184,000 in the same income stream (University of New South Wales, 2018, p. 13), whilst Charles Sturt University received \$14,000 (Charles Sturt University, 2018, p. 93). This variation in royalties, trademarks, and licences can reflect the potential for economic growth of new companies, as identified by Friedman and Silberman (2003, p. 18), as well as the ability to generate revenue for the university.

However, whilst these methods provide the potential for detailed analyses, the potential for them to be repeatable and scalable can be limited. The use of funding sources, which can be identified in bibliometric data, has the most potential to be a metric for further investigation. This is a fruitful avenue to pursue in future research.

2.5 Metrics for the measurement of specialisation and diversification

There are several possible approaches for measuring industry concentration. As Delgado (2020) identified, the role of industry specialisation complements the role of innovation specialisation (in this context, the measurement of publications and author affiliations).

Returning to the underpinning theory, within new economic geography and the focus on competitive and comparative advantage, the measurement of industrial concentration in some form represents the ability to measure specialisations and concentrations. Cerqueti and Cutrini (2021) highlight this feature of regional economies, stating that the agglomeration of industries drives comparative advantage. Furthermore, drawing on the closing messages from the triple helix analysis, researchers must address locally relevant research questions. In this case, the locally relevant research question is measured by the degree of specialisation within a local government area.

In the history of economic specialisation, the derivation of suitable measurement solutions can be seen in Scitovsky (1955, p. 101). There is a discussion on the need for examining the industrial make-up of an economy, not necessarily because of the implications on economic competition (a traditional concern of economists), but rather, the concern of the public who would be interested in the economic and political effects.

Furthermore, Scitovsky (1955, p. 108) discusses the importance and efficacy of knowledge transfer to industrial applications. Whilst focused on the effect of industrial concentration (measured by size of organisation and subsequent market type), there are contrasting options. One is that large (dominant) organisations can invest in new, high-capital machinery. In contrast, the nimbler and potentially up-to-date newcomers and small businesses are forced to innovate and may have better business practices.

Recently, a flurry of studies has been undertaken on the use of specialisation measurements. Cerqueti and Cutrini (2021) reflect this interest in academic research, whilst Pominova et al. (2021) explore the use of the location quotient from the role of government (in this case, the United States Federal Reserve).

Within the choices of indices, Palan (2010) identifies two common approaches to measuring industry concentration: absolute specialisation and relative (heterogeneity) indices. Absolute specialisation captures the dominant industries as a share of the overall employment. In contrast, relative indices capture a relative specialisation between geographies of comparison. For example, in comparing European countries, Palan (2010) demonstrates the differences by using Finland's specialisation in communication technologies relative to other European countries. However, the absolute specialisation was low domestically. Palan (2010) states that there are risks when comparing the degree of specialisation. If there are similar specialisations in other geographical areas, then the risk of misidentification of specialisation (or downplaying the specialisation) is increased. If the specialisation is common across several areas, then the specialisation will be shown in the absolute specialisation measures but reduced in the relative (or heterogeneity) measures; if this specialisation is so common, it is prevalent in a higher geographical area.

Measurement of specialisation represents a method to measure the opportunities for economies of scale either within the individual organisation or amongst the individual organisations (Capello, 2002, p. 389).

2.5.1 Approaches to measuring specialisation

In this section, the two broad approaches Palan (2010) identified are examined in turn – location quotient and entropy-based indexes. Detailing the differences and advantages of each lead to the choice of measurement approach used.

There are two approaches to the measurement of industry specialisation. One is the measurement of specialisation (how specialised is the region?), whilst the counter is the measurement of diversification (how varied is the region's exposure to different industries?).

A desirable attribute is the ability to perform a decomposition of the measurement, a

characteristic that the location quotient and the entropy-based measurements enable. These were the measurements of focus before one measurement approach was selected.

When a high proportion of employment is concentrated into a small number of industries, it leads to the identification of a region as highly specialised. At a basic level, this form of measurement can be considered as a percentage of the population with a threshold greater than another region. Absolute specialisation can be a valuable measurement when exploring the resilience to shock in an economy, as highlighted by Aiginger and Davies (2004). The impact of a shock on an industrial sector with a high absolute specialisation will reflect the impact of a shock on a country's economic performance – scaled down to a regional level. Measurements such as the Hirschman-Herfindahl Index are classified as absolute measurements (Rodgers, 1957), as are the Shannon Entropy Index, the Ogive Index and the Rodgers (1957) Diversification Index. Simple relativity measurements, such as the location quotient, have been used to measure industry specialisation in terms of relativity to an average.

2.6 Gaps in Knowledge and Research Opportunities

From the preceding sections, research opportunities can be identified in the gaps in existing knowledge. This includes the application of the triple helix to the Australian economy as a country-specific study, particularly one with clear layers of governance. Whilst the work of Jefferson et al. (2018) examined 200 universities, the impact of smaller, regional universities on their communities and region may be more significant. Therefore, this research focuses on the relevance of research output on the regional economy and society. Taken together, an overview of knowledge transfer, regional economies, and co-authorship measurement provide an opportunity to analyse the change in a knowledge-based economy consistent with the approach undertaken in Leydesdorff and Cucco (2019).

The investigation will proceed to two stages. First, the knowledge relationships are measured through the application of the triple helix index. This provides the metric for collaboration between the research actors in the chosen landscape.

Second, applying the knowledge economy to develop an understanding of the performance of an economy at a regional level when referenced to both the triple helix and the triple helix index.

Chapter 3: Measuring the Triple Helix

Author affiliation through attribution of their recorded addresses when publishing research is a standard approach to the measurement of the triple (or n-tuple) helix. The challenge, identified by Leydesdorff and Sun, is the attribution of affiliations to one of the categories:

Within each country, even the attribution of addresses to institutes is already a nontrivial task, let alone the identification of all institutes in terms of sectors in the economy. (2009, p. 778)

Also identified, and of equal importance, is the standardisation and subsequent correction of addresses. These records were standardised in terms of precise addresses. Where necessary, name changes because of mergers and acquisitions were corrected so that a set of unique address identifiers was generated (Leydesdorff & Sun, 2009, p. 781).

The roles of universities, industry, and government within the triple helix have been identified, but the method to quantify this has not. Analysis of the approaches used by authors reveals a reliance on existing databases or refined datasets (e.g. Leydesdorff and Sun (2009) with a bespoke dataset formed as a report for Japan, and Abramo et al. (2014, p. 185) who had an ‘... algorithm of 30,000 rules’ with little transparency behind the methodological approach.

Systematic reviews as part of this data collection process are commonplace. Systematic literature reviews are increasingly used as tools for understanding the existing research; the ability to set out a structure to allow for literature examination within academic journals has become a powerful tool to understand the potentially large volume of literature. Miller et al. (2018) state that adopting a systematic literature review has become well-established in collating the required articles. Borrego et al. (2014) explore the use of systematic approaches

in engineering contexts. Their commentary on the adoption of the systematic literature review by other disciplines and the purposes of undertaking a systematic literature review is of interest.

A systematic literature review is a system-driven process completed in stages. Examples are the stages used by Moher et al. (2009), which were subsequently updated by Page et al. (2021) and Miller et al. (2018). Miller et al. (2018) explicitly establish in the first stage the process of the identification of keywords. The process they adopt is to first identify the keywords; second, search the selected databases; third, select the articles; fourth, extract data; and finally, analyse this data using an appropriate tool.

The approach adopted for this research is primarily that of Moher et al. (2009) and Page et al. (2021), with Miller et al. (2018) providing some of the contextual elements that are particular to the research of the triple helix elements, in particular the discussion surrounding database selection. Like many other systematic literature reviews that originate from a discipline other than economics, business, or geography – it is predominantly from medicine. Recent work from Schmitz et al. (2016) examines innovation and academia, whilst Järvi and Kortelainen (2017) use a systematic literature review on business ecosystems, supporting the adoption of the systematic literature review in this area.

A traditional systematic literature review may follow keywords or other search terms. In this case, adopting a systematic literature review required a bibliographic and bibliometric process. Schmitz et al. (2016, p. 373) state that the ‘...bibliometric analysis consisted of the identification of publications by year, main authors, main journals, research areas, and main keywords.’ Historically, Tijssen (2006, p. 1574) utilised a bibliographic technique to examine the relationship between research (and researchers) and industry.

Tools that draw from scientometric, bibliometric, and informetric analytical disciplines are applied to analyse the data collected from the systematic literature review. Whilst these appear interchangeable, they are not in practice. Hood and Wilson (2001, p. 309) describe the terms as related and capable of defining part or all of the combined discipline – treating it as a discipline with a common theme. Therefore, this requires the terms to be defined.

3.1 Bibliometrics, Scientometrics and Informetrics: Differences and Similarities

This section defines the common terms bibliometrics, scientometrics, and informetrics for clarity and consistency in language. Some authors' unfamiliarity with these terms leads to a concern that confusion can exist in the literature. Hood and Wilson (2001) state that this problem occurs when information scientists who are unfamiliar with the differences use the terms. Therefore, a clear definition and identification of the approach used to undertake the analysis are required. This ensures that the risks identified by Hood and Wilson (2001) are reduced.

However, the literature is inconsistent when it comes to establishing an explicit definition. Gingras (2016, p. 1) states that scientometrics is the study of scientific activity in all disciplines. Thus, bibliometrics is a subset of scientometrics as it covers the analysis of publications and their properties. In contrast, Mejia et al. (2021) also identify potential and actual overlap and the degree of interchangeability between terms whilst identifying historical efforts to create boundaries. Further, they state that, in some cases, informetrics can include both bibliometrics and scientometrics (Mejia et al., 2021, p. 2). The definition of Mejia et al. (2021) can be seen in the work of Björneborn and Ingwersen (2004) who examine the role of webometrics (a specific subset of web-based data analysis) within the broader informetric analysis tool set.

Figure 3-1: Relationship between informetrics, bibliometrics, scientometrics, cybermetrics and webometrics.

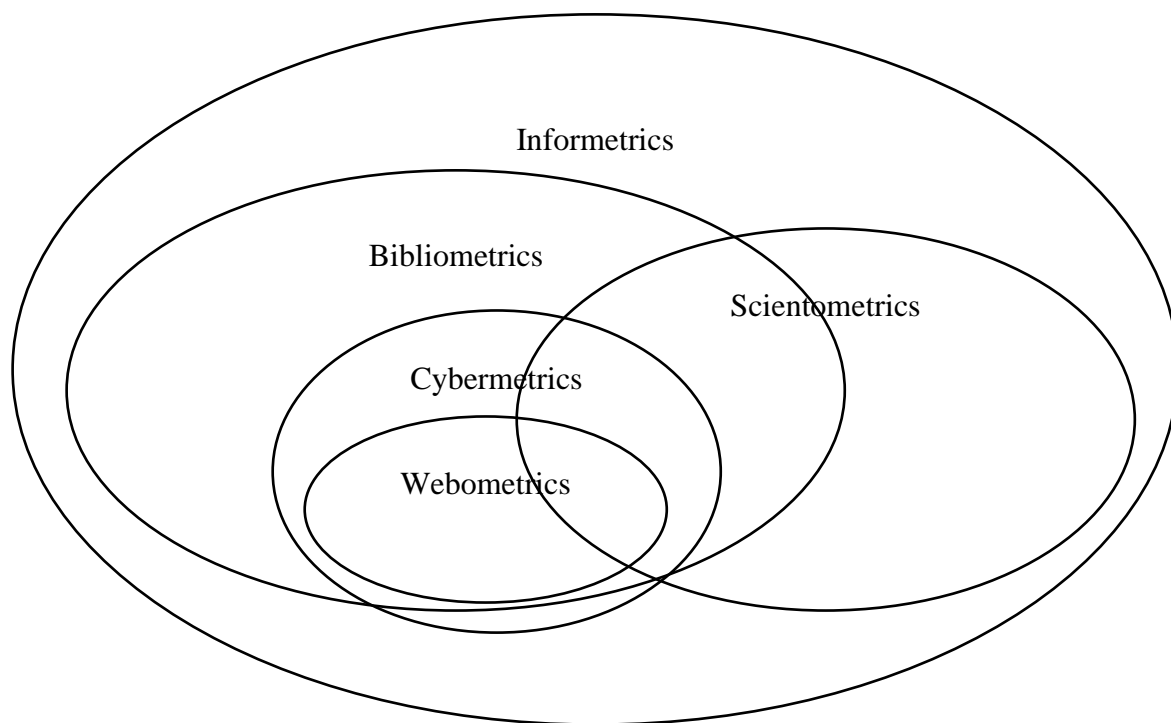


Diagram based on Björneborn and Ingwersen (2004, p. 1217) showing the intersection of the different techniques.

Whilst Figure 3-1 includes the role of cybermetrics and webometrics; both are only included to replicate the original diagram. For this study, cybermetrics and webometrics are not considered further. Shaping this is the recognition that webometrics draws upon the approaches of bibliometrics and informetrics (Björneborn & Ingwersen, 2004, p. 1217), so these are subsets of tools that are under consideration.

Mejia et al. (2021, p. 1) state that:

Bibliometric methodologies are considered useful as supporting tools for decision-making in setting research priorities, tracking the evolution of science and technology, funding allocation, and rewarding scientific excellence, among others.

Furthermore, the availability of the metadata in academic databases such as the Web of Science and the increased availability of tools and methods has allowed the adoption of bibliometric methodologies beyond the traditional library and information science applications.

Subtle differences underpin these methodologies. Authors such as Brooks (1989), Hood and Wilson (2001), Gingras (2016) and Mejia et al. (2021) provide a synopsis of the literature that outlines these differences. This synopsis is used to explore the applications of bibliometric, scientometric, and informatic tools.

As a distinct historical background for each term is clearly identified in the existent literature, the following definitions do not cover the history of the tools. This has been covered in the research surrounding information and library science, including Hood and Wilson (2001). However, where the inclusion of history is pertinent, references are made to the historical context. Both Hood and Wilson (2001, p. 291) and Gingras (2016, p. 1) attribute scientometric dating back to the Russian physicist Vassily Nalimov in 1969. In contrast, bibliometrics originated in the French research environment, with Alan Pritchard identified as the modern originator of the approach.

3.1.1 Definition of Bibliometrics

Bibliometric analysis is a tool used to measure citations, co-authorship, or similar metrics that can be measured from within the publication. The measurement of citations in an index form or publication counts can be traced back many centuries – both Hood and Wilson (2001) and Meijers (2007) recognise the application as dating back to at least the 12th century for the former, whilst the latter can be seen in research from the late 18th century to early 19th century.

At a basic level Godin (2006) states that bibliometrics is the count of papers and subsequent citations. Drawing on the definitions used by Brooks (1989), Tague-Sutcliffe (1992) defined bibliometrics as the quantitative study of information and the subsequent use of mathematical models in a predictive and decision-making role.

3.1.2 Definition of Scientometrics

Brooks (1989) provides some historical context regarding the growth of scientometric analysis. Detailing a meeting in the 1970s, Brooks describes the methods used to measure the performance of Ukrainian research institutions. Tague-Sutcliffe (1992, p. 1) defines scientometrics as the ‘study of the quantitative aspects of science as a discipline or economic activity’. Importantly, and unlike bibliometrics, the quantification includes a wide range of activity rather than only publications.

Hood and Wilson (2001, p. 293) identify the role of scientometrics in the analysis of researcher practices and the potential impact of government policies on science and technology. Furthermore, Brooks (1989, p. 36) identifies the work of Claude Shannon and the role of information theory – explicitly, the measurement of information in bits.

3.1.3 Definition of Informetrics

Hood and Wilson (2001) recognise that there are many interpretations of the definition of informetrics, starting in the late 1970s with Nacke as an element of information science that deals with the measurement of information and the mathematics of measurement. However, this was not a static definition. It has continued to evolve through the later 20th century. With this moving and evolving definition, the position of informetrics is now such that it covers beyond science, which is the conventional application of scientometrics according to Hood and Wilson (2001), Hlavcheva et al. (2019), and Mejia et al. (2021)).

Informetrics is defined as capturing a much wider range of research and knowledge output and is not limited to scientists. Importantly, it looks at information from all social groups, both informal and spoken communication.

3.2 Final Methodological Approach

Mejia et al. (2021, p. 2) state that a scientometric study can measure university–industry collaboration. Furthermore, with Brooks (1989) linking Claude Shannon and information measured in bits, the overarching research approach can be classified as scientometric. Lastly, Hood and Wilson (2001) state that in the 1990s, scientometrics was considered as the method that favoured the examination of policy. This is not surprising given the use of a tool developed by Leydesdorff, who often publishes in *Scientometrics*.

3.2.1 Methodological Approach

Fundamentally an algorithm can be defined as ‘A documented series of steps which leads to the transformation of some data’ (Oxford Dictionary of English, 2010). With this definition, the reference to the use of algorithms is justified. However, the explanation of the algorithm has been limited. For example, Abramo et al. (2014, p. 185) reference an algorithm of 30,000 rules, and therefore (referencing the definition above), the documented steps are limited.

From the outset, the aim has been to develop a transparent algorithmic approach that will allow future research to leverage the knowledge and application and ensure an accelerated repeat of the research methodology.

3.2.2 Scope and Repeatability

Foundational to any of these approaches is the scope of the analysis. By extension, the ability to repeat the same analysis in the future with expanded data requires a clear definition of the scope and terms. Scope can be defined as a geographical area. For example, Abramo et al. (2014) set the geographical boundary as Italy, whilst Leydesdorff and Sun (2009) set the boundary as Japan (with a secondary analysis of Canada). Alternatively, it may be a field of interest. Abramo et al. (2014) set the research of interest as the physical sciences within Italy – combining the two approaches to establishing the scope. The involvement of the Food

Agility CRC as a supporter of this project ensured the focus of the output on the agricultural sectors.

Chapter 4: Data Collection

Etzkowitz and Leydesdorff's (1995) triple helix has been used for many studies of university–industry–government relationships. Focusing initially on knowledge-based economic development, the triple helix has been used to analyse society, uncertainty of knowledge transmission, and extended to cover global relationships of the research partnership.

4.1 Bibliometric data collection

The why of this role in economic development is separate from the method of collecting the data for the required analysis. A methodological focus is missing in many papers, and those discussing data collection only do so in passing. Many articles refer to data originating with the Web of Science, one of several bibliometric databases available to researchers, yet they do not explain the collection method in depth. Importantly, this lack of transparency is one of Gingras (2016, p. 64) criticisms of many bibliometric and scientometric studies. He states that '...evaluations should be as transparent as possible when they can affect people's careers.'

Utilising secondary data, the collection process adopts standard processes for systematic reviews. However, extending this process into adopting a documented replication and extension process ensures that the process becomes increasingly robust.

Other disciplines, particularly health and medical sciences, have a clearly structured approach for collecting large-scale bibliometric databases for systematic review. Adopting such a system increases the replicability of any study and the transfer to other locations using the same methodology. The adoption of the framework set out by Moher et al. (2009) is

commonly referred to as the PRISMA Statement rather than the full name of ‘Preferred Reporting Items for Systematic Reviews and Meta-Analyses’.

An explicitly structured approach to meta-analysis, the PRISMA Statement sets out the processes to be followed to undertake the analysis in such a manner that the quality and structure of the results are clear for all to follow. Increasing the ease of replication is a key tenet of the PRISMA Statement. For this reason, I decided to follow the same structure.

4.1.1 Methodology: PRISMA Statement for Data Collection

Application of the PRISMA Statement to the data collection stage ensures a systematic, recorded approach. Adopting a transparent and replicable approach to data collection in the PRISMA Statement provides the framework for data analysis. Furthermore, this also ensures the ability to repeat the process for either the same data (with a different year range) or a different geographical boundary. The extension of this methodology is a modular approach to the measurement problem and is intentionally scalable, having been tested in a small subset proof of concept scenario.

4.1.1.1 Database Selection

Initially, and in line with the PRISMA Statement, all databases were considered. As other researchers who had collected data had recorded the use of Web of Science, Scopus, and ProQuest databases, the use of these databases was explored. Examples include Borrego et al. (2014) who applied the technique to engineering and Fellnhofer (2019) to entrepreneurship using ProQuest, whilst Scopus was used by Pierpaoli et al. (2013) examining agriculture technology adoption, and Järvi and Kortelainen (2017) for examining research of business ecosystems. Aligning with Gingras (2016, p. 63), where the history of Web Science is discussed, both Web of Science and Scopus were examined as data sources. The increasingly widely used Google Scholar were also considered, but according to Gingras, Google Scholar

is not viable as an alternative data source due to the uncontrolled and variable data. This does not meet the need for consistent address-level data for author affiliation.

Alternatively, new databases such as Lens (<https://www.lens.org/>) and Dimensions (<https://www.dimensions.ai>) attempt to provide consolidated, single points of reference for academic research and patent output. With the capacity to capture not only academic research, but also patent activity (as discussed in section 2.4) and the potential for these databases to replace the traditional databases of Web of Science and Scopus for scientometric analyses of research collaboration. The use of metadata to present detailed breakdown of the research connection and interaction is appealing for scientometric researchers.

4.1.1.2 Rapid Testing with a Small Subset of Data, and Subsequent Flaws Identified

The chosen databases yielded generally successful results, but flaws were identified in an exploratory data validation process. This exploratory analysis used the same search terms across all the databases, yielding inconsistencies in the data stored within those databases. An example, such as Dang et al. (2010), can be found in the databases. However, differences appeared when using a database that relied on the Global Research Identifier Database (GRiD, <https://www.grid.ac/>), as outlined in Table 4-1.

Table 4-1: Difference between Web of Science and Lens

In Web of Science	In Lens (using GRiD)
Queensland Primary Ind & Fisheries, Emerald, Qld 4720, Australia	Emerald Group Publishing
CSIRO Sustainable Ecosyst APSRU, St Lucia, Qld 4067, Australia	Commonwealth Scientific and Industrial Research Organisation
CSIRO Sustainable Ecosyst APSRU, Toowoomba, Qld 4350, Australia	

Difference between addresses for a selection of addresses for Dang et al. (2010)

As several databases adopt GRiD for identifying organisations, issues arose because of inconsistencies in the target data being collected and the address details. This is an issue that

needs to be resolved since the purpose of performing the n-tuple helix analysis is to locate the organisations geospatially. With the use of GRiD, the organisations were consolidated to a head office location, as outlined in Table 4-1 which show that GRiD consolidated the Australian CSIRO into a single entity, as opposed to the individual research offices that are spread throughout Australia. This also applied to universities with multiple campuses or research stations located in regional areas hundreds of kilometres from the main (administrative) campus. Furthermore, the GRiD was configured to process Emerald as Emerald Publishing Group, removing the occurrence of the Queensland Department of Primary Industries and Fisheries in Emerald. This is a risk with any algorithmic process for address categorisation and classification.

Subsequently, databases from Lens, Scopus, Dimensions, and ProQuest were discounted because of this data consolidation using GRiD or similar. This left the Web of Science as the source of data.

4.1.2 Following the PRISMA Statement

The decision to follow the PRISMA Statement provides explicit requirements for the record-keeping and structure required for a systematic review. The following search criteria were used to collect the required data:

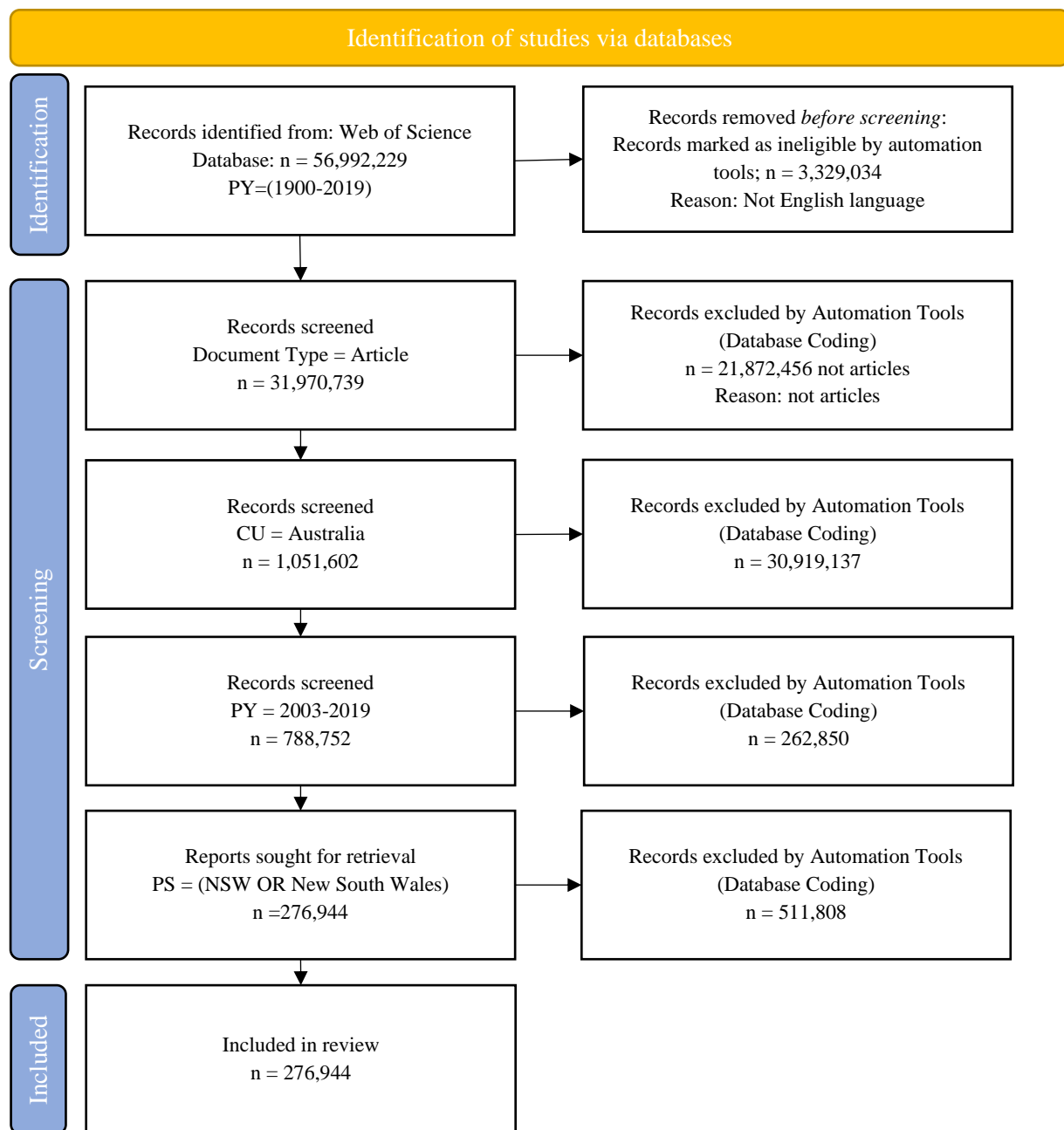
Table 4-2: Web of Science search term including New South Wales

((PY=2003-2019) AND (CU=Australia) AND (PS= (NSW OR New South Wales))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article)	Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years
---	--

Search criteria used to collect the required data, where CU is Country, PY is the Year Published, and PS is the Published State (or territory).

Aligned with the full PRISMA flow diagram, excluded records could be recorded throughout the data collection process. This resulted in the final 276,944 records being identified for subsequent analysis through the application of algorithms.

Figure 4-1: PRISMA 2020 Statement flow diagram



PRISMA 2020 Statement Flow Diagram from Page et al. (2021), Framework retrieved from <http://prisma-statement.org/prismastatement/flowdiagram.aspx>

4.1.2.1 Subsequent Data Collected

To process the data, 276,944 records were downloaded manually from the Web of Science as XLS files of 500 records at a time. This was undertaken over four days in December 2020 and provided the base for further analysis. Full records were chosen and allowed for the capture of 68 variables (some were blank) covering many aspects of the journal articles. The XLS files were organised into year folders upon downloading. To ensure all files were

imported and sorted correctly, import into R and RStudio (R Core Team, 2022; RStudio Team, 2022) was undertaken using scripts.

4.1.3 Following the PRISMA Statement for the Agricultural Subset

Driven by the funding received from the Food Agility CRC, the focus group is research relevant to the areas that the Food Agility CRC is working on.

With the use of the PRISMA Statement, the ease of changing the process to capture subsets at the database level is possible. Selecting Food Science Technology, Agriculture Dairy Animal Science, Agriculture Multidisciplinary, Horticulture, Agricultural Engineering, Agricultural Economics Policy, and Fisheries from the Web of Science subject categories (in the code used for selection, WC) aligns with the areas of interest for the Food Agility CRC.

The search code used for these categories can be seen below:

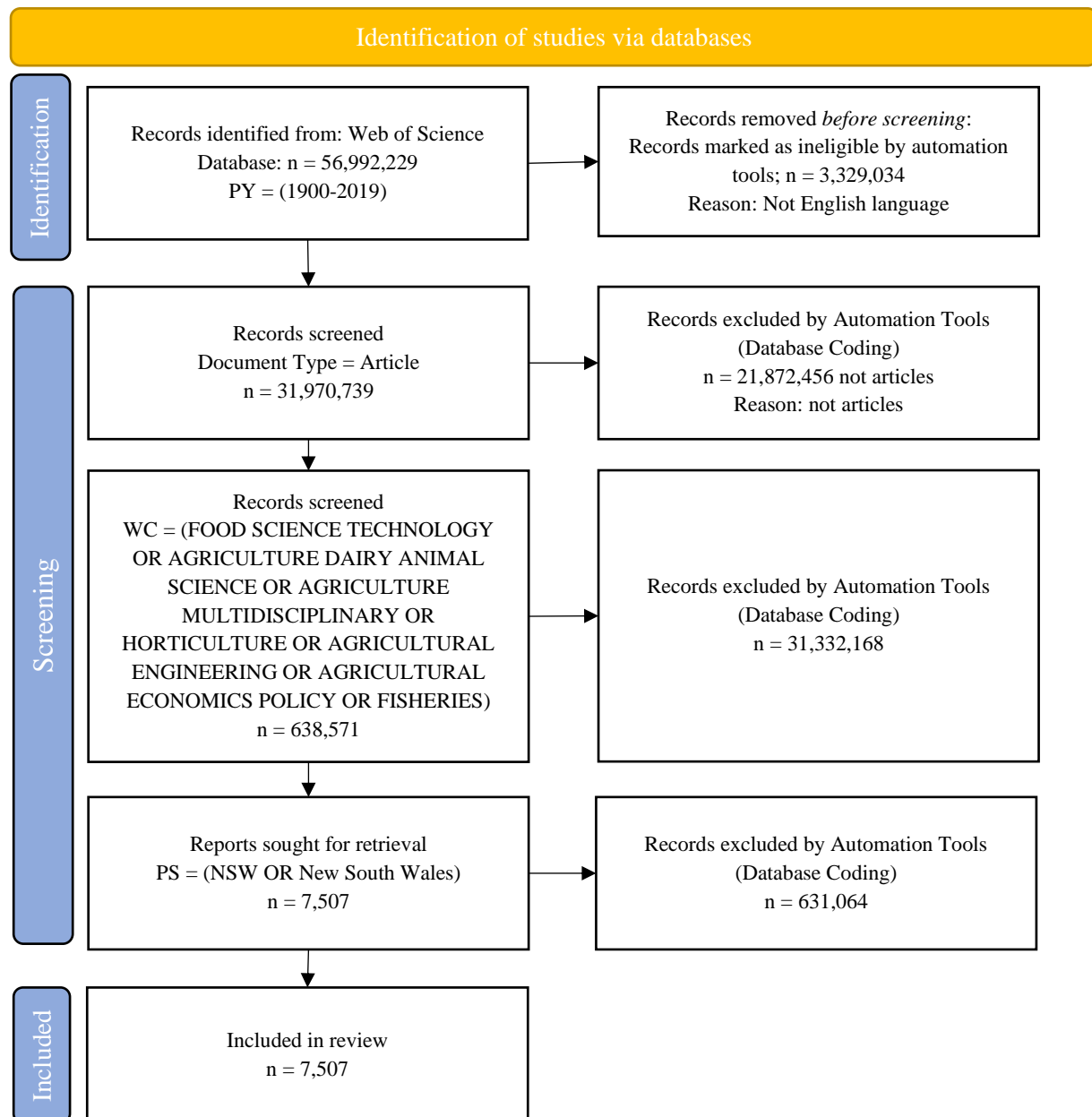
Table 4-3: Web of Science search terms for the agricultural fields

(PY=2003-2019 AND (CU=AUSTRALIA) AND (PS=(NSW OR New South Wales) AND WC=(FOOD SCIENCE TECHNOLOGY OR AGRICULTURE DAIRY ANIMAL SCIENCE OR AGRICULTURE MULTIDISCIPLINARY OR HORTICULTURE OR AGRICULTURAL ENGINEERING OR AGRICULTURAL ECONOMICS POLICY OR FISHERIES))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article)	Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years
---	--

Search criteria used to collect the required data, where CU is Country, PY is the Year Published, PS is the Published State (or territory), and WC is the Web of Science Category.

Following the same process as that set out in Figure 4-1, the addition of the relevant categories can be seen in the following PRISMA flow diagram:

Figure 4-2: PRISMA 2020 Statement flow diagram for an agricultural subset



PRISMA 2020 Statement flow diagram from Page et al. (2021), Framework retrieved from <http://prisma-statement.org/prismastatement/flowdiagram.aspx>

As illustrated, the ease of inclusion at this point, whilst requiring an additional download process, is evident in the traceability of the process undertaken.

4.1.4 Exploratory Data Analysis

With the secondary data collection, a preliminary data analysis could be undertaken. Overall, the number of papers produced increased in the examined period across all research areas;

however, in contrast, agriculture followed a more consistent trend with similar annual numbers tending upwards towards the end of the selected period.

Table 4-4: Comparison of annual figures from Web of Science

Year	First Search (All)	AND (CU = (Australia))	AND (PS = (NSW OR New South Wales))	AND (WC = (FOOD SCIENCE TECHNOLOGY OR AGRICULTURE DAIRY ANIMAL SCIENCE OR AGRICULTURE MULTIDISCIPLINARY OR HORTICULTURE OR AGRICULTURAL ENGINEERING OR AGRICULTURAL ECONOMICS POLICY OR FISHERIES))
2003	809,814	23,246	7,725	352
2004	847,898	24,751	8,304	300
2005	890,346	25,654	8,721	307
2006	937,450	27,894	9,473	343
2007	974,437	30,042	10,339	374
2008	1,038,430	33,016	11,166	415
2009	1,081,555	35,615	12,174	358
2010	1,129,925	38,446	13,188	421
2011	1,207,106	42,319	14,687	393
2012	1,269,668	45,698	15,946	387
2013	1,348,104	50,873	17,849	465
2014	1,393,829	54,192	19,081	496
2015	1,614,110	65,229	22,926	506
2016	1,680,246	68,183	24,398	550
2017	1,739,758	69,626	25,150	596
2018	1,826,067	72,852	26,161	597
2019	2,036,157	81,159	29,647	647

Summary of annual data from Web of Science, as retrieved on 30 of December 2020.

4.2 Industry data

Data available from the Australian Bureau of Statistics Census ensures consistent boundaries and measurement approaches. This provides the industry context at a broad level for the Australian economy.

Using data collected by the Australian Bureau of Statistics Census (2006, 2011 and 2016)¹, measured with the 2016 local government area (LGA) boundaries, 19 industrial groups for

¹ These three census periods were chosen due to the consistency of sub-state level boundaries. ABS statistical geography was not consistent during this period, therefore LGAs were adopted as the most consistent

employment were identified. Returning to the commentary in Chapter 2, and specifically Table 2-1, the role of LGAs as a representation of similar regions is more appropriate and manageable than using the Australian Statistical Geography Standard with the SA3 region. Furthermore, using LGAs allows for a clearer planning and relationship identification strategy within an economic development scenario.

Within the census data, the industry of employment is classified by Australian and New Zealand Standard Industrial Classification (ANZSIC) (Australian Bureau of Statistics, 2006) at the division level – single letter identification – and contains nineteen categories:

Table 4-5: ANZSIC Division Codes as found in the census results

ANZSIC Division Code	Full Name
A	Agriculture, Forestry and Fishing
B	Mining
C	Manufacturing
D	Electricity, Gas, Water and Waste Services
E	Construction
F	Wholesale Trade
G	Retail Trade
H	Accommodation and Food Services
I	Transport, Postal and Warehousing
J	Information Media and Telecommunications
K	Financial and Insurance Services
L	Rental, Hiring and Real Estate Services
M	Professional, Scientific and Technical Services
N	Administrative and Support Services
O	Public Administration and Safety
P	Education and Training
Q	Health Care and Social Assistance
R	Arts and Recreation Services
S	Other Services

ANZSIC Codes used, excluding Inadequate Description

By measuring the labour force industry of employment at the three census periods, it is possible to see the changes in industrial activity and specialisation for a given region.

Chapter 5: Development of Algorithms

The quest for a transparent and repeatable algorithmic approach leads to the adoption of open-source programming languages. This approach also allows for replication using like terms and an individual researcher's set of algorithmic rules – or adopting the set of rules used here for a repeated study of New South Wales research output.

As has been identified, using predefined – often of a black-box nature (i.e., not shared) – to classify organisations is commonplace. With both Abramo et al. (2014) and Leydesdorff and Sun (2009) referencing the use of predefined terms for the organisation types or implying the use of algorithms to generate such lists, there is no explicit reference to these terms. The lack of an algorithm precludes the replication of this methodology.

Furthermore, using current and commonly used programming languages, such as Python or R, allows replicable tools to be developed. With a small set of data, using Microsoft Excel is possible with the correct use of IF statements – an ideal solution for early exploratory analysis. The approach of evaluating a small amount of data was undertaken and demonstrated that the concept of data categorisation was possible. This exploratory data analysis was conducted in Excel until the limitations were identified due to the increasing complexity of the categorisation process. Once the limitations were reached, dedicated programming languages capable of managing a larger dataset and increased repetitive complex functions were adopted.

Languages such as Python and R provide the opportunity for scaling approaches, and both can manage large volumes of data. However, the challenge in this application is the ability to process textual data. For this purpose, R was chosen due to the knowledge available. With the

adoption of R and RStudio, the ability to present a scalable and repeatable methodology enables the replication of the approach in the future.

Fundamental to developing the following algorithm was data management flow to ensure that the original records were undamaged and unaffected. With 68 variables per record, some of which were blank, the volume of data was large.

5.1 Fundamental Stages of Data Handling

The first stage in managing and developing an algorithmic approach is to address identification and separation. With this extraction of organisational address-level data, it is then possible to address the challenge associated with the classification of organisation. The requirement for a clear flow of these processes is fundamental to the transparency and replicability of the methodology.

5.1.1 Address Extraction

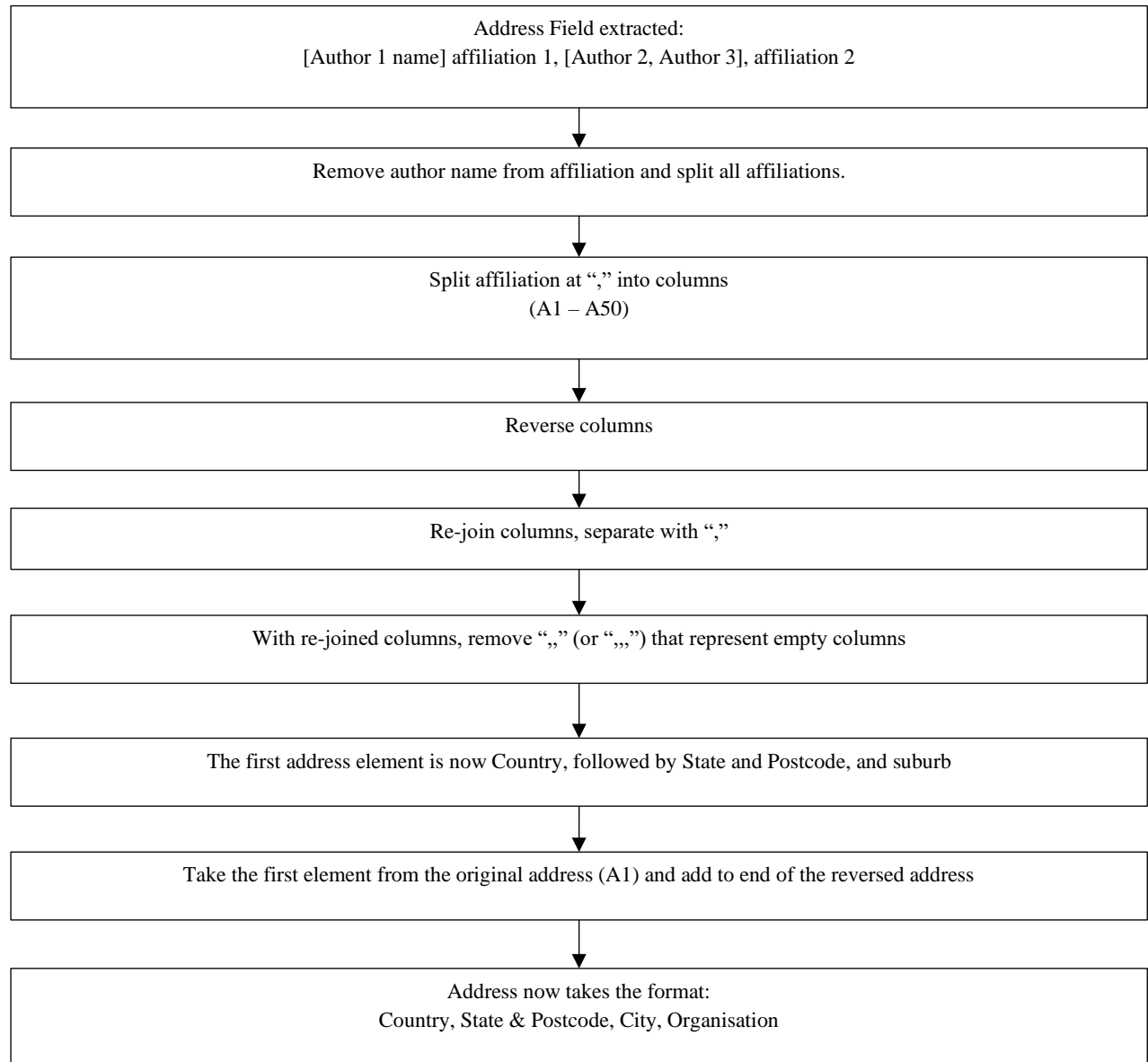
The ability to identify organisational type is fundamental to the identification of the triple helix. To classify organisations whilst presented with the lack of process by existing practitioners, it was necessary first to separate the addresses and then identify organisational types.

Addresses within the downloaded data are stored as a combined field comprising author name and affiliation. However, the exclusion of three years (2003, 2004 and 2005) within the complete Web of Science dataset was necessary as the data was inconsistently formatted and organised to be usable. The resulting dataset from 2006 to 2019 became the focal dataset, and 252,175 records were analysed.

With a standard pattern of addresses identified, it was possible to implement an algorithmic approach to separating the addresses. To extract the author addresses to undertake the n-tuple

helix analysis, it was necessary to break the ‘Addresses’ field down, separating author names from the addresses whilst retaining the data integrity. By separating the addresses from author and individual record, the development of a lookup-style approach to classification is possible.

Figure 5-1: Process to extract the author affiliation address component of the Address field



Process to extract the author affiliation address component of the address field within R

The extraction of addresses was undertaken with the downloaded data. From 252,175 records – with up to 552 addresses per record – 1,287,248 addresses were identified. These addresses are global, and parallels can be drawn with the quadruple helix example for Japan

(Leydesdorff & Sun, 2009), comprising university, industry, government, and foreign collaboration. Leydesdorff et al. (2013) presented an analysis tool, th4.exe, which this study has replicated in R with further extension due to constraints.

Extraction of the Australian addresses from the list of all addresses resulted in 569,030 addresses – not only New South Wales but across all of Australia. The unique function was used with the cleaned and simplified addresses to remove duplicates from the dataset. This resulted in 122,266 records. Without performing standardisation and simplification, this number would have been much greater.

5.2 Data Transformation

To perform the n-tuple helix analysis, it was necessary to classify authors by address as members of university (*U*), industry (*I*), government (*G*), other states (*S*) or overseas (*F*), as in Leydesdorff and Sun (2009). This was performed in two stages. First, by identifying addresses in Australia, and second, by examining the address for indicators of the group they belonged.

5.2.1 Data Item: Address Identification and Cleaning

Applying an approach where the addresses and organisation names are standardised – the time-consuming element Leydesdorff and Sun (2009, p. 778) refer to – requires a systematic approach. Unable to be fully automated, this classification required a partially automated process. The use of R enabled sorting by country; subsequently, a final count of 122,266 was identified as being addresses in Australia.

Typographical layout is one cause of the need for standardisation. Where there is insufficient kerning, this generated errors for combinations such ‘r’ and ‘n,’ which would be read into the address line as ‘m’ instead of ‘rm’. Examples include Melbourne. Other combinations include

‘r’ and ‘m’, where ‘rm’ becomes ‘rrn’. As an example, this occurred with Armidale. Once these patterns become apparent, it is possible to work through the list of addresses and identify where the issues occur.

To reach the final number, corrections were made to the typographical errors, as well as address inconsistencies (particularly the naming of universities where abbreviated names are commonplace or institutions have changed name – Ballarat becoming Federation, University of Western Sydney becoming Western Sydney University), suburb spelling errors, misreading of typed names (examples include Melbourne instead of Melbourne), American English spelling of place names (Coffs Harbor instead of Coffs Harbour), and the use of corporate names without Pty Ltd. Further challenges included names with or without spaces, different orders for department names or extended names, including faculty and department. This aligns with the experience of Leydesdorff and Sun (2009), who standardised the addresses for their Japanese dataset, which also experienced organisational name changes. To address these challenges, it was necessary to simplify addresses, with addresses separated at the comma and then reversed before being re-joined into a single vector.

As the list was organised, other problems appeared within the data. Due to the history of Australia, many domestic place names are common with those in the United Kingdom, the US, Canada, New Zealand, and South Africa. Examples include Penrith, Newcastle, Kensington, Perth, and Sydney. These were discovered through manual searching. Once patterns were identified, they required further analysis. Common signals that these may have been incorrect were lack of Australian postcodes (four digits), use of postcodes for other countries, organisations that did not operate in Australia (for example, the Mountain Rescue Council of England and Wales is headquartered in Penrith, Cumbria, but within the data was found allocated to Penrith, NSW).

Furthermore, when geocoding the addresses with ArcGIS (Esri, 2020), preferencing of the locality over the suburb occurred – an example of this was an Enmore address located in northern inland NSW (Enmore) rather than the Sydney area. This required processing within R to clean the data and ensure it was suitable for use.

These processes align with the study selection, data collection process, and data items identified in the PRISMA Statement.

5.2.2 Data Analysis: Address Classification

As has been highlighted, there are many addresses, but some contain clear clues as to the organisation type (a university is ‘univ’ in Web of Science, ‘Pty Ltd’ denotes an Australian corporate entity, ‘CSIRO’ is the Commonwealth Scientific Industry and Research Organisation). Simple categorisation based on these is possible, however, assumptions can oversimplify and lead to errors. Web of Science abbreviates certain words systematically; once these patterns are identified and understood, creating scripts to categorise data is possible. However, because of the nomenclature used for organisations, initial assumptions can be incorrect. Examples include the categorisation of ‘Sch’ or ‘Coll’ as government or university organisations: Whilst many schools (sch) are government-run, not all are in Australia. ‘Sch’ can also denote a school within a university structure. Therefore, each example of ‘Sch’ needed to be examined individually; patterns could be identified to simplify this. Whilst ‘Coll’ refers to College, these could be a college of higher education – often a commercial entity – or an organisation such as the Australian & New Zealand College of Anaesthetists, a registered charity.

Broad classifications of the standardised data were conducted to perform this data classification. High-level patterns were identified, such as ‘OEH’, ‘Off Environm &

Heritage’ or ‘Off Environm Heritage’² (all of which reference the NSW Office of Environment and Heritage), as well as the abbreviated versions of long-form names. Common abbreviations include ‘Ctr’ for Centre, ‘Off’ for office, ‘Res’ for research and ‘Inst’ for institute. Once these patterns are identified, the systematic method for classifying government organisations becomes much simpler when cross-checking with a search engine. However, there are still risks of typographical errors or inadvertent re-ordering of the organisation name.

Industry organisations required more detailed analysis; once themes were identified, the process of following general knowledge of similar organisations allowed for the identification of the organisations involved. Examples of this process include ‘BHP’, then leading to ‘BHP Billiton’, ‘BlueScope’, ‘Bluescope’, ‘Blue Scope’³, ‘Rio Tinto’ and ‘Xstrata’. Once many of these high-level, simple classifications were completed, it was necessary to work through search tools (Google or the Australian Business Register⁴) to check the organisation type. The result is a dataset that can be used to look up the organisational type for the triple helix calculations, as well as for the geocoding required to locate research in a geospatial context.

² This is not an exhaustive list; other variations include ‘Off Heritage & Environm’, ‘NSW Office Environm & Heritage’, ‘NSW Environm & Heritage’ and ‘NSW Off Environm & He’.

³ R is a case-sensitive language unless explicitly told to ignore case; therefore, BlueScope and Bluescope are treated as different records. Whilst a wild card could be employed, this can be problematic.

⁴ The Australian Business Register is available at <https://abr.business.gov.au/>

Chapter 6: Entropy and Indices

The measurement for the triple helix index and industrial specialisation has adopted a common methodology – the use of entropy. Underpinning the adoption of entropy is the ability to show both diversification and intensity. In this chapter the application of the triple helix index, and the measurement of specialisation through location quotient and entropy-based indices are discussed.

6.1 Triple Helix Index Calculations

At the broadest level, collaborations can be viewed as percentages – however, this represents a share of the research output. The use of the mutual information transmission value of T indicates the concentration of the research activity.

Fundamental to these calculations is the scalable calculations contained within the th4.exe program from Leydesdorff. However, the latest version of th4.exe, released as v2 on 16 February 2021, is quite different to the original version (released by Leydesdorff et al. in 2013). Whilst den Besten (2014) has implemented the historic calculation in R, it has not been updated to match the latest calculation method. Therefore, developing a new code to implement the calculation was necessary.

Intended to be scalable, the th4.exe routine can work with universities, industry, and government, as well as a user-defined fourth option. With accessible source code in Clipper, found at <https://www.leydesdorff.net/software/th4/th4.prg>, replicating the package in a newer programming language is possible. The original package followed the implementation of

Shannon's Entropy and can still be found via the Internet Archive⁵. : Comparison of Clipper Code demonstrates the changes to the new code when compared side by side.

Importantly, whilst the quintuple helix index has been applied before, the analysis that extends Leydesdorff and Sun (2009) approach – that of domestic (or local) university, industry, and government relations with foreign (irrespective of organisation type) – to include other states (a particular question that can be asked within Australia or other countries with this additional tier of government that manages some aspects of research) is rarely undertaken. Sudiana et al. (2020) provide a detailed breakdown of the approaches to the quadruple and quintuple helix beyond the triple helix. Capturing additional factors such as diaspora, community or social enterprise are all additional variables that can be included and have been in the past.

6.1.1 Using Shannon's Entropy Compared to a Percentage Share of Publication by Type

The fundamental difference between Shannon's Entropy (and subsequent derivatives) is that the resulting value represents an increase (or decrease) in independence or lack of collaboration due to the inclusion of the probability of the event not happening. In contrast, the use of a percentage shows the share within the total number of publications for a given year but cannot describe this beyond the narrative – nor any sense of scale when compared to Shannon's Entropy and T-value calculations.

The original Shannon's Entropy calculation is a composite of the probability of an event (or state) or combination of events (states). Therefore, the calculation of the H-value in a Shannon's Entropy calculation requires either the assumption of an equal likelihood

⁵ <https://web.archive.org/web/20180318142738/https://www.leydesdorff.net/software/th4/th4.prg>

distribution (50:50 chance, such as heads or tails) or the calculation of the probability of the event.

6.1.1.1 Calculations

In line with Leydesdorff's calculations, the H-Value (and subsequently the T-value) are calculated using a simplification of Shannon's Entropy calculation and a scaling denominator. The simplified probability calculation no longer reflects a true Shannon's Entropy calculation, but it does remove the negative T-values that were possible in the original calculation.

To create the sets, a row vector is created that comprises university, industry, government, other state/territory and foreign. This set is (u,i,g,s,f). This set is a binary set, where 1 denotes the actor is present in the set, 0 denotes no actor, and * denotes wildcard.

Thus a set that comprises (1,*,*,*,*) would be a single actor university, whilst a set (*,1,*,1,*) would be industry and other state/territory. Extended to three actors, this would be (1,1,1,*,*) as university, industry and government.

Using the following calculations, the probability values were calculated for a given year:

Single Actor (e.g., University)

$$P(U) = \sum \frac{(1,*,*,*,*)}{(*,*,*,*,*)}$$

Equation 6-1

$$P(\overline{U}) = \sum \frac{(*,*,*,*,*) - (1,*,*,*,*)}{(*,*,*,*,*)}$$

Equation 6-2

Two Actors (e.g., University and Government)

$$P(UG) = \sum \frac{(1,*,*,*) + (*,*,1,*)}{(*,*,*,*) \times 2}$$

Equation 6-3

$$P(\overline{UG}) = \sum \frac{(*,*,*,*) - ((1,*,*,*) + (*,*,1,*))}{(*,*,*,*) \times 2}$$

Equation 6-4

Three Actors (e.g., University, Government, and Industry)

$$P(UGI) = \sum \frac{(1,*,*,*) + (*,*,1,*) + (*,1,*,*)}{(*,*,*,*) \times 3}$$

Equation 6-5

$$P(\overline{UGI}) = \sum \frac{(*,*,*,*) - ((1,*,*,*) + (*,*,1,*) + (*,1,*,*))}{(*,*,*,*) \times 3}$$

Equation 6-6

Four Actors (e.g., University, Government, Industry and Other State/Territory)

$$P(UGIS) = \sum \frac{(1,*,*,*) + (*,*,1,*) + (*,1,*,*) + (*,*,*,1,*)}{(*,*,*,*) \times 4}$$

Equation 6-7

$$P(\overline{UGIS}) = \sum \frac{(*,*,*,*) - ((1,*,*,*) + (*,*,1,*) + (*,1,*,*) + (*,*,*,1,*))}{(*,*,*,*) \times 4}$$

Equation 6-8

Five Actors

$$P(UGISF) = \sum \frac{(1,*,*,*) + (*,*,1,*) + (*,1,*,*) + (*,*,*,1,*) + (*,*,*,*,1,*)}{(*,*,*,*) \times 5}$$

Equation 6-9

$$P(\overline{UIGSF})$$

$$= \sum \frac{(*,*,*,*,*) - ((1,*,*,*,*) + (*,*,1,*,*) + (*,1,*,*,*) + (*,*,*,1,*) + (*,*,*,*,1))}{(*,*,*,*,*) \times 5}$$

Equation 6-10

From these, it is now possible to calculate the H-Values.

Single Actor (e.g., University)

$$H(U) = \sum - (P(U) \times \log_2(P(U))) - (P(\overline{U}) \times \log_2(P(\overline{U})))$$

Equation 6-11

Two Actors (e.g., University and Government)

$$H(UG) = \sum - (P(UG) \times \log_2(P(UG))) - (P(\overline{GU}) \times \log_2(P(\overline{UG})))$$

Equation 6-12

Three Actors (e.g., University, Government, and Industry)

$$H(UIG) = \sum - (P(UIG) \times \log_2(P(UIG))) - (P(\overline{IGU}) \times \log_2(P(\overline{UIG})))$$

Equation 6-13

Four Actors (e.g., University, Government, Industry and Other State/Territory)

$$H(UIGS) = \sum - (P(UIGS) \times \log_2(P(UIGS))) - (P(\overline{IGS}) \times \log_2(P(\overline{UIGS})))$$

Equation 6-14

Five Actors

$$H(UIGSF) = \sum - (P(UIGSF) \times \log_2(P(UIGSF))) - (P(\overline{IGSF}) \times \log_2(P(\overline{UIGSF})))$$

Equation 6-15

Subsequently, the T-values can be calculated, following Leydesdorff et al. (2013).

Two Actors (e.g., University and Government)

$$T(UG) = \sum H(U) + H(G) - H(UG)$$

Equation 6-16

Three Actors (e.g., University, Government, and Industry)

$$T(UIG) = \sum H(U) + H(I) + H(G) - H(UG) - H(UI) - H(IG) + H(UIG)$$

Equation 6-17

Four Actors (e.g., University, Government, Industry and Other State/Territory)

$$\begin{aligned} T(UIGS) = \sum H(U) + H(I) + H(G) + H(S) - H(UI) - H(UG) - H(US) - H(IG) \\ - H(IS) - H(GS) + H(UIG) + H(UIS) + H(UGS) + H(IGS) - H(UIGS) \end{aligned}$$

Equation 6-18

Whilst Leydesdorff et al. (2013) expanded the triple helix index to quadruple, there is limited literature explaining the extension to five actors. However, the pattern that the calculation follows (+--+) is recognised as expandable beyond four dimensions – Leydesdorff (2012) states that the sign changes with each selection mechanism added.

$$\begin{aligned} T(UIGS) = \sum H(U) + H(I) + H(G) + H(S) + H(F) - H(UI) - H(UG) - H(US) \\ - H(UF) - H(IG) - H(IS) - H(IF) - H(GS) - H(GF) - H(SF) \\ + H(UIG) + H(UIS) + H(UIF) + H(UGS) + H(UGF) + H(USF) + H(IGS) \\ + H(IGF) + H(ISF) + H(GSF) - H(UIGS) - H(UIGF) - H(UISF) \\ - H(UGSF) - H(IGSF) + H(UIGSF) \end{aligned}$$

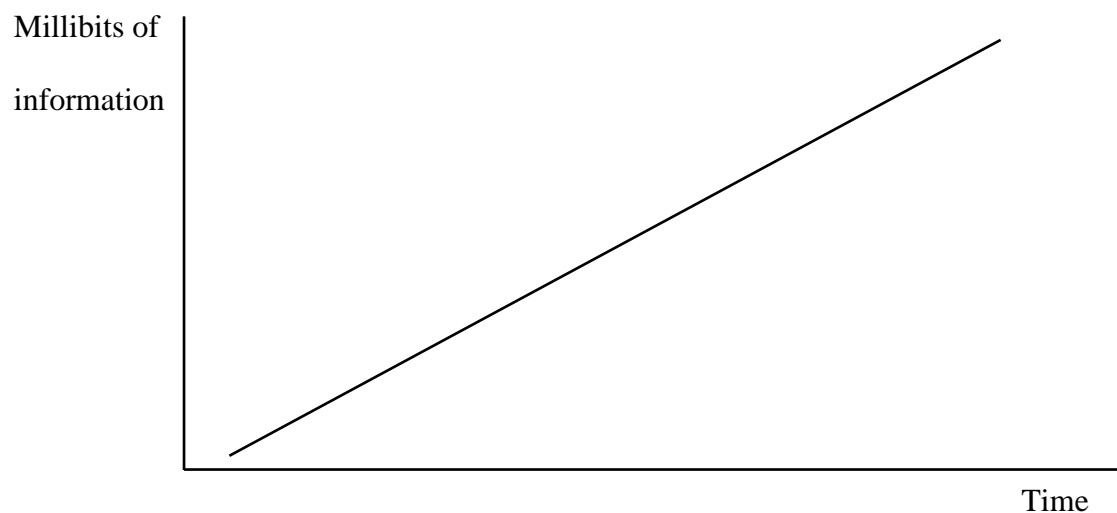
Equation 6-19

6.1.2 Interpreting T-value trends for the purpose of the n-tuple helix index

Drawing these together, transmission (T) can be used to represent the culmination of the frequency of the event as well as the likelihood of the event. This translates to the change in uncertainty for a given combination of co-authorship. Four combinations require examination: positive or negative trends and small change trends in either direction. Lastly, the magnitude of similar trends can be explored. Examples, exaggerated to show the overall trends, are provided below, following the analysis undertaken by Leydesdorff and Sun (2009, pp. 781-782).

A positive trend represents increasing collaboration within the n-tuple helix, whilst the higher value represents decreased independence and closer collaboration.

Figure 6-1: Upward T-value trend

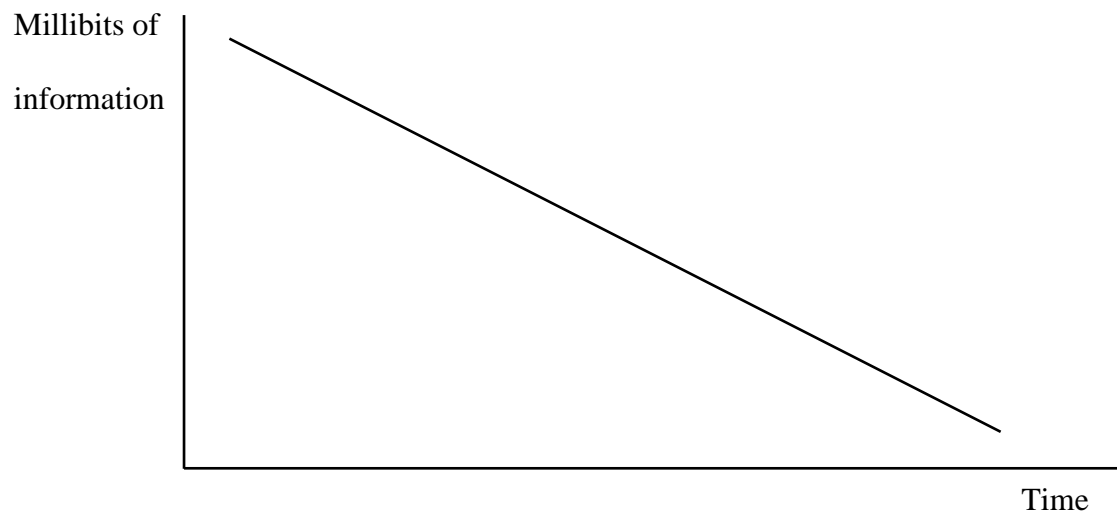


Positive trend representing an increasing collaboration, or expansion, between researchers is shown by an upward sloping trend.

A negative trend represents an increasingly independent, uncoupled, nature of collaboration.

At zero, this represents fully independent.

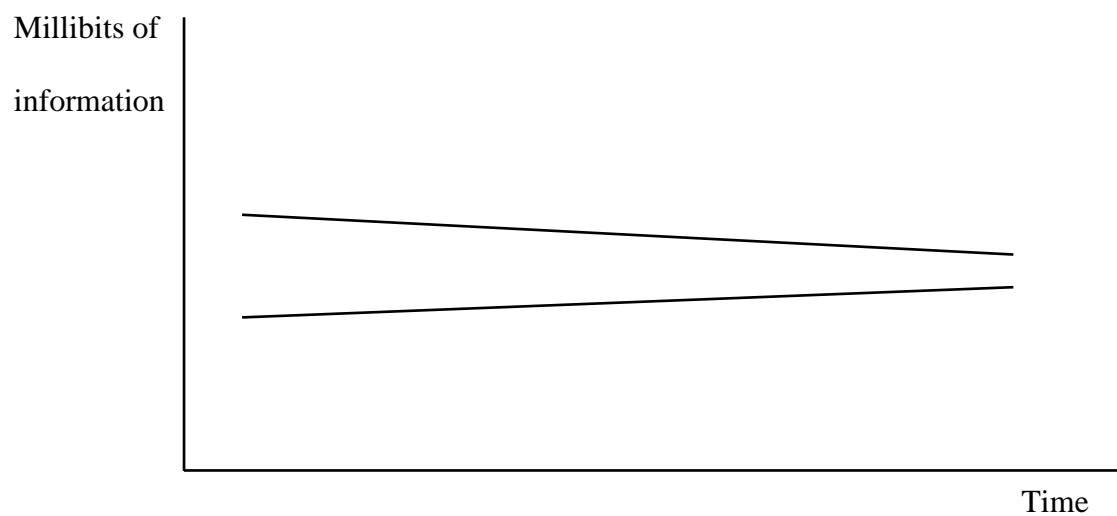
Figure 6-2: Negative T-value trend



Negative trend representing an increasingly independent, uncoupled, nature of collaboration.

A trend with no or limited change is viewed as stable, however, this needs to be considered within the scale of the diagram's y-axis.

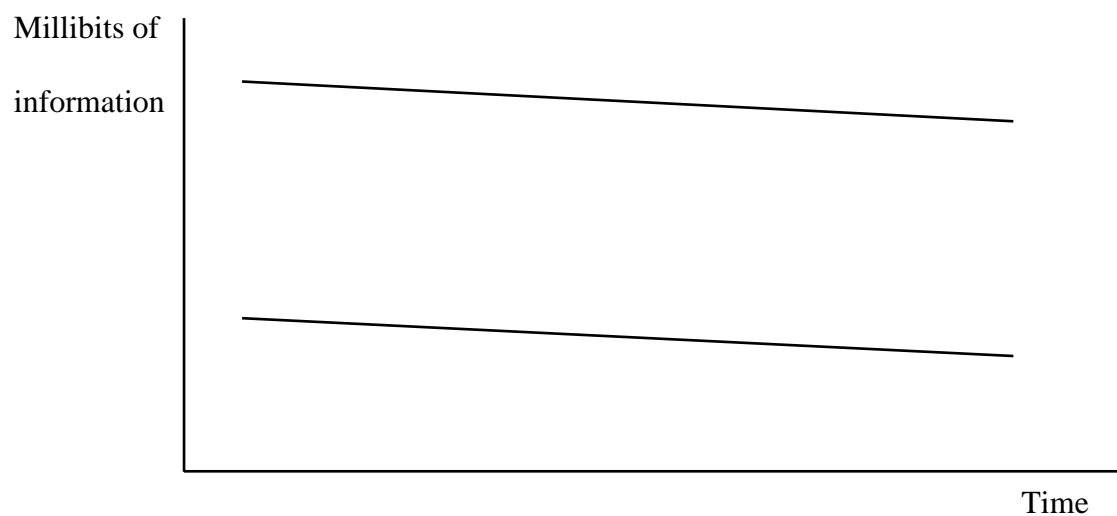
Figure 6-3: Small change T-value trend



Minor change trendlines

Magnitude covers the interpretation of similar trends, but with different values:

Figure 6-4: Magnitude of T-value trend



Examples of different magnitudes, where the lower trend is described as a lower order of magnitude.

Longitudinal analysis of the T-value in an n-tuple helix model captures changes in synergy between the actors. Leydesdorff and Park (2014) examine both the Korean and Japanese research systems, finding that increasing openness to international collaboration occurred during the 1990s. This increased integration with the international research systems, removing the reliance on local connections.

Whilst the numeric T-value, millibits of information, represents the synergistic nature of co-authorship, the actual value is in the over-arching trend that displays the trend of events. These values denote the scope of collaboration and synergy between organisations, as discussed in Zhuang et al. (2021). The T-value represents the degree of interdependence within the triple helix model; subsequently, a large T-value represents a closer collaboration, and a small T-value veers towards independent collaboration.

Applying these exaggerated trends, trends within the data can be explored and discussed. In applying this interpretation, trends are broken into subsets of observations.

6.2 Measurement of Industry Specialisation

Whilst the triple helix index can be used to measure the concentration of research activity and the independence of the activities, entropy can also be applied to industry diversification.

Using an entropy measurement, it is possible to measure the concentration relative to an equal distribution.

6.2.1 Location Quotient

The location quotient is applied to the industry sector and provides the ability to compare the industrial concentration within the state. Examining the relevance and history of the location quotient, as well as its ongoing suitability, Crawley et al. (2013) discuss the application of the location quotient as a tool for the measurement of specialisation and clustering in both the United Kingdom and Europe. It is commonly applied using an employment-based location quotient, where the denominator reflects the locale in question whilst the numerator is the state-level proportions:

$$LQ_{ij} = \frac{s_{ij}/n_j}{S_I/N}$$

Equation 6-20

Where i is industry (at the local level), j is locale in question, s is the number employed in that industry at local, n is the total number employed at local level. Capitalisation refers to state/national level.

Typically, a value greater than one reflects specialisation in that industry based on employment; however, where there are very small populations at a local level, this can lead to an excessive emphasis on the specialisation when compared to a larger population and less common industry of employment. This risk of over-emphasis on specialisation was identified by Pominova et al. (2021), who addressed the challenges of the use of location quotients for small areas (low population numbers) and identified that a minimal number employed in an

industry where there is a low population would result in an over-emphasis of the specialisation.

6.2.2 Entropy-Based Indices

The entropy-based indices described by Cerqueti and Cutrini (2021) are more complex. There are two commonly applied indices. First, like Leydesdorff and Etzkowitz's triple helix index, is Shannon's Entropy applied to the measurement of specialisation. Second, Henri Theil, featured in work by others since the 1960s, applies a modified entropy index to measure industrial concentration. Both these approaches are well regarded as powerful tools to measure between and within groupings to measure specialisation or diversity.

6.2.2.1 Shannon's Entropy

The Shannon Entropy Index is of interest from this range of measurements, lining up with the use of Shannon's Entropy calculations for the triple helix index.

$$SEI = - \sum_{i=1}^I b_i \ln b_i$$

Equation 6-21, from Palan (2010)

Where b_i is the share of industry i in terms of employment in region r .

This was utilised by the Australian Bureau of Statistics (2014) in a similar context to the application in this thesis. The difference is that the ABS measured across Australia at Statistical Area 4 level compared to New South Wales at the LGA level for this study. A maximum value of $\ln(19)$ represents the most diverse region, whilst the minimum of zero represents the most concentrated region.

6.2.2.2 Theil Index

Applied to the measurement of industrial concentration, the Theil Index can measure the concentration of activity with a value between 0 (maximum concentration) and 1 (minimum concentration). Using Theil's (1967) detailed explanation, replication of the calculation is possible.

The advantage of the Theil Index over the location quotient is that there is a clear concentration measurement that only requires one level of measurement. In contrast, the location quotient results in a measurement of relative concentration and specialisation that requires another level of measurement (aggregation of all regions) to undertake the calculation. With the simplification of the measurement, the ability to scale as needed is advantageous.

As a variation of Shannon's Entropy, and in line with the triple helix h values, the Theil Index value reflects the probability of the event:

$$H(y) = \sum_{i=1}^I y_i \log_2 \frac{1}{y_i}$$

Equation 6-22, from Theil (1967, p. 290 & 293)

Where i is industry i , and y is the probability of employees in industry i out of I (all industries) for a given region.

From this, an entropy value can be derived, and the minimum and maximums can be defined.

The maximum concentration can be defined as when equal to zero, which is also the minimum entropy value. When all shares are equal to $1/N$, then $H(y) = \log_2 N$, and therefore, this is the maximum entropy for N .

Applying this, an equal distribution of the nineteen categories of industry would be ≈ 4.25 (2 d.p.); as such, a ratio within that can be calculated as a percentage and reflects the range with the expectation that there are rarely any perfectly distributed industries.

6.2.3 Calculations and Interpretation

With the three sample periods and the 19 employment categories, the industrial concentration can be calculated for the 130 LGAs in New South Wales (excluding offshore and no permanent address). Calculating these values allows changes over time to be observed and measured, reflecting increasing (decreasing) industrial concentration. Adopting Shannon's Entropy, the measurement of concentration and the diversity of the specialisation within the sample environment and the changing specialisation in regions can be mapped.

The Shannon's Entropy calculation used for an LGA (j) is:

$$S_j = - \sum_{i=1}^{19} r_{ij} \ln(r_{ij})$$

Equation 6-23, based on Australian Bureau of Statistics (2014), Mishra and Ayyub (2019) and Palan (2010)

Where r is the share of the employment in industry i in region j .

With Shannon's Entropy, the interpretation of the value ranges from zero to $\ln(I)$, where I is equal to the number of industries (in this case 19), which represents a diverse industrial mix (or no specialisations), or as Mishra and Ayyub (2019, p. 2161) describe, a more equal distribution.

Importantly, a value of zero in entropy is absolute specialisation (Palan, 2010). When examining unprocessed data from the census, it is noted that some industries and regions have zero employees recorded. Whilst these values are valid, when included in the entropy calculation as zeros, they provide two issues: that the logarithmic value of zero is infinite, and a value of zero will lead to an interpretation of the entropy as absolute specialisation. To

counter this problem, a very small offset value is applied uniformly across all data. Including this small offset ($1/10,000^{\text{th}}$) has a negligible effect yet prevents the calculation of zero values. Similarly, this offset has a minimal effect when applied to the Theil entropy calculation.

With this data, the specialisation can be mapped across the local government regions by drawing on the 2006, 2011, and 2016 data (Australian Bureau of Statistics, 2017a) applied to the 2016 LGAs (Australian Bureau of Statistics, 2018b).

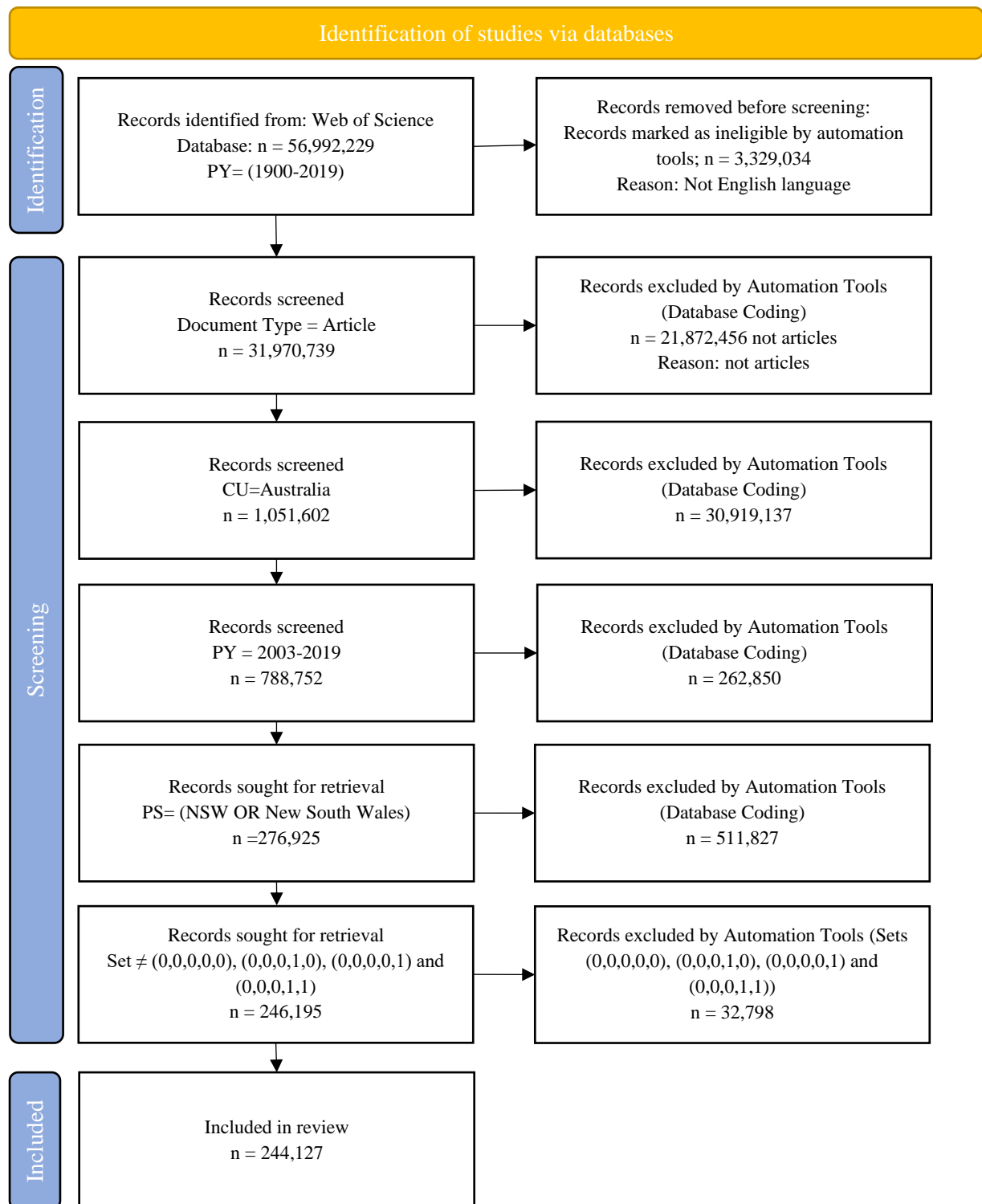
Chapter 7: Results Part One – All of Australia

I analyse the dataset using the approach outlined in the preceding chapter. The estimated results represent a relative comparison within the dataset and allow for a direct comparison of trends and patterns within the data. The trends can be compared to other similar data sets, but the estimated magnitudes will vary. Regarding the analysis of trends, it is important to note that these are relative values.

Butler's (2003) work provides insights into how research has changed over time. Published before the study period of this thesis, the findings provide insight into the role of international co-authorship and the resulting impact measured through citation. These results provide a context for the role of the subsequent data and triple helix index analysis. Importantly, the triple helix index shows that the collaborative nature is changing over time.

The final stage of implementing the PRISMA Statement (Figure 7-1 below) was undertaken at this point. This relied on the cleaned and standardised data, with a revision that excluded data that was either not classified (set of (0,0,0,0,0)) or re-classified and no longer eligible for inclusion (sets of (0,0,0,1,0), (0,0,0,0,1) or (0,0,0,1,1)). This removal reflects the final stages of cleaning and standardisation.

Figure 7-1: PRISMA 2020 Statement Flow Diagram



PRISMA 2020 Statement Flow Diagram from Page et al. (2021), Framework retrieved from <http://prisma-statement.org/prismastatement/flowdiagram.aspx>

The analysis was undertaken using the 244,127 research records in the final dataset. Table 7-1 details the percentage shares, on an annual basis, for the combinations.

Table 7-1: Percentage of publications in single combinations

Year	Total Publications	Within Sectors									
		U		I		G		S		F	
		Count	%	Count	%	Count	%	Count	%	Count	%
2006	9,216	2,809	30.47	390	4.40	91	1.00	0	0.00	0	0.00
2007	10,032	2,989	29.79	404	4.30	119	1.25	0	0.00	0	0.00
2008	10,837	3,076	28.38	426	4.22	134	1.32	0	0.00	0	0.00
2009	11,839	3,264	27.56	399	3.65	100	0.98	0	0.00	0	0.00
2010	12,849	3,370	26.25	363	3.10	111	0.91	0	0.00	0	0.00
2011	14,282	3,517	24.68	355	2.75	113	0.88	0	0.00	0	0.00
2012	15,524	3,871	25.12	331	2.33	127	0.93	0	0.00	0	0.00
2013	17,424	4,098	23.63	337	2.20	127	0.78	0	0.00	0	0.00
2014	18,699	4,125	22.16	295	1.70	104	0.63	0	0.00	0	0.00
2015	22,453	5,197	23.26	355	1.69	182	0.86	0	0.00	0	0.00
2016	23,894	5,014	21.09	319	1.42	188	0.83	0	0.00	0	0.00
2017	24,553	4,891	19.99	289	1.25	169	0.72	0	0.00	0	0.00
2018	25,538	4,488	17.64	260	1.12	153	0.64	0	0.00	0	0.00
2019	26,987	4,424	16.45	227	0.93	172	0.67	0	0.00	0	0.00

Table detailing the single actor sectors (within sectors) in percentage terms, where U is university, I is Industry, G is Government, S is Other State/Territory, and F is foreign.

As indicated in Table 7-1, explicit patterns appear in the collaboration. In the case of all singular collaborations – collaborations that occur within the same organisational types – all exhibit the same decline but of varying rates, with industry declining 80%.

Table 7-2: Count of publications in pairwise combinations

Year	Total Publications	Between Sectors									
		UI	UG	US	UF	IG	IS	IF	GS	GF	SF
2006	9,216	582	212	709	2,223	37	238	343	84	150	0
2007	10,032	681	226	781	2,373	40	276	368	93	156	0
2008	10,837	661	214	858	2,726	38	284	341	77	176	0
2009	11,839	724	274	973	3,068	34	263	375	74	184	0
2010	12,849	841	309	1,038	3,461	39	295	368	84	200	0
2011	14,282	873	377	1,160	3,984	32	329	416	114	208	0
2012	15,524	844	384	1,272	4,501	35	288	459	100	197	0
2013	17,424	967	446	1,456	5,084	28	293	441	135	214	0
2014	18,699	874	463	1,597	5,733	26	294	428	140	195	0
2015	22,453	980	473	1,988	6,871	38	311	495	194	258	0
2016	23,894	970	517	2,012	7,545	37	322	481	219	305	0
2017	24,553	959	473	1,945	8,103	28	282	487	184	279	0
2018	25,538	970	476	1,989	9,140	28	286	475	217	279	0
2019	26,987	1,040	486	2,061	10,008	29	279	466	168	288	0

Table detailing the pairwise (between sectors) combinations

Regarding the pairwise collaboration, the internationalisation that Leydesdorff and Sun (2009) examined, and also referenced by Leydesdorff (2012), is apparent in the increased share of publications by universities and foreign collaborations. However, other combinations that included foreign have remained relatively unchanged as a share of publications.

Table 7-3: Percentage of publications in pairwise combinations

Year	Total Publications	Between Sectors									
		UI	UG	US	UF	IG	IS	IF	GS	GF	SF
2006	9,216	6.14	2.29	7.69	24.11	0.44	2.63	3.89	0.94	1.67	0.00
2007	10,032	6.53	2.19	7.78	23.65	0.45	2.83	3.94	1.00	1.65	0.00
2008	10,837	5.81	1.89	7.92	25.14	0.41	2.79	3.53	0.78	1.80	0.00
2009	11,839	5.83	2.18	8.22	25.90	0.31	2.33	3.69	0.70	1.77	0.00
2010	12,849	6.29	2.34	8.09	26.90	0.37	2.44	3.36	0.72	1.71	0.00
2011	14,282	5.87	2.55	8.13	27.84	0.27	2.43	3.40	0.87	1.70	0.00
2012	15,524	5.30	2.39	8.25	28.60	0.28	2.02	3.41	0.75	1.41	0.00
2013	17,424	5.33	2.51	8.39	29.23	0.23	1.83	2.99	0.89	1.46	0.00
2014	18,699	4.58	2.41	8.58	30.78	0.19	1.76	2.66	0.86	1.29	0.00
2015	22,453	4.29	2.07	8.89	30.74	0.20	1.50	2.56	0.93	1.39	0.00
2016	23,894	4.00	2.13	8.46	31.71	0.20	1.51	2.53	0.98	1.67	0.00
2017	24,553	3.85	1.90	7.95	33.11	0.16	1.35	2.47	0.92	1.66	0.00
2018	25,538	3.72	1.83	7.81	35.91	0.15	1.29	2.38	0.94	1.60	0.00
2019	26,987	3.78	1.77	7.66	37.19	0.14	1.18	2.15	0.71	1.54	0.00

Table detailing the pairwise (between sectors) in percentage terms

With *university and overseas* exhibiting the largest increase, this represents a substantial overall increase in research efforts by universities in New South Wales. With the larger number of publications, this share represents an increase of over 8,000 publications between 2006 and 2019 that were co-authored between the *university and overseas* sectors.

Declining shares in collaborations can be seen when *industry* is a sector, as well as *university and government*. Notably, the total number of publications is increasing, and therefore there is an increase in the number of publications by all collaborations.

In total, the share of publications with either solely *university* or combinations containing university are dominant, reflecting the university's role in generating new knowledge codified in research publications.

Whilst pairwise collaborations have been neutral in terms of changes, there are distinct (albeit smaller) increases across many three-actor collaborations.

When examining the three-actor collaborations, a collaboration containing *university and overseas* (in this case, *university, other state/territory and overseas*) is once more dominant in terms of both share and increase.

Table 7-4: Count of publications in triple combinations

Year	Total Publications	Between Sectors									
		UIG	UIS	UIF	UGS	UGF	USF	IGS	IGF	ISF	GSF
2006	9,216	85	160	235	46	77	384	15	10	118	34
2007	10,032	96	150	243	54	102	462	29	12	121	40
2008	10,837	131	189	297	67	124	551	17	7	129	42
2009	11,839	124	217	355	79	151	641	21	9	168	44
2010	12,849	169	235	378	104	179	670	20	19	160	55
2011	14,282	168	264	442	144	249	818	19	9	188	55
2012	15,524	235	281	468	154	226	928	25	11	184	56
2013	17,424	271	317	488	185	321	1,171	16	16	192	88
2014	18,699	322	365	574	207	358	1,400	27	16	231	87
2015	22,453	336	424	580	235	391	1,633	29	10	277	128
2016	23,894	380	416	761	240	487	2,012	28	19	278	131
2017	24,553	352	468	820	306	522	2,108	33	13	326	137
2018	25,538	346	499	835	262	529	2,395	31	14	327	112
2019	26,987	365	502	857	333	601	2,537	32	16	357	177

Table detailing the triple combinations (between sectors)

A standout is the *university, other state/territory and foreign* as the dominant collaboration set. By 2019, it is almost 3.5 times the size of the second-largest combination when examining percentage share, and 6.6 times in absolute terms. This combination captures any collaboration between universities that are outside either New South Wales or Australia, as well as government or industry collaborators located outside the region.

Table 7-5: Percentage of publications in triple combinations

Year	Total Publications	Between Sectors (in percentage terms)									
		UIG	UIS	UIF	UGS	UGF	USF	IGS	IGF	ISF	GSF
2006	9,216	0.88	1.71	2.39	0.46	0.79	4.17	0.17	0.11	1.36	0.38
2007	10,032	0.91	1.44	2.16	0.45	0.92	4.60	0.32	0.14	1.30	0.41
2008	10,837	1.15	1.61	2.35	0.54	0.97	5.08	0.19	0.06	1.37	0.44
2009	11,839	1.02	1.73	2.50	0.59	1.06	5.40	0.22	0.12	1.57	0.46
2010	12,849	1.27	1.70	2.45	0.75	1.24	5.17	0.16	0.16	1.46	0.49
2011	14,282	1.14	1.74	2.62	0.94	1.51	5.64	0.15	0.08	1.50	0.45
2012	15,524	1.47	1.67	2.60	0.90	1.34	5.87	0.19	0.12	1.47	0.45
2013	17,424	1.49	1.70	2.36	0.95	1.62	6.37	0.10	0.14	1.32	0.63
2014	18,699	1.68	1.79	2.72	1.00	1.68	7.08	0.18	0.17	1.51	0.57
2015	22,453	1.47	1.80	2.26	0.98	1.51	6.83	0.17	0.13	1.56	0.78
2016	23,894	1.56	1.59	2.70	0.94	1.66	7.99	0.14	0.15	1.50	0.73
2017	24,553	1.39	1.72	2.88	1.08	1.61	8.27	0.18	0.16	1.58	0.74
2018	25,538	1.32	1.80	2.77	0.94	1.57	9.07	0.15	0.13	1.67	0.60
2019	26,987	1.33	1.73	2.77	1.15	1.77	9.11	0.13	0.16	1.71	0.92

Table detailing the triple combinations (between sectors) in percentage terms

Combinations containing *industry* as an actor increased the least or were neutral, with even a small decline in share (*industry, government, and other state/territory*) observed.

With the overall increase in collaboration, these combinations reflect a trend in increasing collaboration between multiple actors – unlike the pairwise and single authorship combinations where there are many declining shares.

Increases in all collaborations are observed with the addition of the fourth and fifth actors in the quadruple and quintuple collaborations. Once again, and as every combination now includes a research partner external to New South Wales, there are clear increases.

Table 7-6: Publications in quadruple and quintuple combinations

Year	Total Publications	Between Sectors											
		UIGS		UIGF		UISF		UGSF		IGSF		UIGSF	
		Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
2006	9,216	19	0.20	26	0.28	95	0.97	31	0.33	3	0.03	10	0.11
2007	10,032	28	0.25	34	0.32	78	0.69	46	0.45	14	0.15	17	0.16
2008	10,837	40	0.34	36	0.33	123	0.95	41	0.32	11	0.11	21	0.18
2009	11,839	44	0.34	48	0.36	114	0.82	56	0.38	14	0.13	22	0.18
2010	12,849	58	0.44	47	0.35	170	1.11	68	0.47	13	0.12	25	0.17
2011	14,282	65	0.44	65	0.44	192	1.16	72	0.44	10	0.11	44	0.27
2012	15,524	91	0.56	62	0.35	234	1.25	109	0.62	10	0.09	41	0.24
2013	17,424	110	0.62	114	0.61	301	1.52	138	0.67	17	0.14	53	0.27
2014	18,699	101	0.50	129	0.61	344	1.57	157	0.74	16	0.13	91	0.45
2015	22,453	122	0.51	153	0.60	429	1.61	233	0.83	9	0.11	122	0.48
2016	23,894	158	0.64	193	0.74	487	1.72	232	0.80	18	0.13	125	0.47
2017	24,553	181	0.70	204	0.73	499	1.80	279	0.95	20	0.18	196	0.70
2018	25,538	199	0.75	177	0.61	578	1.90	292	0.99	23	0.17	158	0.54
2019	26,987	167	0.61	210	0.68	584	1.80	346	1.02	23	0.20	232	0.75

Table detailing the quadruple and quintuple combinations (between sectors) in percentage terms

Overall shares of publications in quadruple and quintuple publications are small – less than 1% in all cases apart from those containing *university, other state/territory and foreign*. This aligns with the observations made in the triple helix but with the addition of the fourth actor (government or industry) as the growing sector by share.

7.1 T-values and N-tuple helices

In this section, each of the author combinations is examined with the n-tuple helix index calculation applied (rather than in percentage terms). In contrast to the percentage shares above, note that the n-tuple helix index calculation captures the occurrence of pairs (and subsequent triples and quadruple helices) within all events. For example, university and

industry pair T-values would also capture the occurrence of university and industry in the triple, quadruple, and quintuple helices. This can be observed in the other state/territory and foreign pair. This pair is explicitly excluded from the dataset; however, it does have a T-value when analysed.

The use of a Shannon's Entropy based index is beneficial compared to the descriptive statistics presented above. The benefit of the use of an Entropy based index is the ability to handle zero values without affecting the index value. This is evidenced in Leydesdorff and Sun (2009), where both Japan and Canada exhibited zero and low values in complex (three and four actors) combinations.

7.1.1 Single Author Type Publications

Whilst these may be single authors, they also reflect publications that have co-authorship from organisations of the same type. Dominated by university, the data was cleaned, so the misclassified other state/territory or foreign affiliations were removed based on the set values.

Table 7-7: Single actor sets and counts

Combination	Sets	Counts
University	1,0,0,0,0	55,133
Industry	0,1,0,0,0	4,750
Government	0,0,1,0,0	1,890
Other State/Territory	0,0,0,1,0	0
Foreign	0,0,0,0,1	0

Table detailing the combinations expressed as sets and the total numbers.

Examples include universities (collaborations between universities), government (federal and state are both counted as government, and as a single author type), or industry (as an example, vertical collaboration in the development of an innovative technology). These capture the organisational type where, irrespective of the number of collaborators in the combination, the value is only counted as one.

7.1.1.1 Single Author Types: University

With 55,133 records having only university authors between 2006 and 2019, the overall trend was a decline in sole organisational type authorship whilst showing a broad increase in the number of papers published by universities as a percentage.

7.1.1.2 Single Author Types: Industry

The least common (aside from miscategorised/erroneous other state and overseas) author type was industry, with a count of 4,750. Potentially reflecting a reluctance to produce research as published documents, the low sole authorship is not surprising. This category also captures research carried out in vertical integrations or collaborations.

7.1.1.3 Single Author Types: Government

Single authors from government are less numerous (1,890) than sole authorship from industry. However, it is noted that this may reflect many government authors collaborating rather than just one author individually publishing. As discussed above, this may not accurately reflect the collaborative nature within the governmental research sector as this data captures both state and federal activity.

7.1.1.4 Single Author Types: Other State and Overseas

Whilst these values are zero (due to the criteria of at least one New South Wales author), there may be underlying errors at the database level. It is not possible to manually verify that there are no other errors (particularly errors opposite to the ones found; for example, New South Wales addresses affiliated to Canada, or Penrith, UK capturing Penrith, NSW).

Detailed analysis of these categories is outside the scope of this research; however, as actors in subsequent combinations, they must be considered within those pairings. When comparing New South Wales and Australia in a more extensive comparison, both have a place in output

measurement. The single actor is calculated as an extraction from the pairwise, triple, quadruple, and quintuple combinations. As an example, these calculations are for Other State:

$$P(S) = \sum \frac{(*,*,*,1,*)}{(*,*,*,*,*)}$$

Equation 7-1

$$P(\bar{S}) = \sum \frac{(*,*,*,*,*) - (*,*,*,1,*)}{(*,*,*,*,*)}$$

Equation 7-2

As can be seen, the single Other State actor calculation captures the frequency of the *other state* author affiliation within all combinations where it occurs.

7.2 Pairwise Publications

Reflecting the simple collaboration model of two organisational types (which may include more than two organisations), these combinations commonly occur.

Table 7-8: Pairwise combinations, sets and counts

Combination	Sets	Counts
University and Industry	1,1,0,0,0	11,966
University and Government	1,0,1,0,0	5,330
University and Other State/Territory	1,0,0,1,0	19,839
University and Foreign	1,0,0,0,1	74,820
Industry and Government	0,1,1,0,0	469
Industry and Other State/Territory	0,1,0,1,0	4,040
Industry and Foreign	0,1,0,0,1	5,943
Government and Other State/Territory	0,0,1,1,0	1,883
Government and Foreign	0,0,1,0,1	3,089
Other State/Territory and Foreign	0,0,0,1,1	0

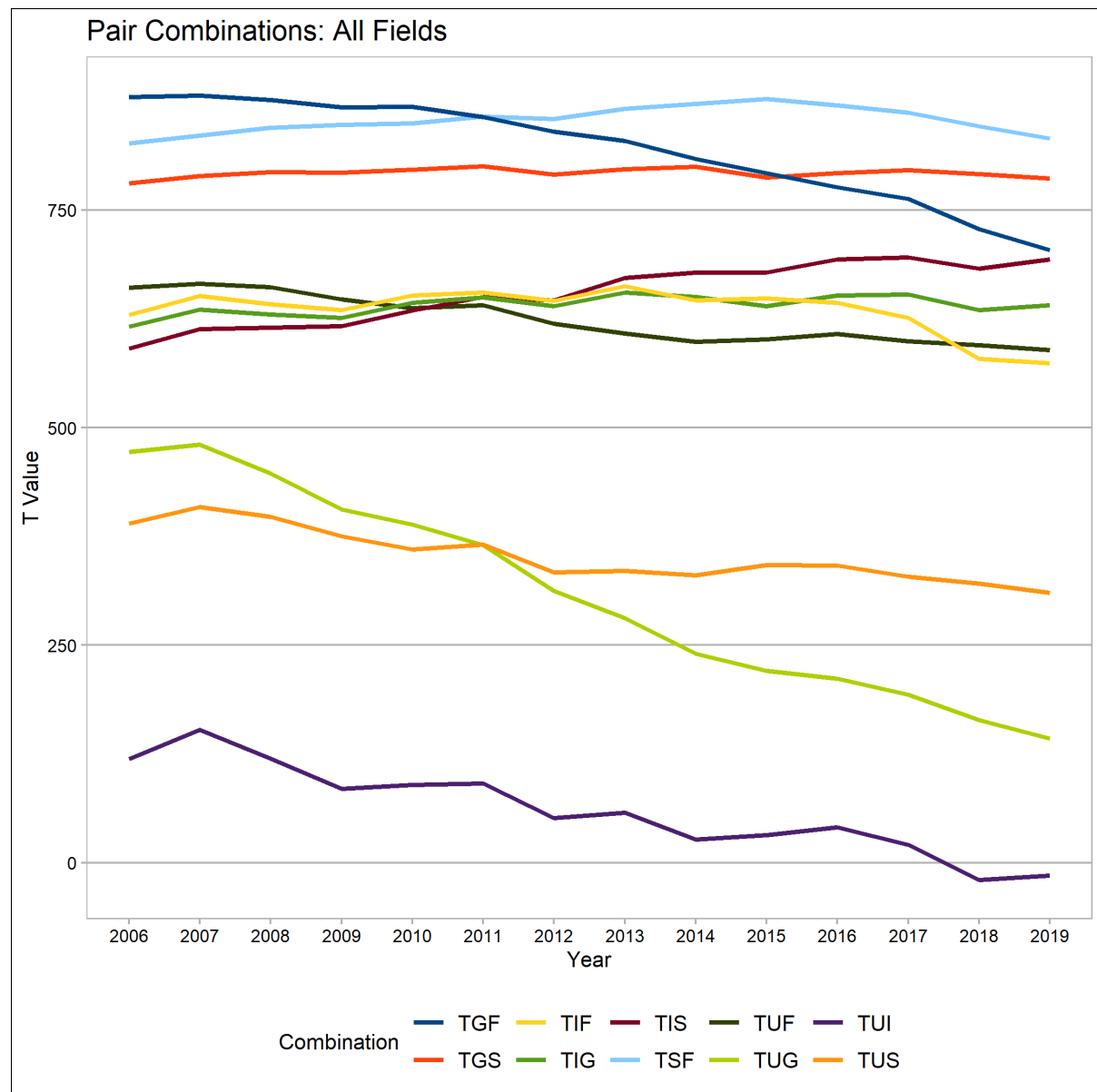
Table detailing the combinations expressed as sets and the total numbers.

This totalling is crucial as it captures any erroneous inclusions in the calculations. Whilst the last row details the pairs that made up ‘other state/territory and foreign’, this row should be zero because there should be no included publications that contain only authors outside of New South Wales. Returning to the PRISMA Statement, as outlined in Figure 4-1, this can be recorded as another method of exclusion (as well as those publications with only *other state*

or *foreign* affiliations). This was carried out with an additional line of code within the R scripts, removing those sets, as illustrated in Figure 7-1.

In the subsequent sections, overall trends with possible causes of peaks and troughs are addressed, as well as the resilience of the combination.

Figure 7-2: All Pair combinations at the same scale on the Y axis



Calculated values derived from Web of Science bibliometric data.

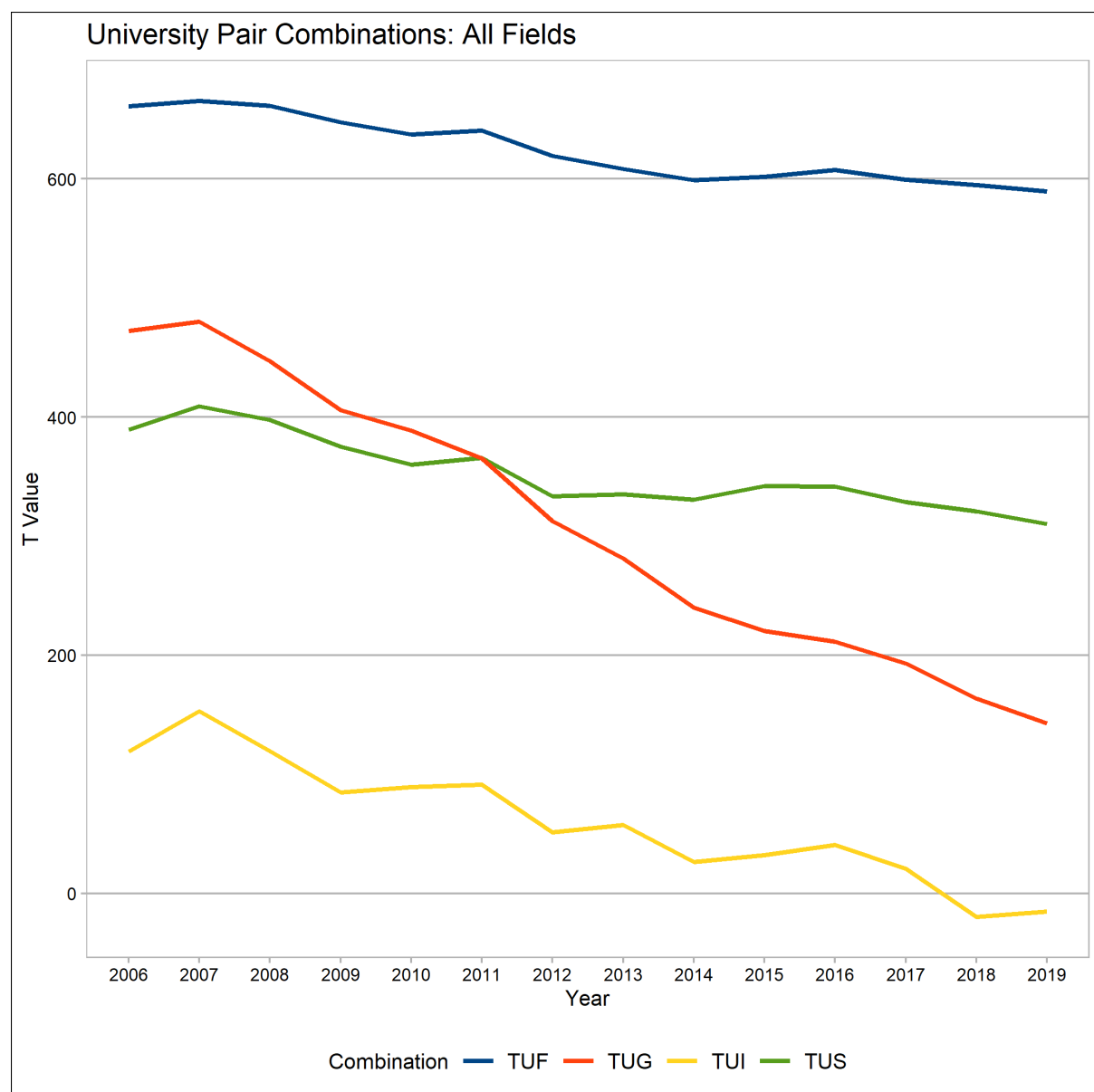
If a small group is examined outside the larger context of the combinations, it is easy to over-emphasise a small factor – or an over-expectation on the impact of the influence. Therefore, it

is necessary to be mindful of this risk and systematically consider the combinations, drawing attention to the collaborations in a structured manner.

7.2.1 University Pairs

Measuring the combinations that contain university within the collaborations, the broad overarching trends can be observed with the exclusion of other combinations.

Figure 7-3: University pairs



Calculated values derived from Web of Science bibliometric data.

All combinations exhibit similar trends – a decreasing collaboration or increasing independence – but three have different magnitudes (as per Figure 6-4). For example, *university and industry* (TUI) is similar to *university and other state/territory* (TUS), albeit at a different magnitude. In both these cases, they had a narrow range of around 100 millibits of information, compared to over 200 millibits of information between *university and foreign* (TUF) and *university and government* (TUG).

7.2.1.1 University and Industry

Whilst there are periods of increasing collaboration, the pattern for *university and industry* co-authorship tends to be one of decreasing collaboration. Importantly, research resilience can be observed as adhering to a bounce-back type model – that is, short rebounds to a level above pre-change/shock can be observed. Whilst these rebounds do not undo previous declines (leading to an overall downward trend), they certainly slow the decrease in collaboration.

The small increases in collaborative publications in 2014 align with the Excellence in Research for Australia⁶ round in 2015. Further analysis that use funding and reporting data would be required to draw clear causality. Whilst the trend continues beyond the reporting round, this may be the legacy of publication lags or the identification of subsequent opportunities for publication from the original piece of work. Conversely, the decline in 2016 may reflect the finish of the flurry of publications for the current reporting period and the gearing up for the next reporting period. In line with Khan and Park (2011), the political situation is considered; 2016 was stable, with no government change at a state (an election in 2015 returned the previous government) or federal level that may influence research activity.

⁶ <https://www.arc.gov.au/evaluating-research/excellence-research-australia>

7.2.1.2 *University and Government*

A consistent decreasing collaboration – or increasing independence – can be observed in the T-values. Whilst still potentially influenced by ERA reporting periods, the increasing independence of research collaboration can be observed. There is no observable resilience in the overall trend as it follows an overall decrease throughout the whole period. However, the overall trend has limited observable impacts of exogenous shocks. With a higher level of collaboration and a wider range of change – one of the largest ranges in the pairwise combinations – the overall trend points towards a much lower level of collaboration.

Whilst the overall trend was a decrease in collaboration, there are periods of accelerated decrease. For example, the period between 2011 and 2014 exhibited this accelerated decrease, whilst the ensuing 2014 – 2017 period displayed a slowdown in the pace of decline.

7.2.1.3 *University and Other State/Territory and University and Foreign*

Reflecting not only inter-university collaborations but also those of other government or industry partners, both the *university and other state/territory* and *university and foreign* collaboration can be seen to have similar changes in the T-value over time: an overall trend of decreasing collaboration.

Furthermore, this combination reflects the changing structure of the research coordination and organisation – an area Leydesdorff and Sun (2009) introduce, drawing upon previous work, as areas where the triple helix index can be used to measure and assess directly.

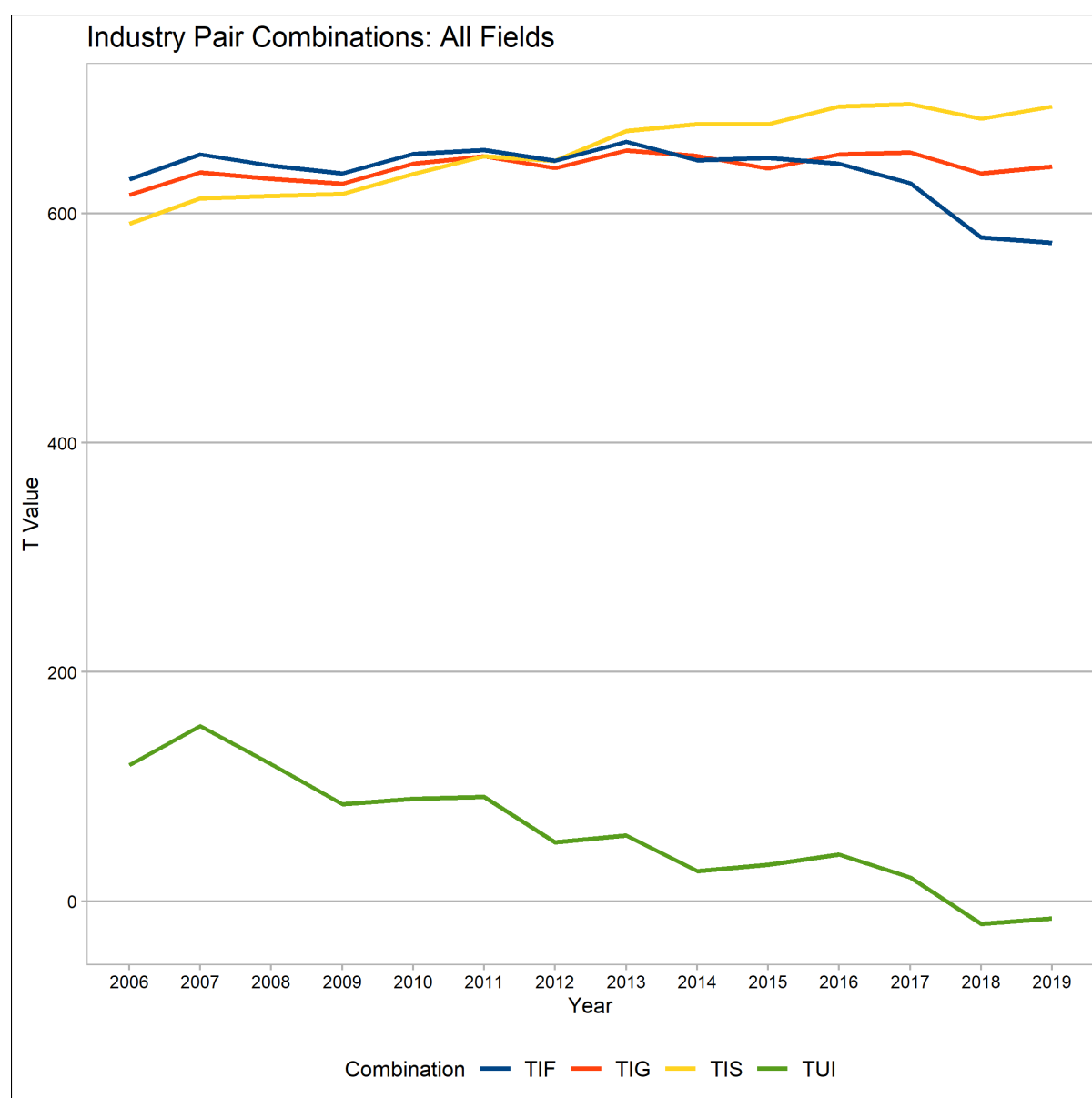
As Leydesdorff and Sun (2009) identified in their study on Japan and Canada, these pairings (and subsequent variations in the triple and quadruple helices) reflect the outward-looking collaboration of the university sector. Often driven by government policy, it can also reflect the potential impact of the research on the wider research sector.

The theoretical background states that the outward-looking collaboration is driven by increased prestige (e.g. Leydesdorff (2012) discusses the role of internationalisation and the collaboration between the increased prestige of international collaboration compared to industry relevance) or an external demand for the knowledge, e.g. Gingras (2016). When there is a weakening in the relationship (reflected in declining T-values), then there is a weakening of the knowledge capital exchange being undertaken.

7.2.2 Industry Pairs

Examining the collaboration undertaken by industry in New South Wales illustrates broadly neutral trends of *industry and foreign (TIF)* and *industry and government (TIG)*, whilst *industry and other state/territory (TIS)* exhibits increasing collaboration. The final combination, *university, and industry (TUI)*, exhibits a declining collaboration at a much lower magnitude than the other industry collaborations.

Figure 7-4: Industry pairs



Calculated values derived from Web of Science bibliometric data.

7.2.2.1 Strengthening relationships

Both *industry and other state/territory (TIS)* and *industry and government (TIG)* exhibit increasing collaboration. Both reflect collaborations that exclude NSW universities, but reflect the collaboration between NSW-based industry and NSW government (*industry and government*) and that of *industry and other state/territory*, which includes not only interstate industry but also interstate government and university partners. Overall, the trend for both is one of increasing collaboration, although the rate of change is slowing. When there is a pause

or slowing in the increase in collaboration, the bounce back displaying resilience is often at a faster rate than before the pause or slowdown – but only for a short period of time before the pause/slowdown process repeats. Each time this cycle occurs, the period of resilient growth shortens.

Whilst this holds for the early part of the period, after 2011, the trend decreases to below the previous point, but the rebound is greater – reflecting an increased collaboration.

7.2.2.2 Weakening relationships

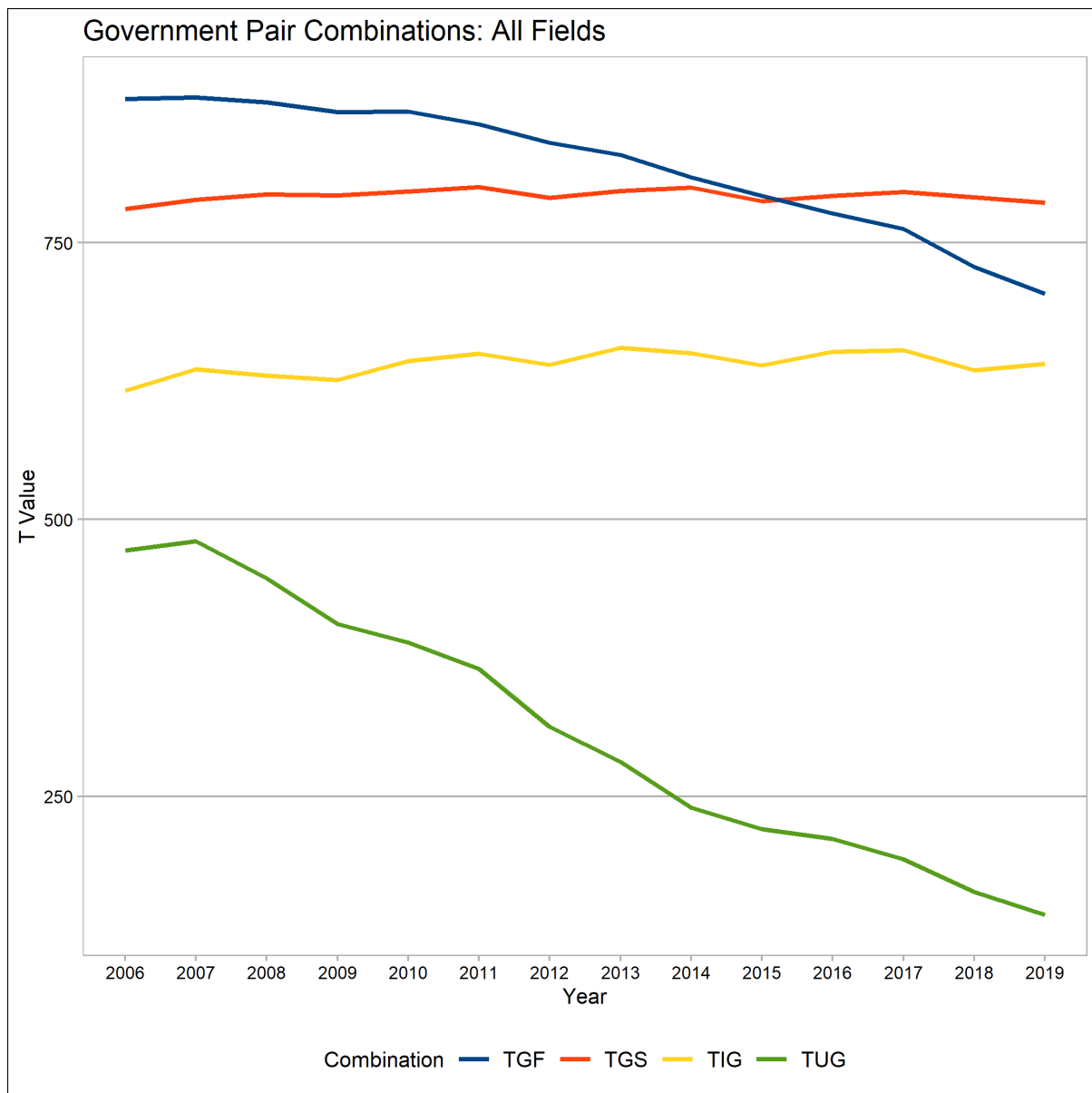
Whilst 7.2.2.1 examined the strengthening relationships, weakening relationships can be seen in *industry and university (TUI)* and *industry and foreign (TIF)* co-authorship. Weakening relationships may reflect the lack of knowledge available within NSW, both within the university and industry sectors when framed within the transferability (or exportability) that Gingras (2016) refers to as New South Wales or Australian knowledge. Conversely, these pairings may reflect the need for industry to partner with other state or government organisations as these relationships have strengthened.

7.2.3 Government Pairs

Capturing both state and federal government collaboration with research partners from the university, industry, and government sectors, these pairs have the potential to be further broken down for more detailed analysis in future work. The actions of federal research agencies (CSIRO et al.) across Australia are captured here, as well as their collaborations with other specialised research agencies.

Examination of the government pairs shows two trends: declining (*government and foreign (TGF)* and *university and government (TUG)*) or neutrality (*industry and government (TIG)* and *government and other state/territory (TGS)*).

Figure 7-5: Government pairs



Calculated values derived from Web of Science bibliometric data.

Importantly, whilst there are two divides in terms of decline or neutrality, there are also two divides in magnitude, where collaborations with partners outside of New South Wales being a higher magnitude than those of the collaborations within the state.

The *government and other state/territory* (TGS) co-authorship T-value remained comparatively neutral relative to the other government collaborations. This neutrality is made up of small changes culminating in the final strengthening of collaboration (albeit small).

With an overall decrease in *government and foreign* co-authorship across the complete period, accelerating after 2010, the increasing independence of this combination reflects the reducing knowledge exchange between government and foreign actors.

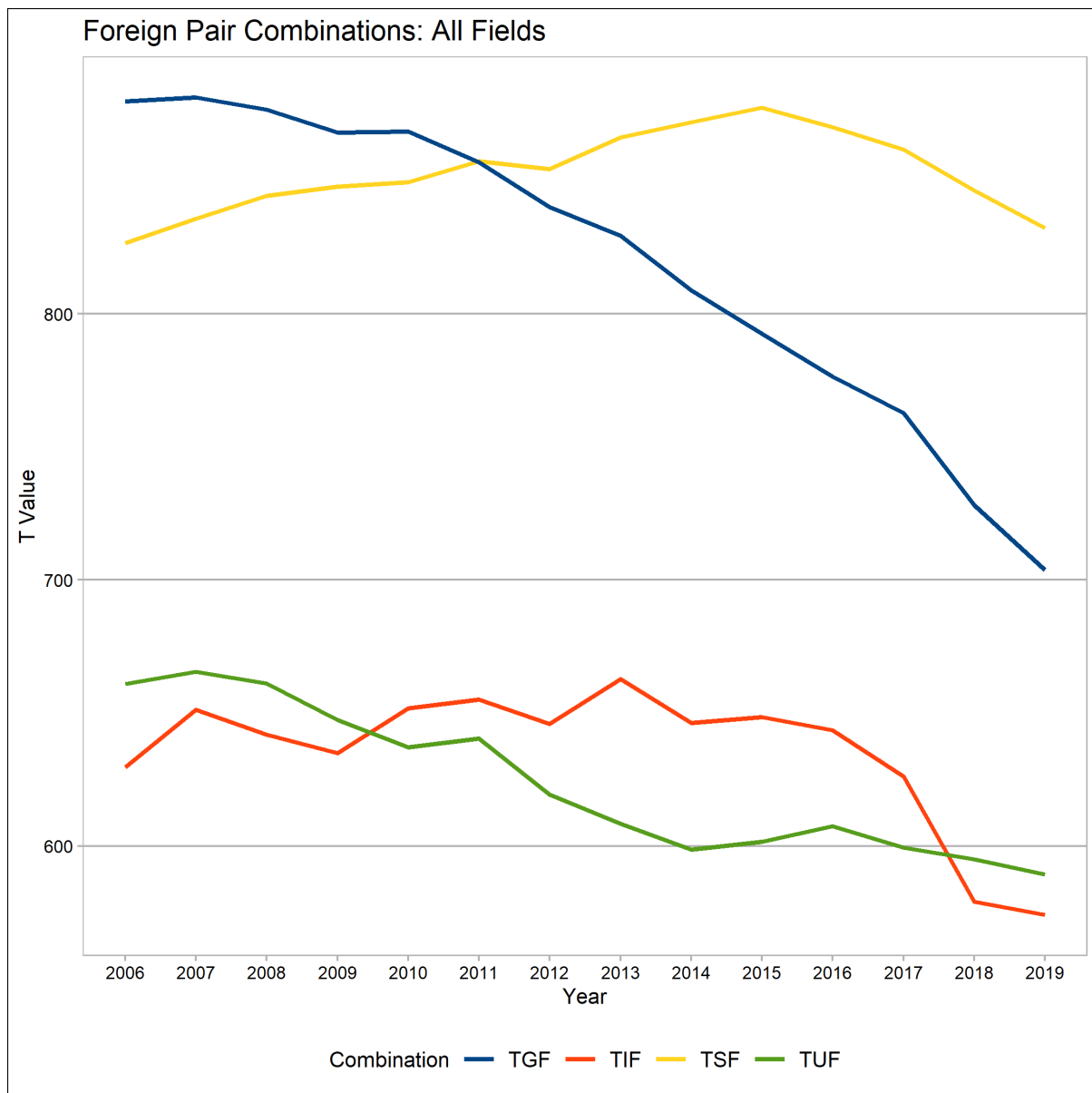
As with *government and other state/territory*, the foreign category captures all the actors in that category rather than breaking them down into university, industry, or government. This broad categorisation, along with the lack of clear points of change, limits the identification of causes.

7.2.4 Other State/Territory and Foreign Pairs

With both *other state/territory* and *foreign* pairs capturing the same core groups irrespective of organisational type, the collaborative behaviours can be viewed as similar. With no distinction between university, industry or government in the other state/territory or foreign classifications, the collaborative behaviours can be considered together within a broad grouping.

Within the overall comparisons, *university (TUF)* or *government (TGF)* have exhibited substantially increasing independence. In contrast, *industry, and other state/territory (TIS)* (see Figure 7-4) has an increasingly collaborative trend. Once more, 2015/16 is an important time of change, with decreasing collaboration in *other state/territory and foreign (TSF)* and a small increase in collaboration for *government and other state/territory (TGS)* and *industry and other state/territory (TIS)*.

Figure 7-6: Other state/territory and foreign pairs



Calculated values derived from Web of Science bibliometric data.

7.2.4.1 Other State/Territory and Foreign

The calculation of the T-value requires the inclusion of any occurrence of Other State/Territory and Foreign as an affiliation. This calculation reflects the subsequent combinations (triple, quadruple, and quintuple).

7.3 Triple Combinations

Triple combinations represent increasingly complex relationships found within the changing research relationships. With the capture of these complex relationships and the substitution of

singular author type for increasingly co-authored research outputs, the triple combination reflects some of the same tendencies as the paired publications.

Table 7-9: Triple combinations, set and count

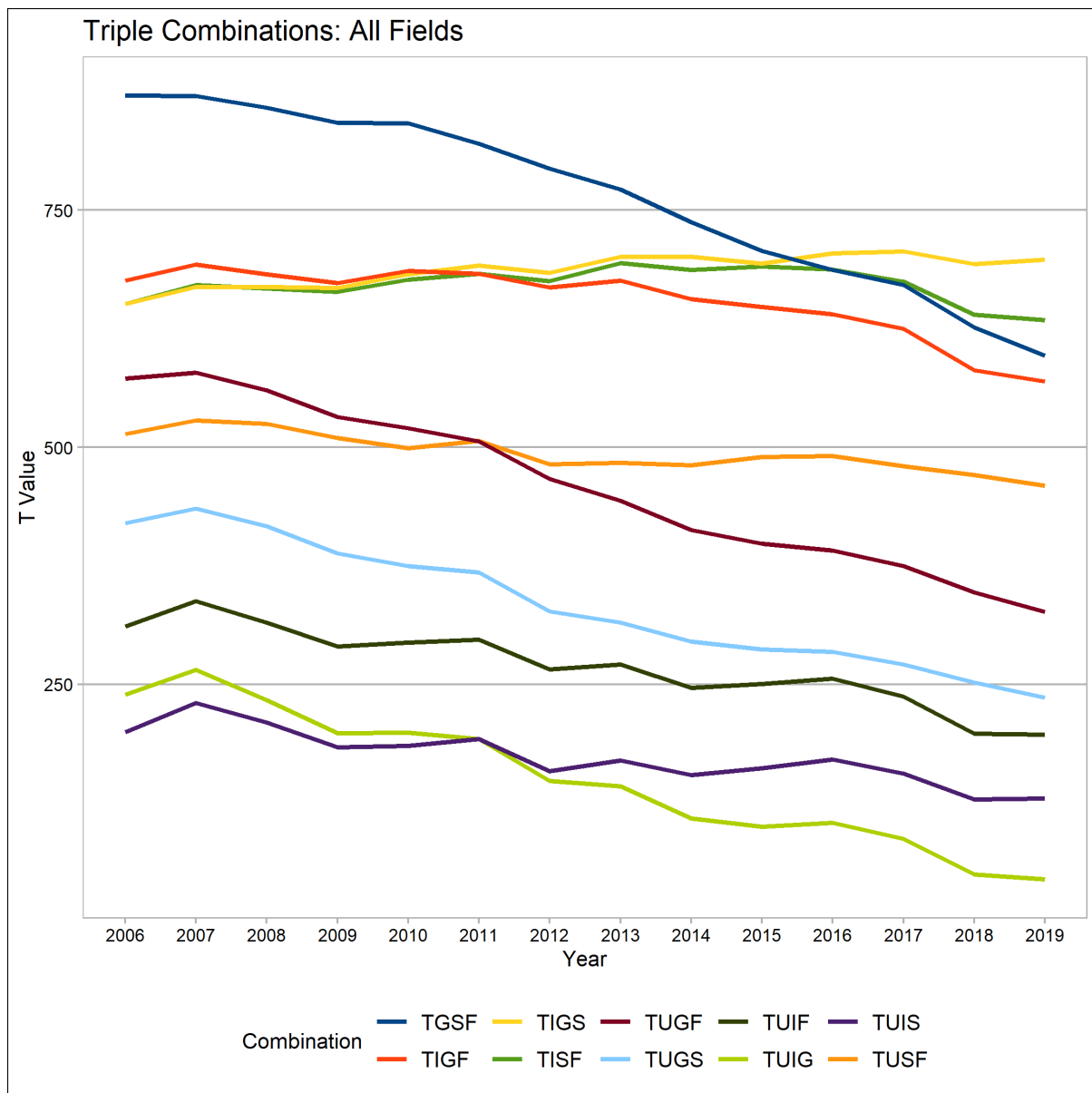
Combination	Set	Count
University, Industry and Government	1,1,1,0,0	3,380
University, Industry and Other State/Territory	1,1,0,1,0	4,487
University, Industry and Foreign	1,1,0,0,1	7,333
University, Government, and Other State/Territory	1,0,1,1,0	2,416
University, Government, Foreign	1,0,1,0,1	4,317
University, Other State/Territory, and Foreign	1,0,0,1,1	17,710
Industry, Government, and Other State/Territory	0,1,1,1,0	342
Industry, Government, Foreign	0,1,1,0,1	181
Industry, Other State/Territory and Foreign	0,1,0,1,1	3,056
Government, Other State/Territory, and Foreign	0,0,1,1,1	1,186

Table detailing the combinations expressed as sets and the total numbers.

With a range of totals between all the combinations, the collaboration with three organisational types was varied. Dominated by *university, other state/territory, and foreign* overall, these combinations exhibit decreasing collaboration in many cases. With only a few increasingly collaborative, the common thread through all decreasing combinations was that of the university as a collaborative partner. In contrast, industry working with non-New South Wales research partners experienced increasing collaboration.

With the overall dominance by volume of the *university, other state/territory, and foreign* collaborations, yet showing an overall decreasing collaboration over time, the increasing collaborations can be seen in *industry, government, and other state* and *industry, other state, and foreign*. In all three cases, this may represent the transferability of the knowledge generated in New South Wales. Gingras (2016, p. 54) refers to the exportable nature of research as a leading reason for collaboration with international partners, which can be extended to include the co-authorship with *other state*.

Figure 7-7: All triple combinations at the same Y-axis scale



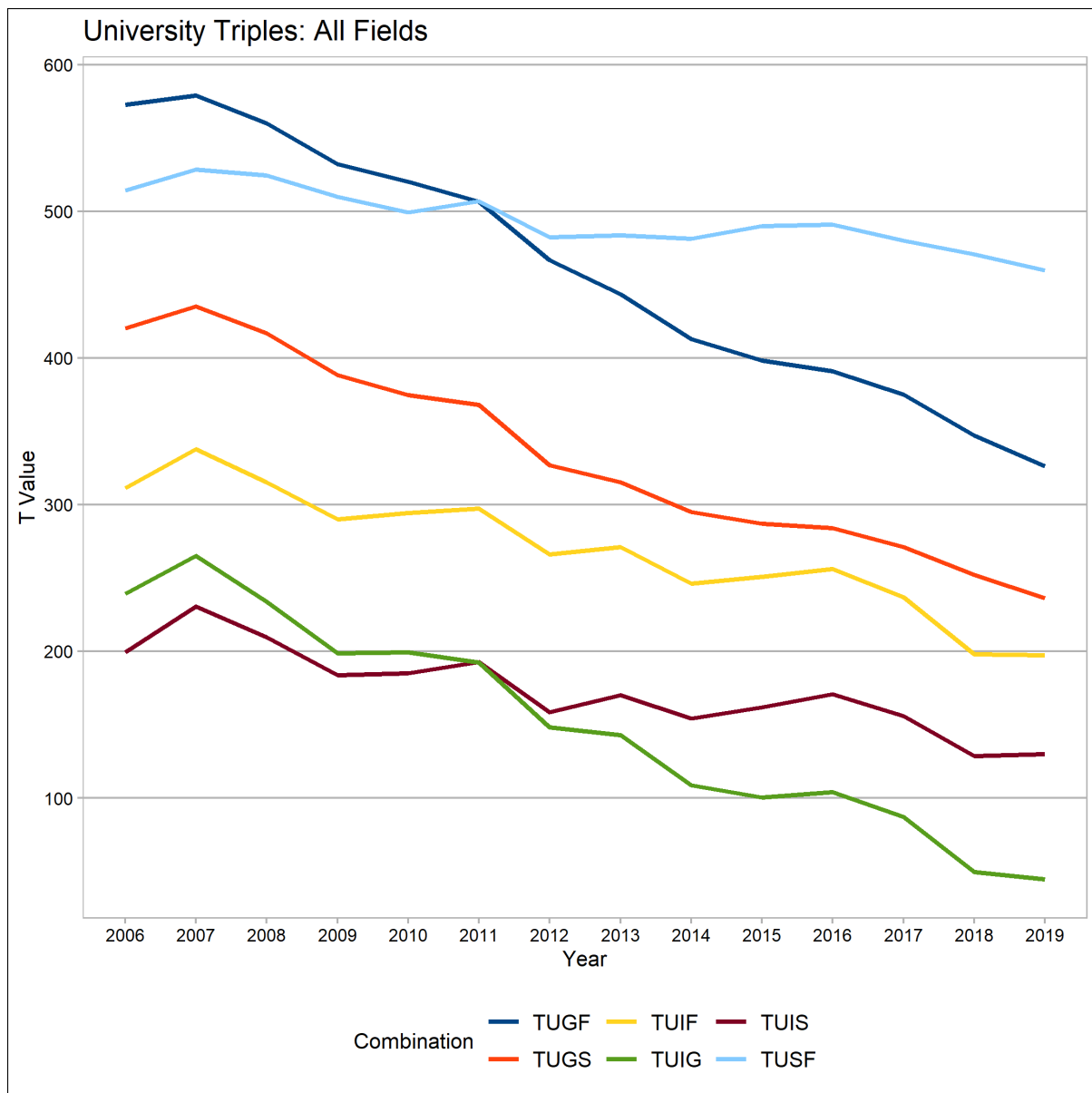
Calculated values derived from Web of Science bibliometric data.

This section compares the combinations that contain specific actors and focuses on the specific combinations and the subtle trends within those combinations.

7.3.1 Triple Combinations with University

All combinations with the university as a co-author exhibit an increasing independence, with varying rates of change.

Figure 7-8: Triple combinations with university affiliation



Calculated values derived from Web of Science bibliometric data.

Some are much greater in the rate of change (*university, other state and foreign* and *university, government and foreign* are all examples exhibiting this accelerated rate of change) whilst *university, industry, and other state* experienced a much lower rate of change.

Once more, drawing on Gingras (2016), the trend of the exportable nature of the research, driven by shifts between theoretical and practical applications, can be observed in these collaborations.

Exhibiting a neutral trend, *university, industry, and other state*, this desire for exportable research can be observed. In contrast, the trend in *university, industry, and overseas* reflects similar collaborations (*university and industry*) that are not experiencing the same export opportunity for research output. Furthermore, this trend is also observable in the three combinations with *overseas* (*F* in the legend above). Contrasting with the *overseas* collaboration, the involvement of *other state* or same state *government* or *industry*, the trends are decreasing at a lower rate of change.

7.3.1.1 University, Industry, and Government

Throughout the period under analysis, the collaboration between *university, industry, and government* decreased. Whilst exhibiting short periods of neutrality, the trend was of steady decline throughout the period.

The only combination that captures work solely within New South Wales, this combination follows a similar trend to that of *industry, government, and other state/territory* – with an overall trend of increasing independence that accelerates after 2011. Due to the inclusion of *government*, where there is no distinction to the level of government, analysis from the perspective of policy changes at a government level is limited.

Whilst this caveat is in place, the role of *industry and university* in collaboration with *government* at an intrastate level reflects efforts to minimise the risk of undervalued local objectives, as highlighted by Gingras (2016, p. 55).

7.3.1.2 University, Industry, and Other State/Territory

In contrast, *university, industry, and other state/territory* was much more varied. As with any collaboration that contains *other state/territory*, it captures *university, industry, or government* actions in the *other state/territory*. The capture of *other/state territory* may capture *industry organisations* with multiple locations domestically, and therefore the dispersal of knowledge

within the organisation in this combination. Furthermore, this actor may capture government or university actors within the combination that are outside of New South Wales.

7.3.1.3 University, Industry, and Foreign

An overall trend towards increasing independence between the actors can be observed. As with other combinations, the use of the broad group of foreign captures university, industry, and government in one group.

Representing a possible exchange of Australian knowledge and foreign applications (or vice versa), this reflects a change in the transferability of knowledge. Furthermore, government policy changes will have implications for international collaboration and the incentives (or disincentives) to work with universities or industries. Showing an overall trend, the increase in independence can be seen to accelerate in 2013/14 and 2016 onwards. However, the returns – the resilience – can be seen in 2008 and 2014, with similar rates of return.

7.3.1.4 University, Government, and Other State/Territory

Exhibiting a near complete trend towards independence, the collaboration demonstrates periods of accelerating independence and short periods of slowing. As there is no distinction between the level of government, any interpretation of the nature of interstate collaboration (such as government agencies working across different sites, or state and federal government working together) is limited due to the lack of granularity. Likewise, the inclusion of other state/territory captures both government and university with no distinction.

7.3.1.5 University, Government, and Foreign

Along with *university, government, and other state/territory*, the inclusion of foreign with university and government activity exhibits a long-term trend to increasing independence. As one of the largest increases in independence, this may represent a policy shift from university and government actors.

A slowing decline between 2014 and 2015 led to a resumption with a similar rate of change until 2019. This reflects a decline in collaboration between *university, government, and foreign* in line with government changes at a federal level in 2013, and the research output suffered from a lag as the writing up and closing of research activities was undertaken.

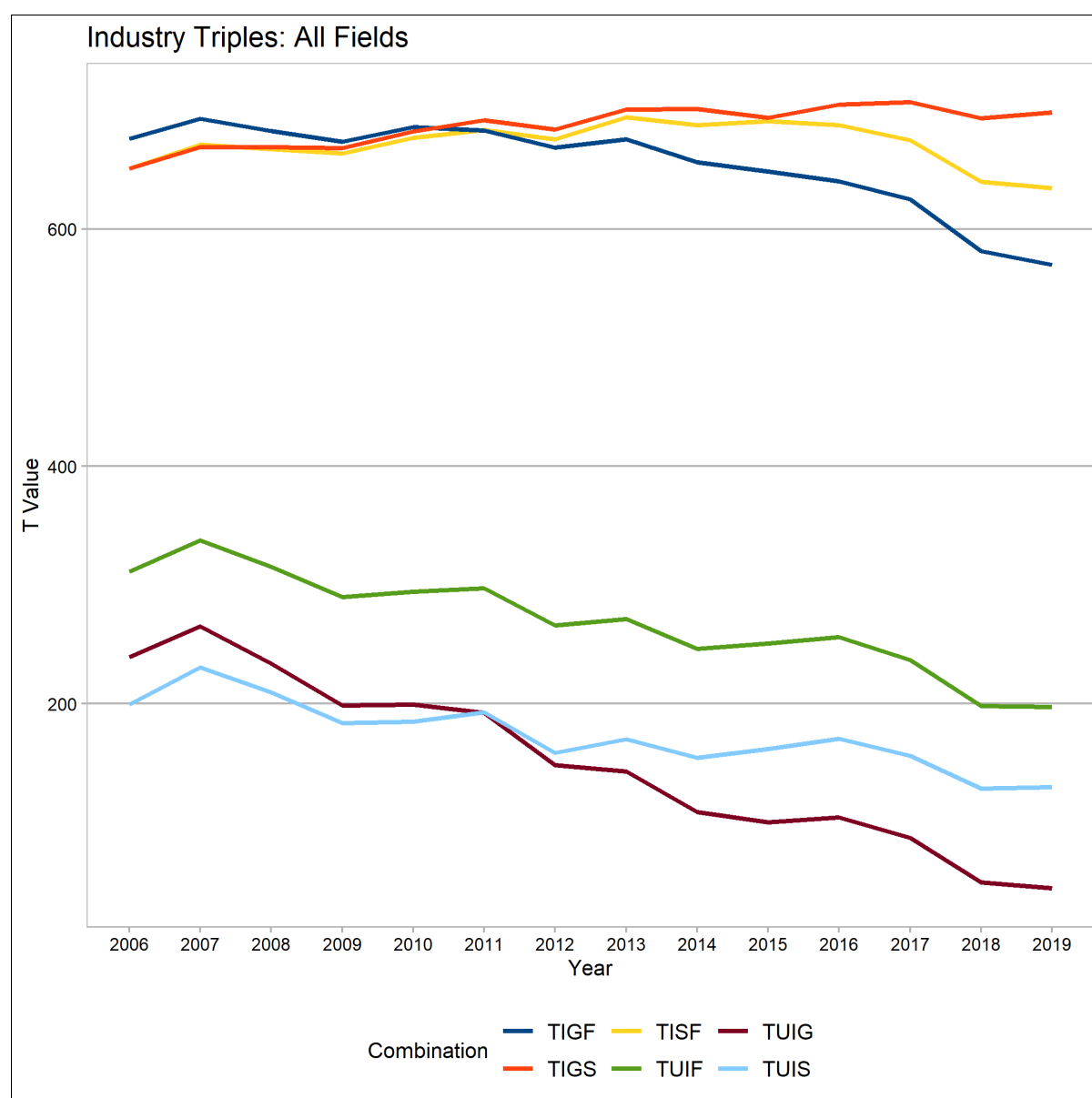
7.3.1.6 University, Other State/Territory, and Foreign

Exhibiting a continued trend towards decreasing collaboration, the T-values are counter to the percentage share of all those that use this combination. Whilst the percentage share is increasing, the decline in the T-value represents increasing independence and movement away from exportable knowledge generation.

7.3.2 Triple Combinations with Industry

Industry involvement in research reflects an increase in efforts to ensure a competitive advantage through the adoption of new knowledge and techniques or by evidencing the generated new knowledge through industrial research.

Figure 7-9: Triple combinations with industry affiliation



Calculated values derived from Web of Science bibliometric data.

Within Australia, the CRC program frequently engages industry and university research into common projects that address industry needs. With a clear split between research conducted when industry works with non-university (government, other state/territory, or foreign) and university co-authors, the university collaborations can all be seen to exhibit a decreasing collaboration whilst the non-university collaborations can be seen to be in the slightly increasing (except for *industry, government, and foreign*, which is decreasing within a neutral range).

7.3.2.1 *Industry, Government, and Foreign*

Within the greater magnitude of collaboration grouping, the activities of *industry, government, and foreign* can be seen as the anomaly through the slight decrease in collaboration. Whilst exhibiting a decrease, there is still substantially higher collaboration activity when compared to the collaboration with *university* in New South Wales.

7.3.2.2 *Industry, Government, and Other State/Territory*

Countering the trends seen so far in other triple combinations, the *industry, government, and other state/territory* combination exhibits an increasing collaboration. Whilst there are periods of neutral trends or single-year decreases, the trend continues as increasing collaboration over time.

With the involvement of industry and government at a New South Wales level, there is no indication of the nature of those two actors. There is the potential that the *other state/territory* is the same industrial organisation or government department located outside of New South Wales. Whilst this measurement highlights the collaborative nature between university, industry, and other state/territory, there is a risk that this (when scaled up to Australia) would reveal a series of pairwise combinations rather than the triple combinations as the actors may be the same organisation operating interstate.

7.3.2.3 *Industry, Other State/Territory, and Foreign*

The last of the non-university combinations, *industry, other state/territory, and foreign* exhibits increases in collaborations flattens, and decreases a small amount whilst still finishing with an overall increase when compared to the start of the period.

This combination may represent either the import or export of knowledge, and with the other state/territory and foreign actors can capture university, industry, or government partnerships in these undefined areas. Returning to the other state/territory and foreign pair, this trend

aligns with the observed decreases after 2015. Whilst industry and non-university collaborations maintained an elevated level, evidenced by the upward trends, the university collaborations all exhibited decreases – an increasing independence.

7.3.2.4 Industry and University Combinations

Whilst these combinations have been examined in depth within the context of university combinations, the comparison to the other industry combinations is of interest.

Exhibiting the largest decrease within the industry triple combinations, the *university, industry, and foreign* combination maintained a decrease after 2007 that continued throughout the period with only small periods of resilience (rebound) that never slowed the decline.

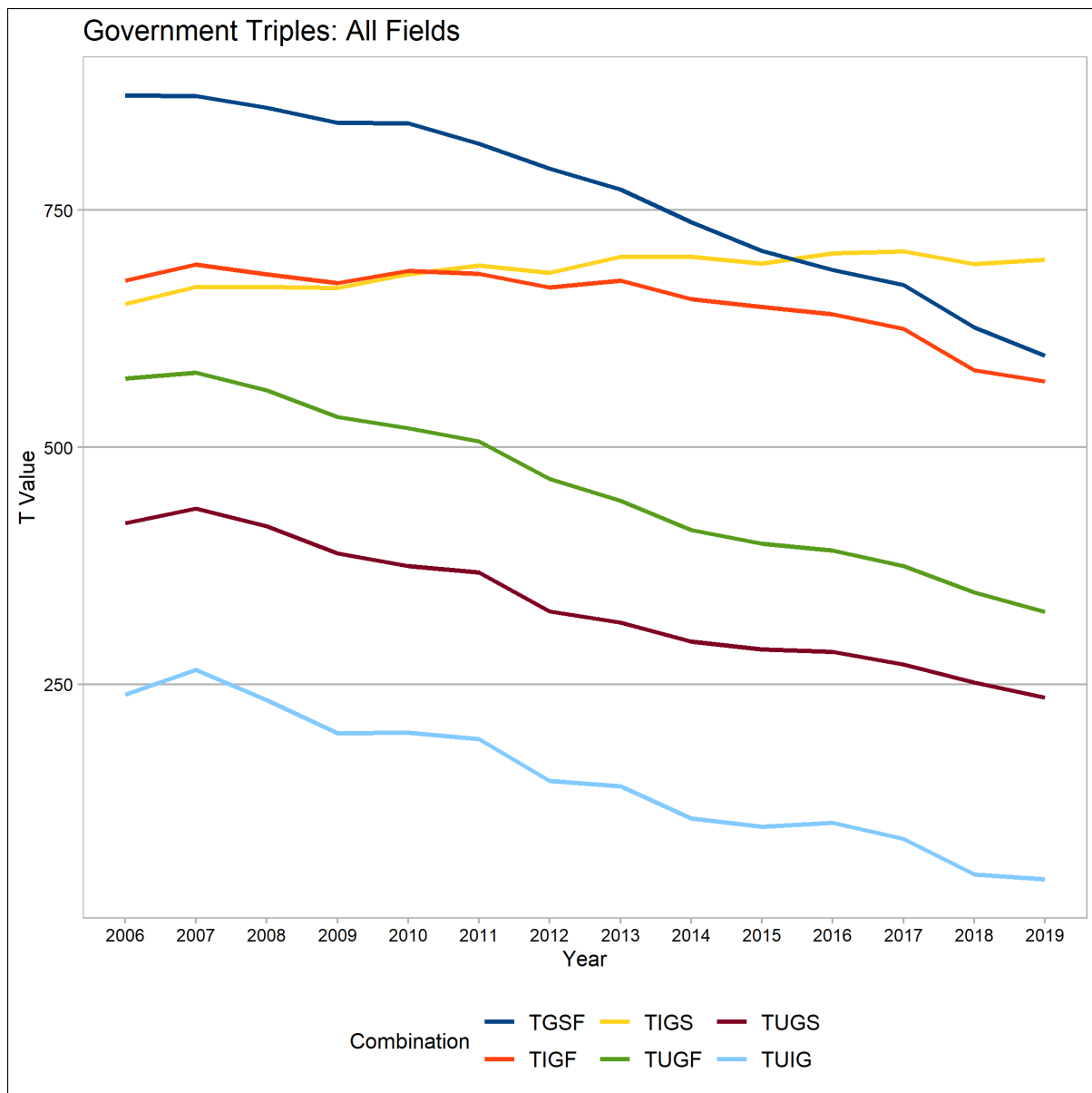
Trending towards increasing independence when compared to the other combinations with university and industry, the *industry, university, and government* combination exhibited a smaller increase in independence than university, industry, and foreign.

When comparisons of *industry, university, and other state/territory* are undertaken with the other combinations that contain university and industry, this combination trended to a near-neutral change through the period, resulting in the smallest decline in collaborations.

7.3.3 Triple Combinations with Government

Examining the triple combinations containing government without duplicating the previous two sections leaves only *government, other state/territory and foreign*. However, the comparisons between the combinations with government activity are still appropriate.

Figure 7-10: Triple combinations with government affiliation



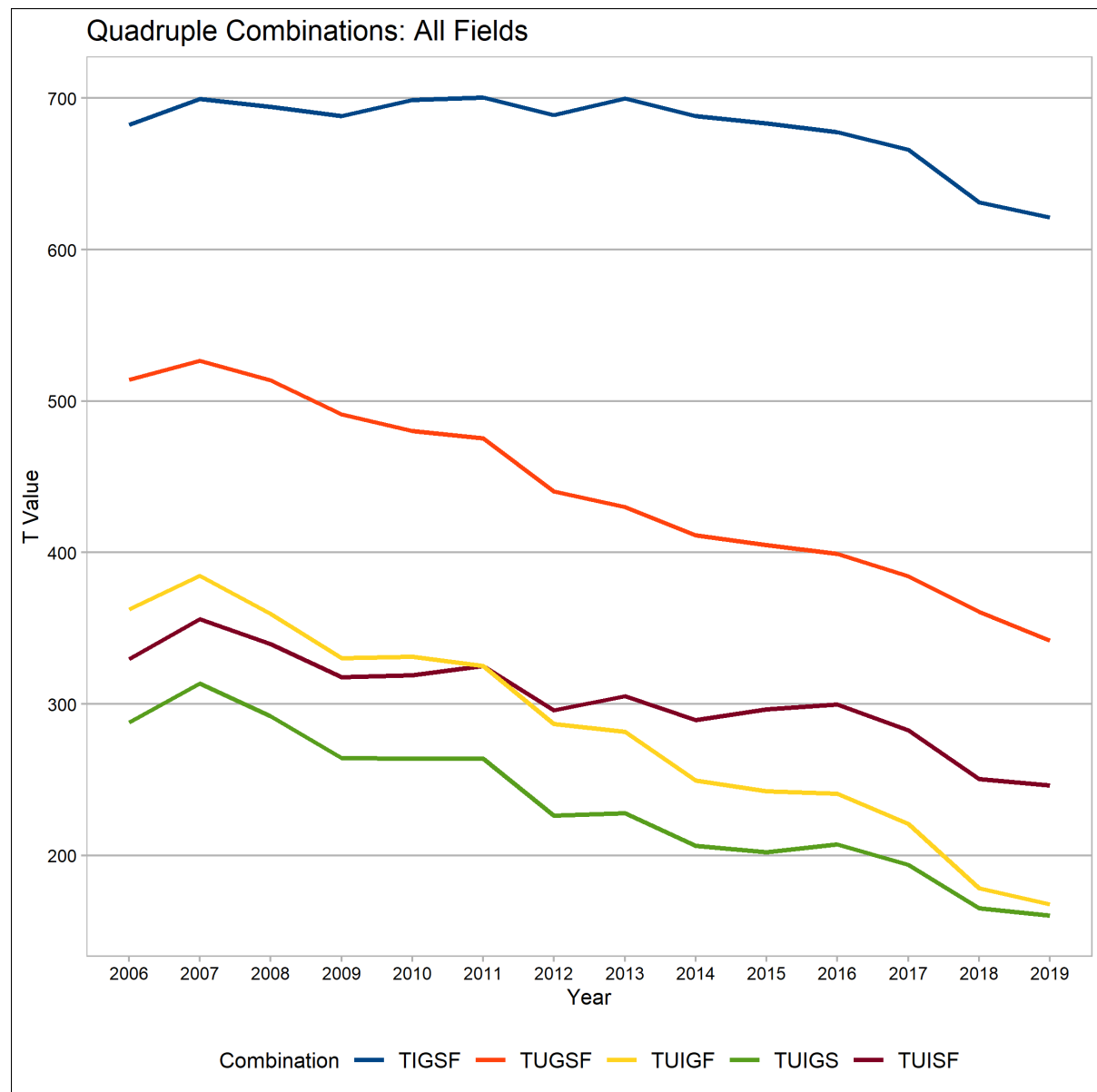
Calculated values derived from Web of Science bibliometric data.

With declining collaborations observable in many combinations, the exception is the industry, government and other state/territory combination that had a slight increase in collaboration. Within the declining combinations, the smallest decline was in a combination very similar; instead of other state/territory, it was the foreign engagement. With these combinations both exhibiting changes within a neutral range, it is possible that government and industry involvement is beneficial for knowledge transfer. However, there is no indication of the flow of this knowledge transfer, so further conclusions cannot be drawn.

7.4 Quadruple Helix Combinations

Representing the penultimate set of combinations, these capture the deeper and more complex collaborations, particularly the required inclusion of either other state/territory or foreign to achieve this combination – and in three cases, both.

Figure 7-11: Quadruple helix combinations



Calculated values derived from Web of Science bibliometric data.

Within these combinations, there are two distinct trend groupings when the T-values are examined, as shown in Figure 7-11.

Table 7-10: *Quadruple helix combinations*

Combination	Set	Count
University, Industry, Government and Other State/Territory	1,1,1,1,0	1,383
University, Industry, Government and Foreign	1,1,1,0,1	1,498
University, Industry, Other State/Territory and Foreign	1,1,0,1,1	4228
University, Government, Other State/Territory and Foreign	1,0,1,1,1	2,100
Industry, Government, Other State/Territory and Foreign	0,1,1,1,1	201

Table detailing the combinations expressed as sets and the total numbers.

With clear trends towards increasing independence, the combinations containing university all trend at a similar rate, with a faster rate for *university, government, other state/territory, and foreign*. In comparison, *university, industry, government, and other state/territory* had the smallest decrease in collaboration.

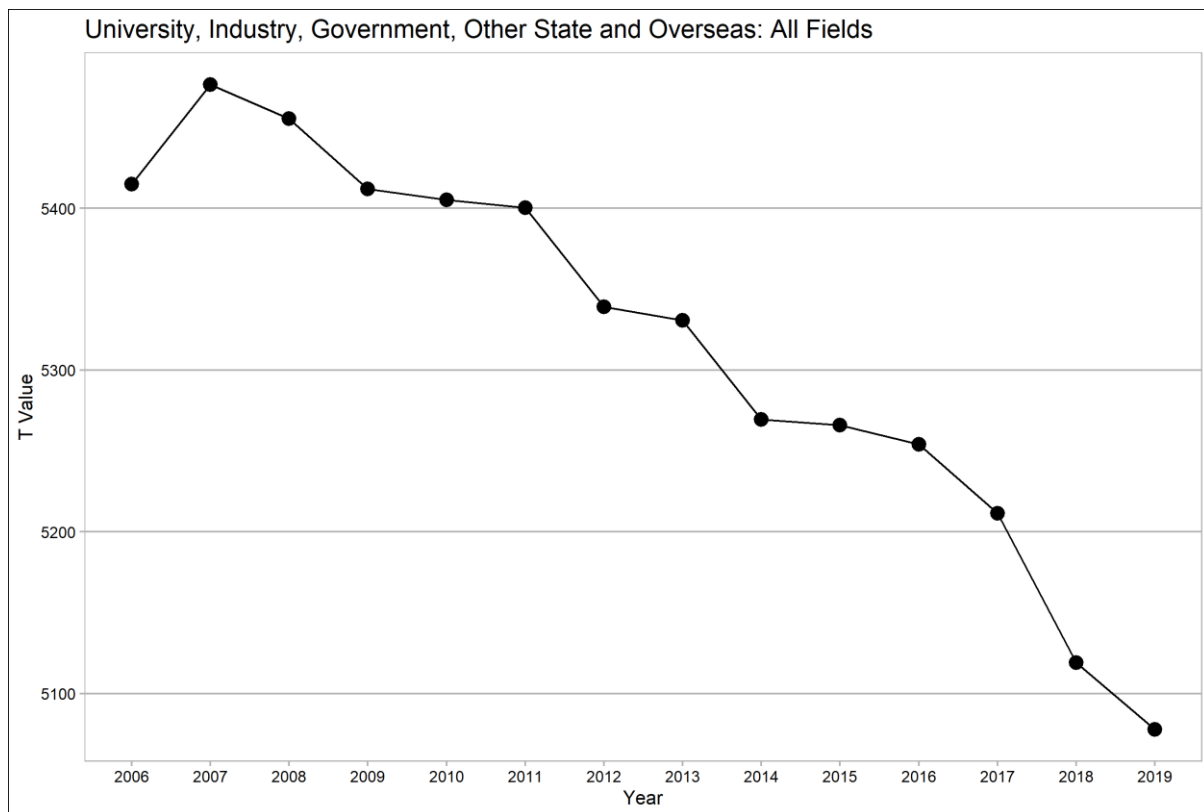
The dominance of university and the requirement for *other state/territory* or *foreign* in this change represents the transferability of knowledge changing from the universities within New South Wales.

In contrast to the decline in university co-authored publications, the *industry, government, other state/territory, and foreign* collaboration followed a neutral/trending to increasing collaboration. However, the caveat of the type of *government* (local, state, or federal) actor is unknown, and likewise, the possibility of *industry* actors located in *other state/territory* (or even overseas, captured in *foreign*) is not known. This limits the ability to critique this any further.

7.5 Quintuple Helix Combination

The final combination is the quintuple. This reflects the most complicated author collaboration, and throughout the period in question, only 1,157 papers had this author combination.

Figure 7-12: Quintuple helix



Calculated values derived from Web of Science bibliometric data.

Reflecting the combination with all the actors, this has trended towards an increasingly independent research landscape.

7.6 Conclusions

Overall, increasing collaboration can occur when industry is involved with government and/or other states. However, the other state does not denote what type of organisation. These could be government, industry, or university; the data does not explain this, nor which level of government (local, state, or federal).

If the collaboration is declining between New South Wales universities or industries (and, to a lesser extent, government) and foreign actors, then this may reflect a decline in the competitive advantage that New South Wales has in knowledge capital. Increasing collaboration may reflect an advantage that those organisations have.

Whilst there are limits to the efficacy of the analysis, with the scalable approach to the n-tuple helix, it is possible to break down the large amounts of data (once the appropriate classification work has been undertaken) and identify the key combinations or the actors within these combinations.

The n-tuple, and the triple and quadruple helix before, does not explicitly inform or identify the causal factors, nor which are the ‘best’ outcomes. Firstly, causal factors may be numerous and varied; policies from both funding bodies, as well as internal policies, may influence these. Collaboration may be influenced by research themes, technology, or knowledge exchange. These influences are excluded from this analysis. Secondly, the role of independence of research outcomes may be beneficial – the ‘best’ outcome question.

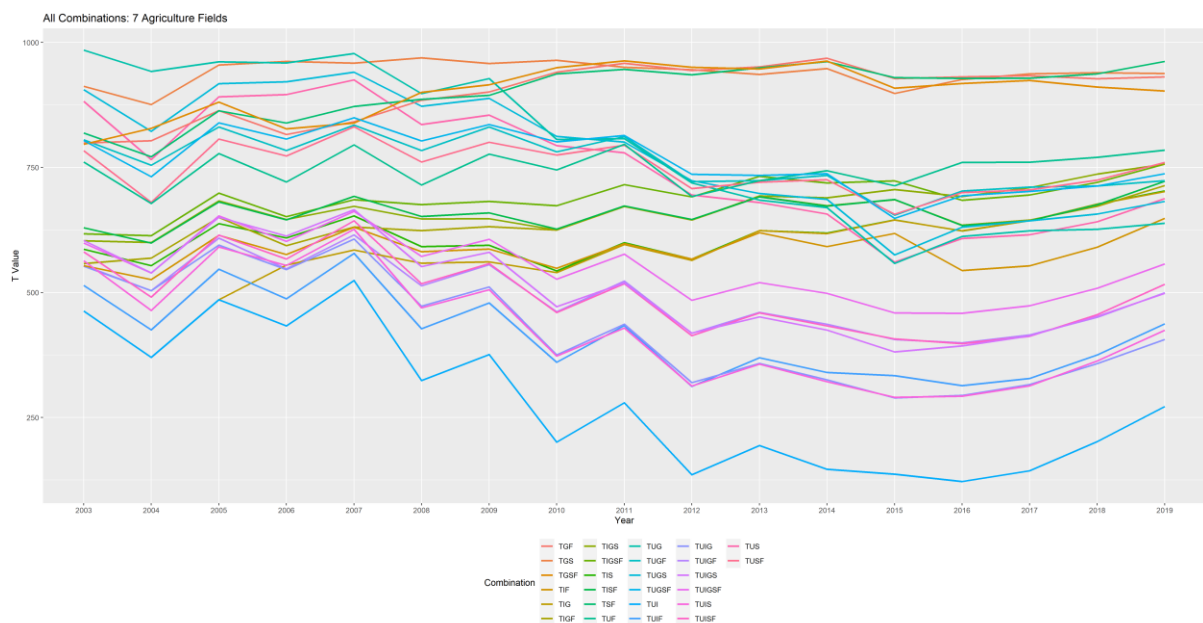
Over the analysis period, the overall trend is for increasing independence in research – that is, there is less collaboration captured in the quadruple or quintuple helix. However, the application of the quintuple helix highlights the benefit of increased granularity in the analysis tools. With this increased granularity, the role of other state or overseas in the New South Wales research ecosystem can be examined.

Chapter 8: Results Part Two – Agriculture-Related Fields

The development of a scalable (large-scale) approach means that it can be scaled up and used in a scaled-down version to be applied to a sub-sector analysis of the full dataset. Once again, the PRISMA Statement was followed to collect data from the Web of Science. In contrast to the entire Web of Science dataset, adding 2003–2006 data was possible as the author affiliation was in a more standard format.

In-program (within the R environment) cleaning resulted in the acceptance of 7,498 items covering 17 years. Using this approach, with the same algorithm applied to a subset of data, no changes were made – apart from the smaller dataset used. Therefore, the following can be observed:

Figure 8-1: All Combinations within the 7 Agriculture Fields



Calculated values derived from Web of Science bibliometric data.

With 26 combinations identified, the analysis is too complex in a single diagram. Following the same approach adopted in Chapter Seven, a study of agricultural sector research is conducted.

A declining university sole authorship reflects potential policy changes, although the decline in government sole authorship is substantially larger. In contrast, in the pairwise results, collaboration between university and industry sectors increased, as did university and foreign collaboration.

Importantly, in contrast to the larger dataset, much larger fluctuations result in more varied trends for all combinations, reflecting the smaller nature of the dataset and the increased variation in publication trends.

8.1 Single Author Type Publications

Single-author types, where authors are all from the same organisational type, reflect the research with no inter-sectoral collaboration – but not necessarily the least collaboration.

Table 8-1: Count and percentage of publications in single combinations

Year	Total Publications	Within Sectors									
		U		I		G		S		F	
		Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent
2003	321	76	23.68	2	0.62	59	18.38	0	0.00	0	0.00
2004	287	81	28.22	5	1.74	47	16.38	0	0.00	0	0.00
2005	305	63	20.66	1	0.33	47	15.41	0	0.00	0	0.00
2006	333	63	28.22	2	1.74	47	16.38	0	0.00	0	0.00
2007	366	73	19.95	0	0.00	36	9.84	0	0.00	0	0.00
2008	408	86	21.08	1	0.25	38	9.31	0	0.00	0	0.00
2009	347	60	17.29	4	1.15	35	10.09	0	0.00	0	0.00
2010	408	78	19.12	2	0.49	28	6.86	0	0.00	0	0.00
2011	385	77	20.00	3	0.78	23	5.97	0	0.00	0	0.00
2012	383	77	20.10	1	0.26	20	5.22	0	0.00	0	0.00
2013	460	93	20.22	5	1.09	14	3.04	0	0.00	0	0.00
2014	491	77	15.68	4	0.81	13	2.65	0	0.00	0	0.00
2015	498	90	18.07	4	0.80	10	2.01	0	0.00	0	0.00
2016	545	83	15.23	2	0.37	8	1.47	0	0.00	0	0.00
2017	594	62	10.44	3	0.51	15	2.53	0	0.00	0	0.00
2018	592	58	9.80	4	0.68	11	1.86	0	0.00	0	0.00
2019	614	71	11.56	6	0.98	10	1.63	0	0.00	0	0.00

Calculated values derived from Web of Science bibliometric data.

An overall decrease in single-author publications – with a substantial decrease from over 18% to under 2% observable in government-authored publications (and in absolute terms from 59 publications down to 10), there are significant changes in publication trends.

Industry as a sole author type has generally remained consistent in a band spanning 1.5 percentage points, fluctuating between 0.25% and 1.75% (with no publications in 2007).

Possible reasons for the decreasing trend of publication by government include a shift from fundamental research to extension. Furthermore, for fundamental research, there may also be a requirement for increased collaboration, particularly with researchers in either other State/Territory, Overseas, or within the university sector (either within NSW or external in the previous groupings) to access the relevant knowledge or facilities. With the example of government, the shift in these publications towards collaborative publishing trends and who these collaborations are with are focused on.

8.2 Pairwise Publications

These combinations commonly occur when reflecting a simple collaboration model of two organisational types (which may include more than two organisations).

Table 8-2: Count of publications in pairwise combinations

Year	Total Publications	Between Sectors									
		UI	UG	US	UF	IG	IS	IF	GS	GF	SF
2003	321	2	27	24	24	4	4	1	32	16	0
2004	287	2	31	24	25	1	4	2	26	10	0
2005	305	4	21	30	34	0	8	7	34	12	0
2006	333	2	36	38	31	1	10	1	33	17	0
2007	366	3	42	20	35	3	16	2	57	17	0
2008	408	3	41	39	53	2	5	3	50	15	0
2009	347	1	36	38	57	1	8	5	37	17	0
2010	408	2	28	52	79	2	10	3	36	18	0
2011	385	4	33	33	73	0	9	7	35	15	0
2012	383	1	37	47	79	0	10	6	19	16	0
2013	460	4	35	47	112	3	10	2	29	13	0
2014	491	6	44	36	125	1	5	4	24	15	0
2015	498	12	35	50	135	1	12	5	18	16	0
2016	545	5	39	38	153	0	11	5	27	15	0
2017	594	11	54	49	175	4	6	6	23	14	0
2018	592	6	41	47	171	1	17	7	26	23	0
2019	614	8	53	54	172	1	19	4	26	21	0

Calculated values derived from Web of Science bibliometric data.

Examining these trends, the shift in collaboration towards that between university and foreign is clear in the relative terms. A substantial increase from almost 7.5% (24) to 28% (172) in

research output accounts for the majority of the decrease in solely university-authored publications (which decreased by 12.11 percentage points in that time).

Table 8-3: Percentage of publications in pairwise combinations

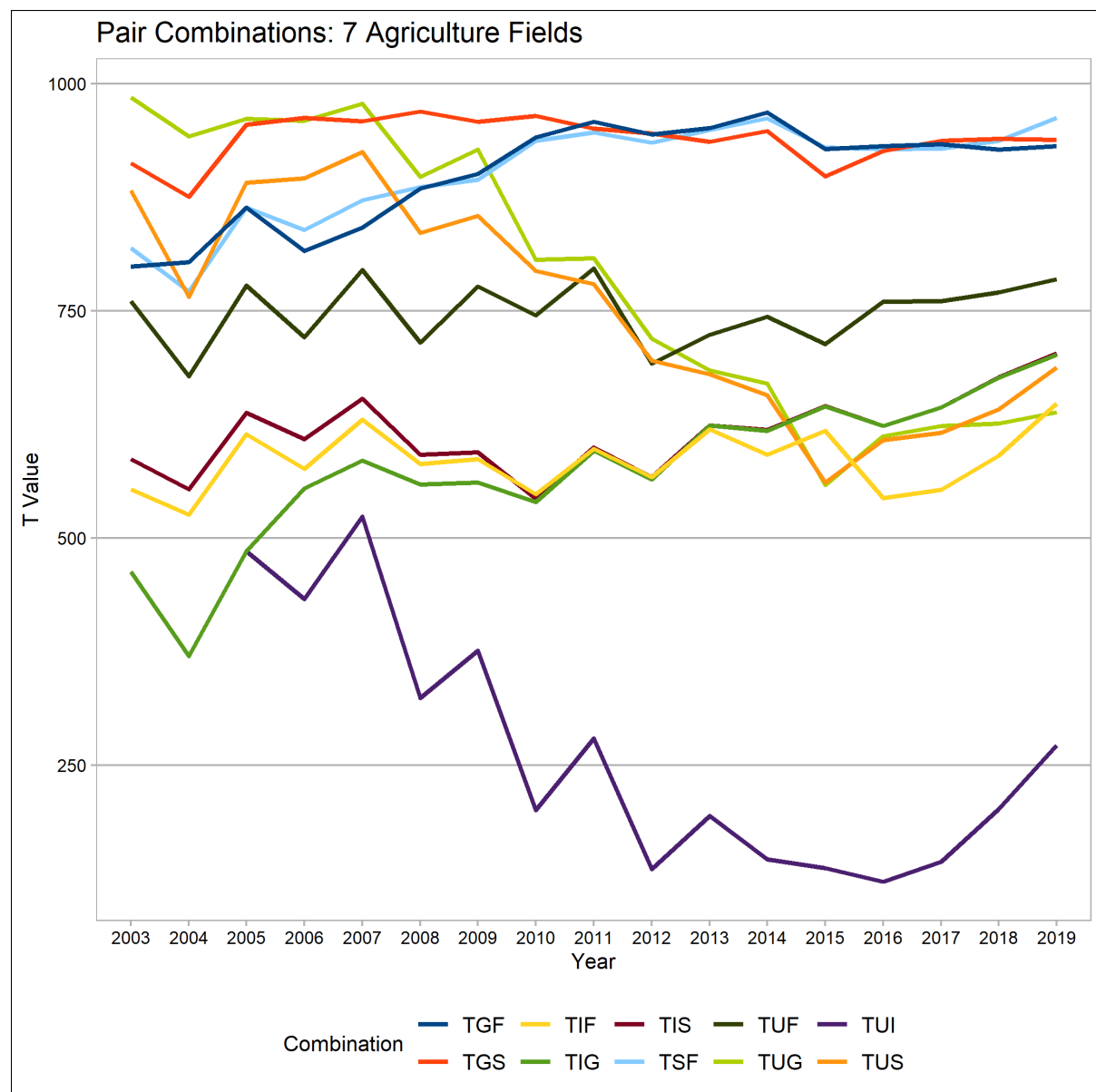
Year	Total Publications	Between Sectors									
		UI	UG	US	UF	IG	IS	IF	GS	GF	SF
2003	321	0.62	8.41	7.48	7.48	1.25	1.25	0.31	9.97	4.98	0.00
2004	287	0.70	10.80	8.36	8.71	0.35	1.39	0.70	9.06	3.48	0.00
2005	305	1.31	6.89	9.84	11.15	0.00	2.62	2.30	11.15	3.93	0.00
2006	333	0.70	10.80	8.36	8.71	0.35	1.39	0.70	9.06	3.48	0.00
2007	366	0.82	11.48	5.46	9.56	0.82	4.37	0.55	15.57	4.64	0.00
2008	408	0.74	10.05	9.56	12.99	0.49	1.23	0.74	12.25	3.68	0.00
2009	347	0.29	10.37	10.95	16.43	0.29	2.31	1.44	10.66	4.90	0.00
2010	408	0.49	6.86	12.75	19.36	0.49	2.45	0.74	8.82	4.41	0.00
2011	385	1.04	8.57	8.57	18.96	0.00	2.34	1.82	9.09	3.90	0.00
2012	383	0.26	9.66	12.27	20.63	0.00	2.61	1.57	4.96	4.18	0.00
2013	460	0.87	7.61	10.22	24.35	0.65	2.17	0.43	6.30	2.83	0.00
2014	491	1.22	8.96	7.33	25.46	0.20	1.02	0.81	4.89	3.05	0.00
2015	498	2.41	7.03	10.04	27.11	0.20	2.41	1.00	3.61	3.21	0.00
2016	545	0.92	7.16	6.97	28.07	0.00	2.02	0.92	4.95	2.75	0.00
2017	594	1.85	9.09	8.25	29.46	0.67	1.01	1.01	3.87	2.36	0.00
2018	592	1.01	6.93	7.94	28.89	0.17	2.87	1.18	4.39	3.89	0.00
2019	614	1.30	8.63	8.79	28.01	0.16	3.09	0.65	4.23	3.42	0.00

Calculated values derived from Web of Science bibliometric data.

The following sections analyse the combinations in turn. Whilst this results in multiple assessments of the trends, the direct comparison with like combinations identifies key driving factors in the increasingly complex combinations and collaborations.

With the overall decline in the *university* pair combinations, the remaining trends for different pairs are more neutral or slightly increasing. As research strategies shift, alternative research collaborations will occur.

Figure 8-2: All pairs



Calculated values derived from Web of Science bibliometric data.

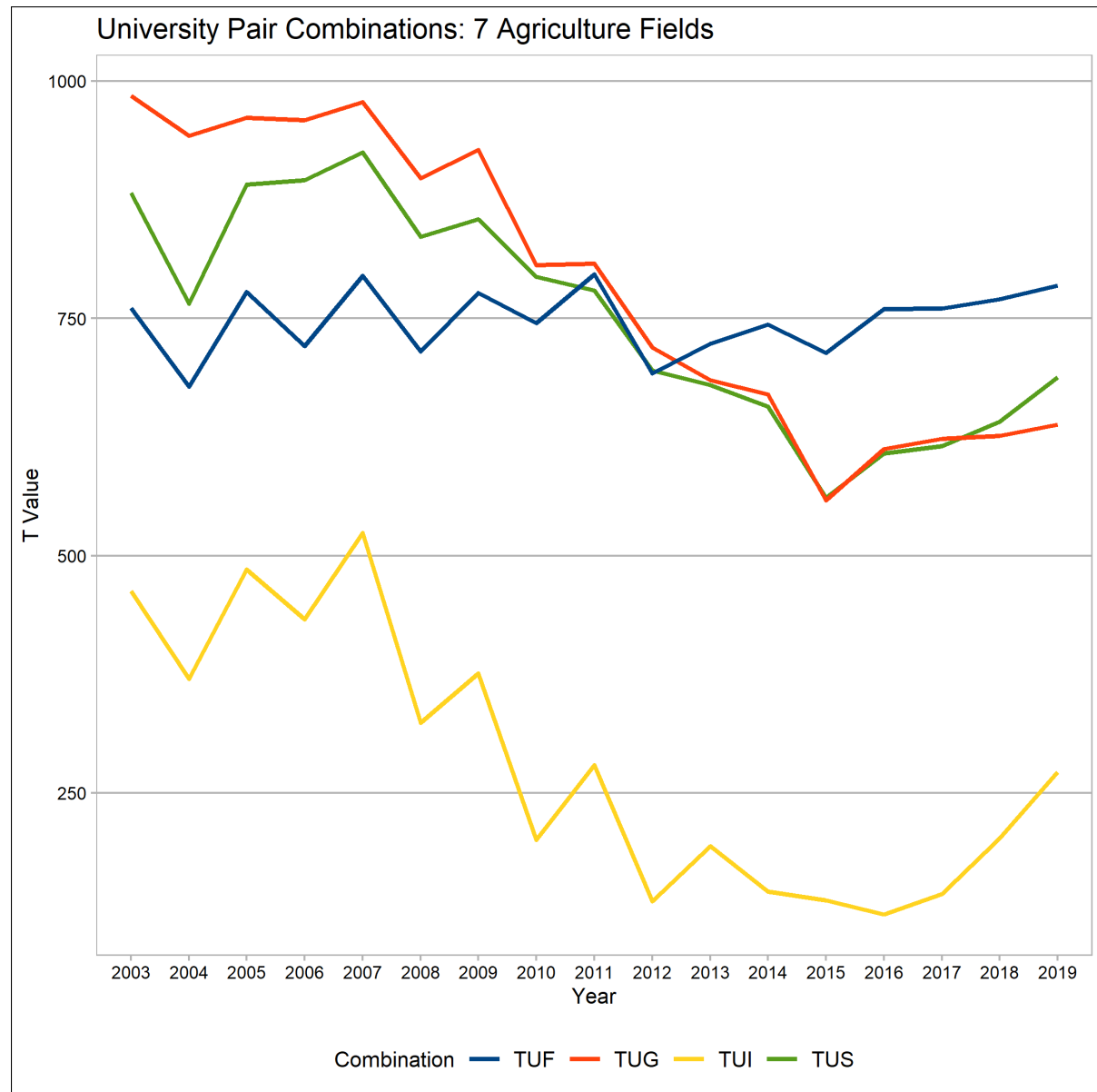
Importantly, these pairs also underpin the calculations of the three, four, and five actor combinations. This explains the difference in the trends when compared to the percentages in Table 8-3.

8.2.1 Pairs Containing University

Reflecting collaboration between university and other actors, these combinations experienced similar trends across all combinations. A near-neutral trend can be observed between

university and foreign, whilst increasing collaboration can be observed in other combinations.

Figure 8-3: University pairs



Calculated values derived from Web of Science bibliometric data.

With clear matching trends at a similar magnitude observed in *university and government* (TUG) and *university and other state/territory* (TUS), all exhibit increasing collaboration after 2015, and 2016 for *university and industry*. The trend towards collaboration in agriculture is contrary to that observed in all research fields. Politically, 2016 was a stable

year, with no government change at the federal level that may influence research activity; however, the National Farmers Federation (NFF) \$100b plan was announced.

8.2.1.1 Highlighted Combinations

The changes in collaboration can be observed with the increased detail. The university acting within agriculture research may work collaboratively, which can be observed in both *university and government* and *university and other state/territory* with similar magnitudes and trends. With the engagement in the government collaboration, there is no breakdown of the type of government between state or federal actors.

Reflecting not only inter-university collaborations but also that of other government or industry partners, the *university and other state/territory* collaboration, with a similar magnitude to *university and government*, is indicative that these relationships may be very similar collaborators, but now in *other state or territory*. Without breaking down the *other state or territory*, the identification of the collaborator as a government or other actors is not possible.

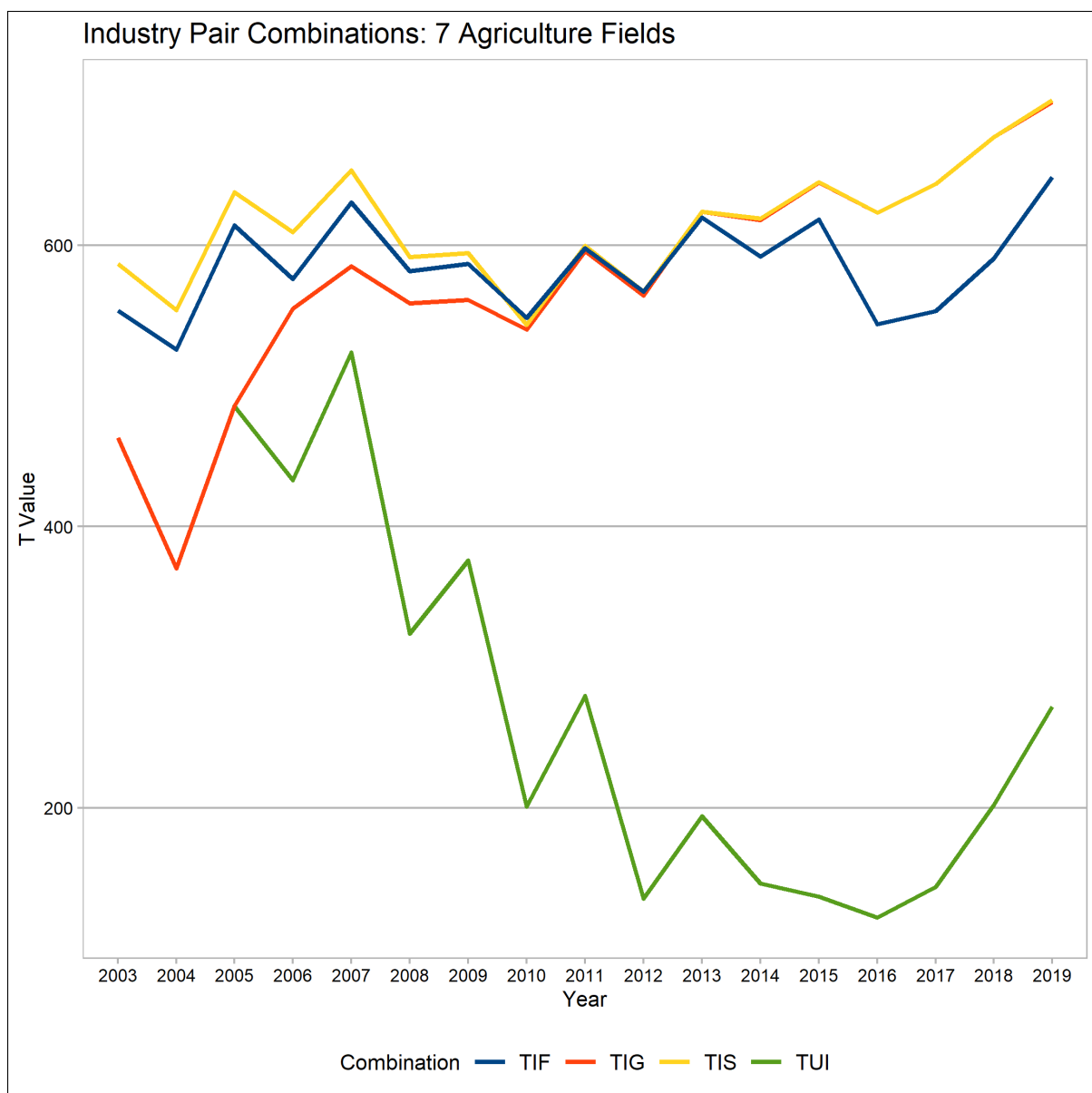
Intra and international collaboration within the agricultural fields reflects the transferability of the knowledge that New South Wales (and Australian) universities generate; with the affiliation of universities restricted to New South Wales only, there are limitations in the transferability. However, these limitations are reduced when subsequent combinations containing university, foreign and other state/territory are examined.

The inclusion of overseas captures the relevance of Australian knowledge within agriculture at a global level; where stronger collaboration reflects an increasing demand for knowledge.

8.2.2 Industry Pairs

Clear matches in trend and magnitude – almost identical – between *industry and foreign* (TIF), *industry and government* (TIG) and *industry and other state/foreign* (TIS) at differing periods all exhibit an ultimate increase in collaboration after a period of decline then neutrality. Exhibiting an increase in collaboration after 2016, aligning with the launch of the NFF strategy, the *university and industry* (TUI) combination also increased in collaboration after a much greater decline.

Figure 8-4: Industry pairs



Calculated values derived from Web of Science bibliometric data.

8.2.2.1 Highlighted Combinations

Following the observations in the same combinations with university, the industry collaborations with *government, foreign, and other state/territory* exhibit remarkably similar trends. Exhibiting overall increasing collaboration, after a period of neutrality, the increase in collaboration accelerated in all combinations after 2016.

Whilst *industry and government* and *industry and other state/territory* exhibit very similar trends from 2010 onwards, *industry and foreign* follows a different pattern when examined individually. With increases in collaboration observable from 2010 onwards within *industry and government* and *industry and other state/territory*, the increased collaboration started much earlier than when universities were involved.

Industry and government clearly exhibit a long-running increase from 2004 onwards and continued to 2019. Whilst potentially demonstrating the role of the extension of government agencies and the drive for industry adoption, this combination may capture these activities.

Reflecting collaborations that exclude NSW universities, the *industry and other state/territory* T-values reflect the collaboration of industry based in NSW collaborating not only with interstate industry but also interstate government and university partners. In line with other combinations, there is a strong increase in collaboration after 2010, following a substantial downturn from 2007. Whilst the increase is lower than the trend from 2004 to 2007, the rebound is of consistently increasing collaboration.

Industry and foreign captures the research undertaken by the wide range of industry (or private entities) actors, as well as foreign partners. This collaboration captures university, industry, and government actors overseas – the relevance of Australian knowledge and application on a global scale.

Although there is a lack of clear trends, the result is an increased collaboration by 2019.

Interspersed with declining collaborations in 2007, as well as cyclical collaboration trends until 2016, this can be best described as fluctuating and irregular whilst trending to an overall increase in collaboration from 2016 – in line with the *industry and other state/territory* combination.

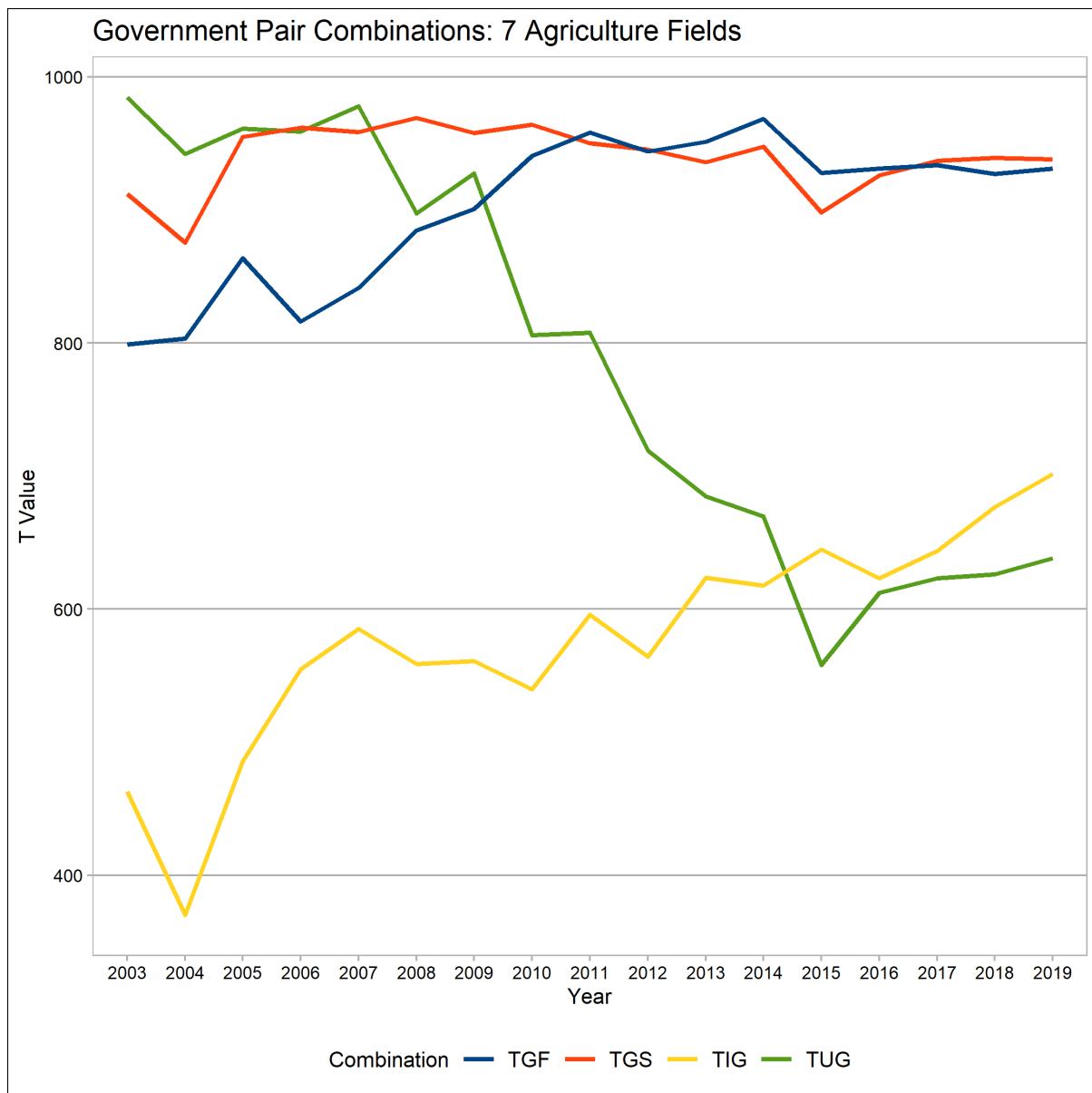
8.2.3 Government Pairs

With the combinations containing government, there is no distinction in the level(s) of government that may be acting together, nor when including collaborations outside of New South Wales if those collaborations are with or without other government collaborators.

Capturing both state and federal government collaboration with research partners from the university, industry, and government sectors, this pair has the potential to be further broken down for more detailed analysis in future work.

With *government and foreign* (TGF) initially tending to follow the *government and other state/territory* (TGS) combination, there was a slowing in the increase of collaboration, plateauing in 2004 for *government and other state/territory*, becoming near neutral to decreasing. Also increasing collaboration, the *government and industry* (TIG) collaboration started at a lower magnitude but increased at a rate greater than the *government and foreign* combination. In contrast, the *government and university* (TUG) combination exhibits substantial decreases in collaboration until 2015, when there was a slight increase in collaboration to 2019.

Figure 8-5: Government pairs



Calculated values derived from Web of Science bibliometric data.

8.2.3.1 Government and Other State/Territory

Focusing on a single combination, the role of *government and other state/territory* (TGS), actions of federal research agencies (e.g., CSIRO et al.) across Australia are captured within this combination, as well as collaborations with other specialised research agencies.

These collaborations of federal organisations may explain the activity in *government and other state/territory* combinations – and the generally neutral trend in that combination.

8.2.3.2 *Government and Foreign*

Representing an increasing collaboration on a global scale, and as with the *government and other state/territory*, the *foreign* category captures all the actors in that category rather than breaking them down into university, industry, or government. This broad categorisation, along with the lack of clear points of change, limits the identification of causes.

There is an increasing trend of collaboration until 2011 and then neutrality, the collaboration continued at a similar magnitude and trend to *government and other state/territory*.

8.2.4 *Other State/Territory Pairs and Foreign Pairs*

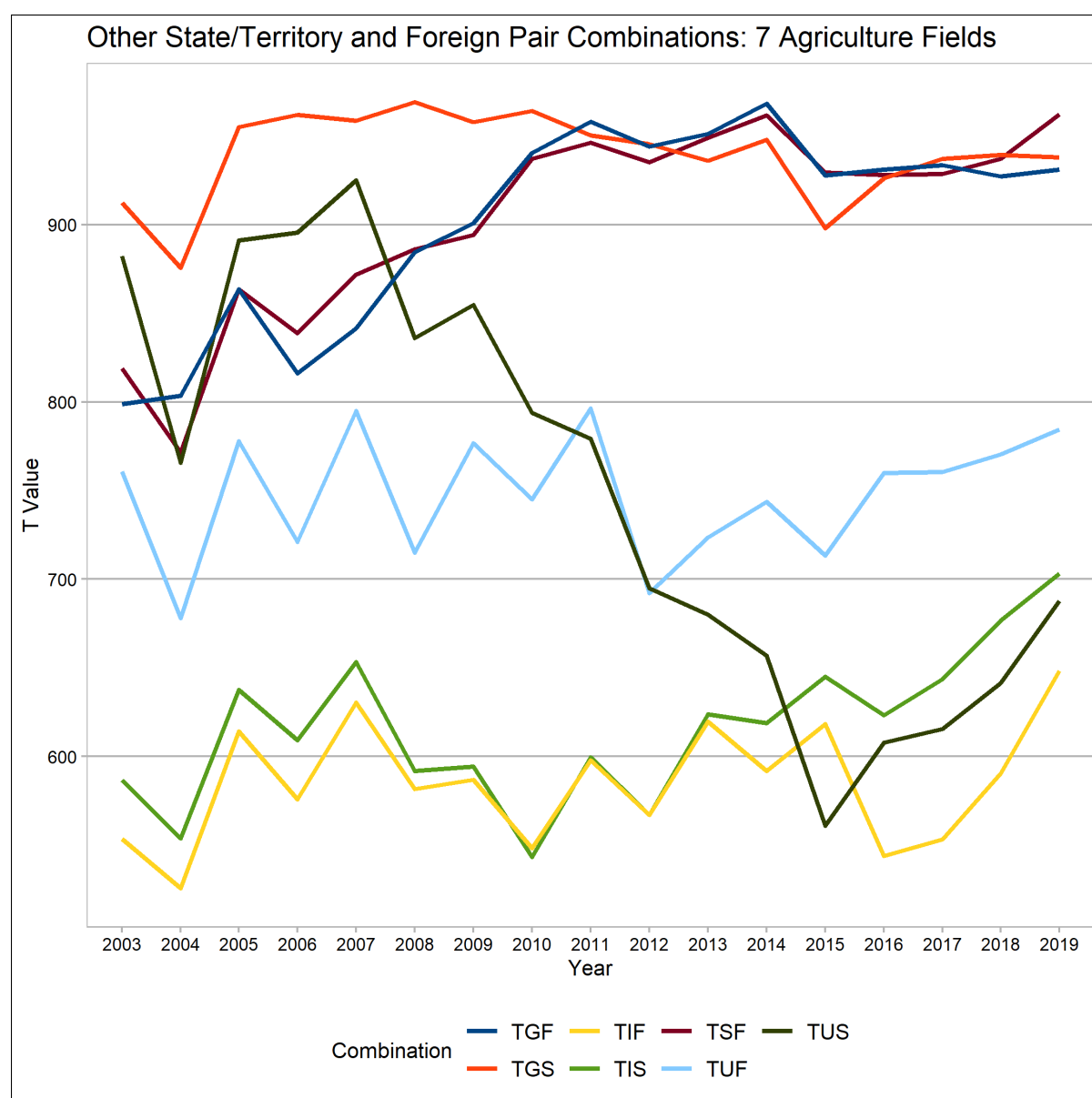
The inclusion of *other state/territory* captures the transferability of knowledge from New South Wales to areas outside of the state, whilst *foreign* captures the international relevance of knowledge and collaboration practices.

When comparing the behaviour of the different combinations, it is necessary to be mindful that the total number of other state/territory or foreign publications is excluded from the overall calculation – the values here represent those captured within the dataset.

The overall calculation of the T-value requires the inclusion of any occurrence of *other state/territory and foreign* as an affiliation, as the pure combination is specifically excluded from the calculation.

With all combinations that contain a non-New South Wales actor captured within Figure 8-6, the similarity of trends can be observed. First, the near matching of *industry and foreign* (TIF) with *industry and other state/territory* (TIS) until 2013, when *industry and other state/territory* increased collaboration. Second, at a higher magnitude, the similarity of *other state/territory and foreign* (TSF) and *government and foreign* (TGF) exhibited an increasing collaboration throughout the time.

Figure 8-6: Other state/territory and foreign pair combinations



Calculated values derived from Web of Science bibliometric data.

Contrasting these observations is the decline seen in *university and other state/territory* (TUS), as well as the near-neutral behaviour of *government and other state/territory* (TGS). The magnitude of all combinations within

When comparing the behaviour of the different combinations, it is necessary to be mindful that the total number of other state/territory or foreign publications is excluded from the overall calculation – the values here represent those captured within the dataset.

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With all combinations that contain a non-New South Wales actor captured within Figure 8-6, the similarity of trends can be observed. First, the near matching of *industry and foreign* (TIF) with *industry and other state/territory* (TIS) until 2013, when *industry and other state/territory* increased collaboration. Second, at a higher magnitude, the similarity of *other state/territory and foreign* (TSF) and *government and foreign* (TGF) exhibited an increasing collaboration throughout the time.

Figure 8-6: Other state/territory and foreign pair combinations – not considered in the analysis of many other combinations – is substantially lower at under 1,000 milli-bits of information transmitted.

8.3 Triple Combinations

Representing the increasingly complex nature of research, in percentage terms, there are clear and substantial increases in collaboration. Whilst overall numbers are substantially smaller than those seen in the sole and pair combinations, there are clear increases in collaboration when the combination includes *university* and *foreign* affiliations.

Examining the transmission values, increases in *industry*, *government*, and *foreign* and *government*, *other state/territory*, and *foreign* can be observed. In contrast, combinations involving New South Wales universities exhibit decreased collaboration – or increasingly independent.

Table 8-4: Count of publications in triple combinations

Year	Total Publications	Between Sectors									
		UIG	UIS	UIF	UGS	UGF	USF	IGS	IGF	ISF	GSF
2003	321	1	5	2	13	5	8	2	1	2	9
2004	287	1	0	1	6	6	6	1	0	1	4
2005	305	0	2	2	14	6	8	2	0	1	3
2006	333	4	1	2	17	2	12	5	0	1	3
2007	366	2	1	2	15	11	14	5	0	2	5
2008	408	2	5	3	22	8	13	2	0	1	4
2009	347	2	3	0	20	6	8	3	0	0	4
2010	408	3	1	3	30	6	16	0	0	0	5
2011	385	2	1	2	19	9	24	1	0	2	7
2012	383	4	0	0	29	7	16	1	0	1	7
2013	460	6	4	1	27	10	15	0	0	4	12
2014	491	3	8	5	41	14	34	2	3	3	17
2015	498	3	2	3	22	25	24	0	0	4	11
2016	545	3	6	2	17	44	45	7	0	6	13
2017	594	1	4	1	22	37	51	2	1	9	18
2018	592	4	6	8	33	40	52	1	1	4	8
2019	614	1	7	7	27	23	43	4	1	7	15

Calculated values derived from Web of Science bibliometric data.

The substantial change in collaborations can be seen to increase in *government, other state/territory and foreign* (TGSF) at the highest magnitude in this range of collaborations, reflecting government knowledge sharing with other organisational types at both Australian and international levels.

Table 8-5: Percentage of publications in triple combinations

Year	Total Publications	Between Sectors									
		UIG	UIS	UIF	UGS	UGF	USF	IGS	IGF	ISF	GSF
2003	321	0.31	1.56	0.62	4.05	1.56	2.49	0.62	0.31	0.62	2.80
2004	287	0.35	0.00	0.35	2.09	2.09	2.09	0.35	0.00	0.35	1.39
2005	305	0.00	0.66	0.66	4.59	1.97	2.62	0.66	0.00	0.33	0.98
2006	333	0.35	0.00	0.35	2.09	2.09	2.09	0.35	0.00	0.35	1.39
2007	366	0.55	0.27	0.55	4.10	3.01	3.83	1.37	0.00	0.55	1.37
2008	408	0.49	1.23	0.74	5.39	1.96	3.19	0.49	0.00	0.25	0.98
2009	347	0.58	0.86	0.00	5.76	1.73	2.31	0.86	0.00	0.00	1.15
2010	408	0.74	0.25	0.74	7.35	1.47	3.92	0.00	0.00	0.00	1.23
2011	385	0.52	0.26	0.52	4.94	2.34	6.23	0.26	0.00	0.52	1.82
2012	383	1.04	0.00	0.00	7.57	1.83	4.18	0.26	0.00	0.26	1.83
2013	460	1.30	0.87	0.22	5.87	2.17	3.26	0.00	0.00	0.87	2.61
2014	491	0.61	1.63	1.02	8.35	2.85	6.92	0.41	0.61	0.61	3.46
2015	498	0.60	0.40	0.60	4.42	5.02	4.82	0.00	0.00	0.80	2.21
2016	545	0.55	1.10	0.37	3.12	8.07	8.26	1.28	0.00	1.10	2.39
2017	594	0.17	0.67	0.17	3.70	6.23	8.59	0.34	0.17	1.52	3.03
2018	592	0.68	1.01	1.35	5.57	6.76	8.78	0.17	0.17	0.68	1.35
2019	614	0.16	1.14	1.14	4.40	3.75	7.00	0.65	0.16	1.14	2.44

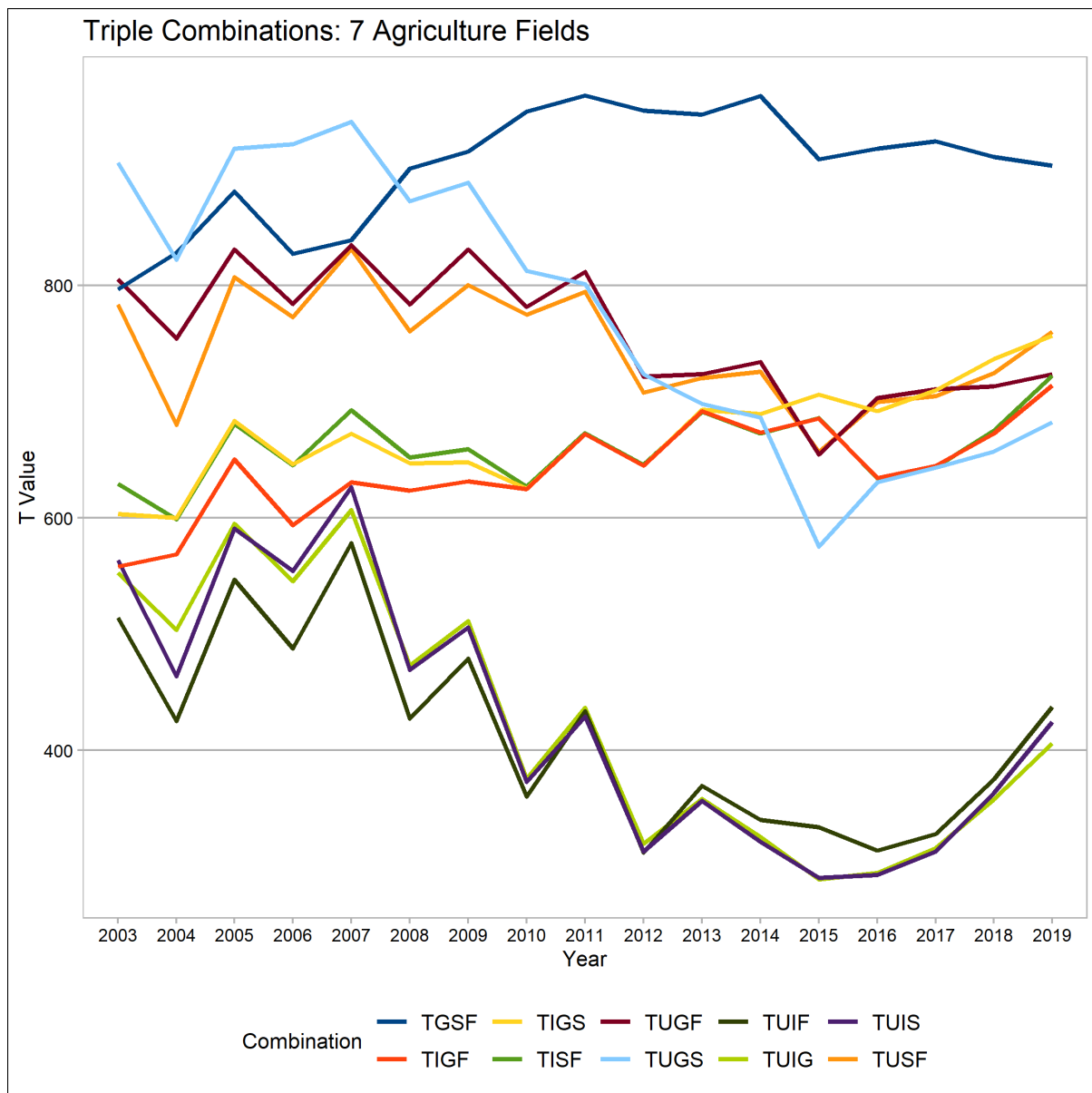
Calculated values derived from Web of Science bibliometric data.

With the declining collaborations, combinations that contain *university* began to return to increasing collaboration from 2015/16, accelerating after 2017 for *university, industry, and foreign*, the *university, industry, and foreign* and *university, industry, and government* combinations.

An earlier change in collaborations can be seen in the increase in *industry, government, and foreign* (TIGF), *industry, government, and other state/territory* (TIGS) and *industry, other state/territory, and foreign* (TISF), all tending to the same trajectory in 2010.

These shared trajectories may represent the periods of no collaborative papers published in those combinations; however, it is to be noted that whilst there were no papers published in the *industry, government, and foreign* combination between 2004 and 2017, the T-value includes the co-authorship of these three actors in the quadruple and quintuple combinations.

Figure 8-7: Triple combinations



Calculated values derived from Web of Science bibliometric data.

With a smaller subset analysed, there are years where there are no (or very low numbers of) publications; this can be seen where there are periods of neutrality, particularly with *industry*, *government*, and *foreign*.

The *university*, *industry*, and *other state/territory* combination was much more varied. Any collaboration containing other state/territory will capture university, industry, or government actions in the other state/territory. Exhibiting a trend of decreasing collaboration until 2015,

the trend returned to an increase from 2015. This post-2015 increase can be observed in *university, industry, and foreign*, with similar trends throughout the period.

Table 8-6: Triple combinations, sets and counts

Combination	Set	Count
University, Industry and Government	1,1,1,0,0	41
University, Industry and Other State/Territory	1,1,0,1,0	55
University, Industry and Foreign	1,1,0,0,1	42
University, Government, and Other State/Territory	1,0,1,1,0	331
University, Government, Foreign	1,0,1,0,1	250
University, Other State/Territory, and Foreign	1,0,0,1,1	393
Industry, Government, and Other State/Territory	0,1,1,1,0	42
Industry, Government, Foreign	0,1,1,0,1	8
Industry, Other State/Territory and Foreign	0,1,0,1,1	47
Government, Other State/Territory, and Foreign	0,0,1,1,1	154

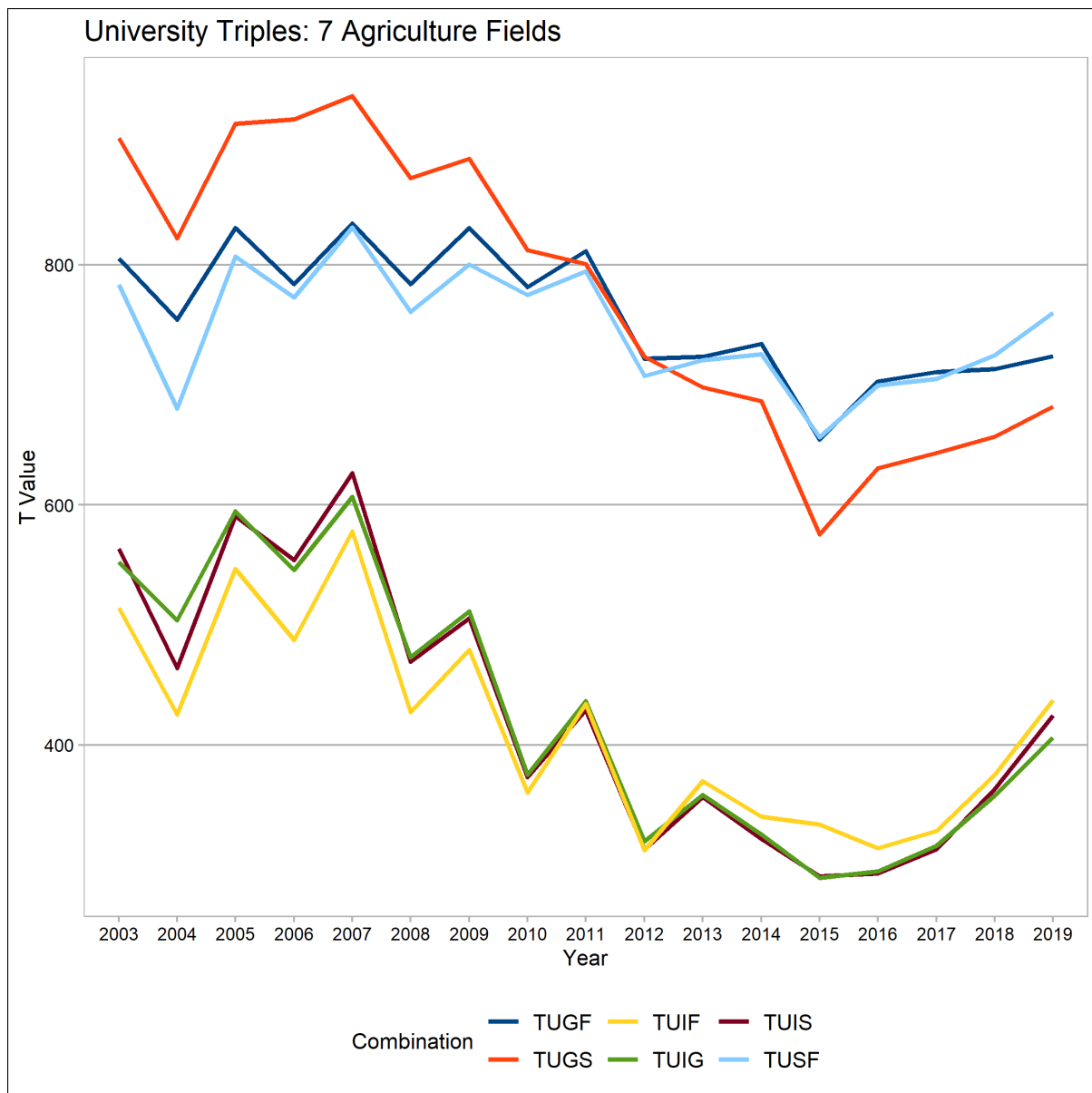
Calculated values derived from Web of Science bibliometric data.

With both these combinations, the broad grouping of *other state/territory* and *foreign* captures university, industry, and government in one group and may mask the collaboration in these other areas.

8.3.1 University Triple Combinations

The triple combinations that contain *university* affiliations split into two distinct groupings separated by the difference in magnitude; those combinations that contain *government and other state/territory* or *foreign* and both *other state/territory* and *foreign* are of the highest magnitude, whilst the combinations that contain *industry* are of a lower magnitude, with very similar trends after 2010.

Figure 8-8: Combinations containing university



Calculated values derived from Web of Science bibliometric data.

8.3.1.1 University, Industry, and Foreign

With a varied trend between 2003 and 2012, a regular trend can be observed after 2013, culminating in an increase post-2016. This irregularity prior to 2007 still trended to an increasing collaboration before a decrease in collaboration.

This combination experienced no publications in 2009 and 2012 but was contained within subsequent combinations when expanded to four and five actors.

8.3.1.2 *University, Government, and Other State/Territory*

Exhibiting a decrease in independence, followed by an 8-year period tending towards independence prior to a rebound of decreased independence (again, after 2015), the collaboration demonstrates periods of accelerating independence, as well as short periods of slowing.

With the inclusion of government, there is no distinction between the level of government. Therefore, any interpretation of the nature of interstate collaboration (such as government agencies working across different sites, or state and federal government working together) is limited due to the lack of granularity..

8.3.1.3 *University, Other State/Territory, and Foreign and University, Government, and Foreign*

When university and foreign are combined with *other state/territory* and *government*, the trends prior to 2011 are very similar, exhibiting fluctuations at similar magnitudes.

For both *university* and *government* combinations, the inclusion of either *other state/territory* or *foreign* with university and government activity exhibits a trend to increasing independence prior to 2015 until an increase in collaboration after 2015.

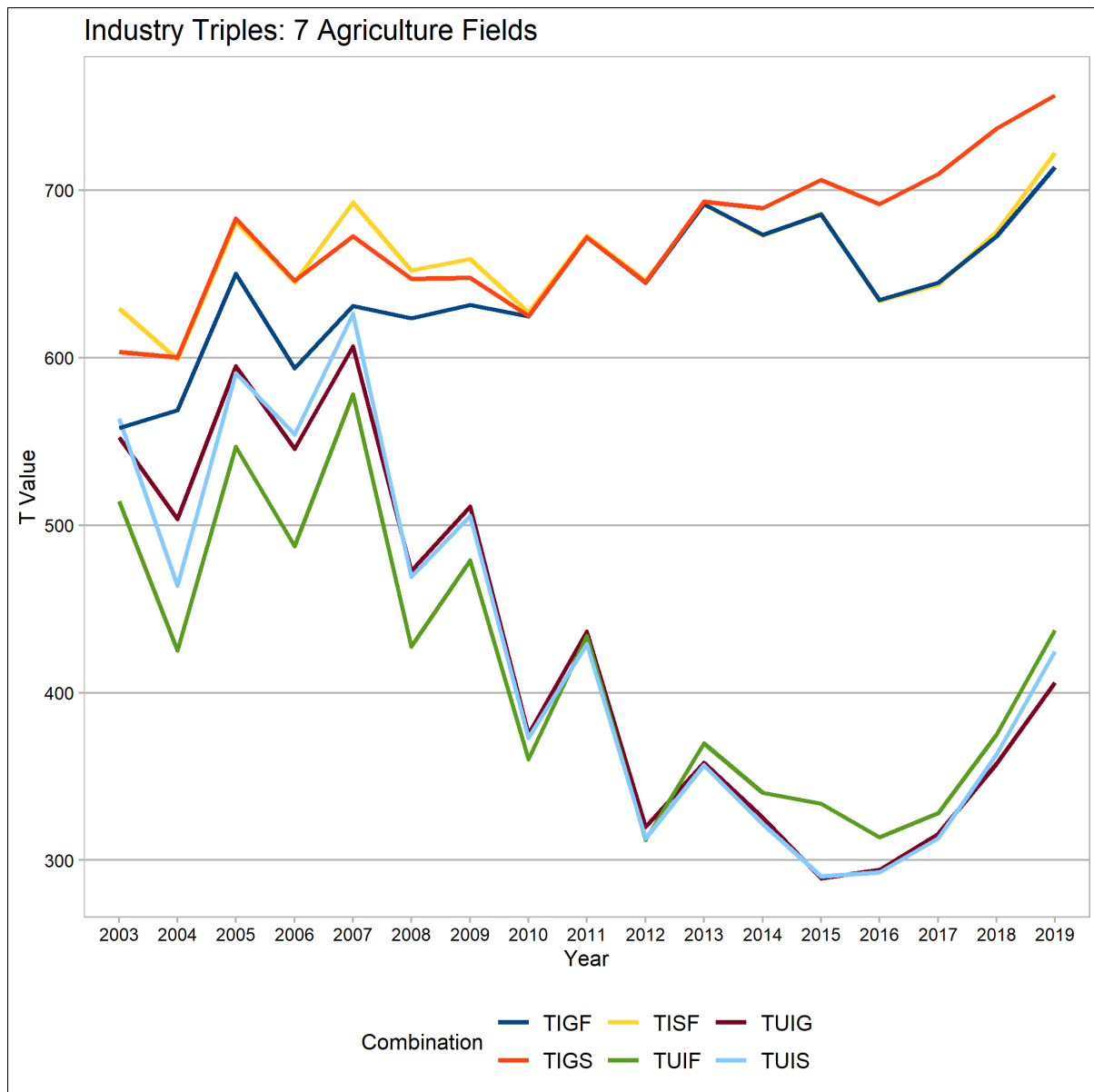
Whilst the *university, government, and foreign* combination had a small short-term decrease in collaboration in 2004, and the *university, other state/territory, and foreign* combination also exhibited a decrease in collaboration, it was much greater in the same period. After this, the trends were very small for the remaining years.

Finally, 2017 to 2019 exhibited a greater increase in collaboration for the *university, other state/territory, and foreign* when compared to *university, government, and foreign* combination.

8.3.2 Industry Triple Combinations

Whilst the *university* combinations split clearly into two groups of differing magnitude, *industry* started at similar levels with a substantial split after 2007. Collaborations with *university* exhibited a significant decrease in collaboration, returning to an increase in collaboration after 2015.

Figure 8-9: Industry triple combinations



Calculated values derived from Web of Science bibliometric data.

8.3.2.1 *Industry, Government, and Other State/Territory*

With the largest increase in collaboration, the *industry, government, and other state/territory* combination exhibits a steady increase compared to the other combinations containing *industry*. Whilst there are periods of neutral trends or single-year decreases, the trend continues as an increasing collaboration trend over time.

Reflecting the transferability of knowledge (either inwards or outwards), this combination highlights the industrial and government relationships within Australia. This combination contains university, government, and industry in the *other state/territory* component and captures the demand for (or supply of) knowledge exchange.

Furthermore, this may contain government or industry from the same organisation located in other states/territories. This reflects an internal transfer of knowledge as opposed to when there are other industry or government agencies, which could reflect external transfer.

8.3.2.2 *Industry, Government, and Foreign*

Like the *industry, government, and other state/territory*, the *industry, government, and foreign* combination captures both the exchange of knowledge and university, industry, or government actors overseas.

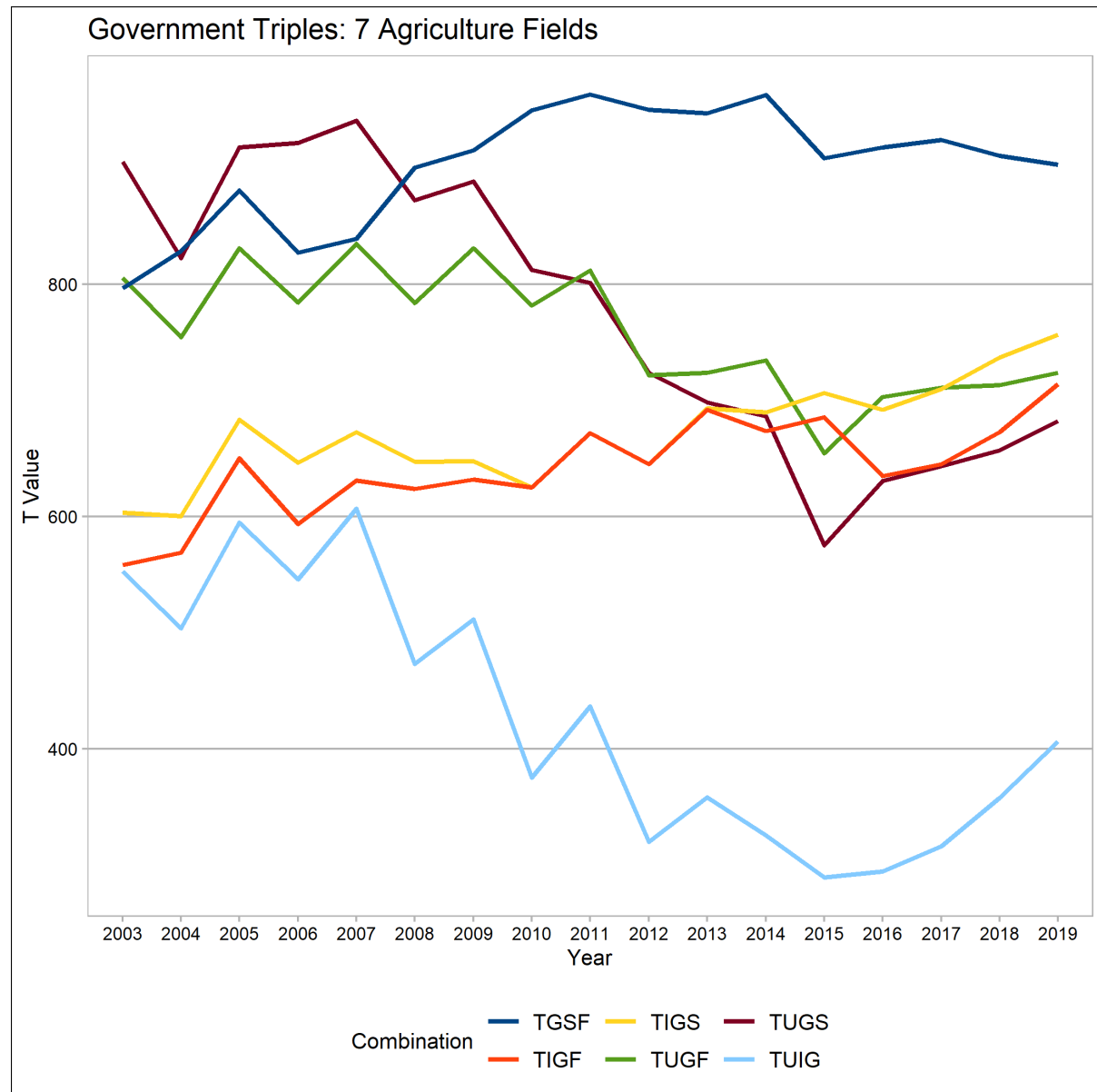
With an overall trend of increasing collaboration, both combinations highlight the potential of increasing applied research driven by industry and government activities.

8.3.3 *Government Triple Combinations*

A more varied and less clear range of trends, combinations containing *government* exhibit two trends of interest. *Government, other state/territory, and foreign* (TGSF) exhibits increasing collaboration at the highest magnitude, whilst both *university, industry, and*

government (TUIG) and *university, government, and other state/territory* (TUGS) become increasingly independent at a lower magnitude.

Figure 8-10: Government triple combinations



Calculated values derived from Web of Science bibliometric data.

With these two combinations, the point of change is 2007. This reflects the increasing collaboration within the *government, other state/territory, and foreign* combination and the decreased collaboration for both *university, industry, and government* and *university, government, and other state/territory* combinations.

8.4 Quadruple Helix Combination

The quadruple helix combinations represent the more complex relationships that are increasingly common. However, these combinations have periods where no publications exist throughout the period. In all cases, the increasingly complex collaborations can be seen as the increase from zero to small numbers of publications (between 2 and 17).

Table 8-7: Count and percentage of publications in quadruple combinations

Year	Total Publications	Between Sectors									
		UIGS		UIGF		UISF		UGSF		IGSF	
		Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent
2003	321	0	0.00	0	0.00	0	0.00	2	0.62	0	0.00
2004	287	0	0.00	1	0.35	2	0.70	0	0.00	0	0.00
2005	305	3	0.98	1	0.33	0	0.00	2	0.66	0	0.00
2006	333	0	0.00	1	0.35	0	0.70	4	0.00	0	0.00
2007	366	1	0.27	1	0.27	1	0.27	1	0.27	1	0.27
2008	408	3	0.74	0	0.00	3	0.74	5	1.23	0	0.00
2009	347	1	0.29	0	0.00	0	0.00	0	0.00	1	0.29
2010	408	0	0.00	0	0.00	0	0.00	5	1.23	1	0.25
2011	385	1	0.26	0	0.00	1	0.26	4	1.04	0	0.00
2012	383	3	0.78	0	0.00	1	0.26	1	0.26	0	0.00
2013	460	2	0.43	1	0.22	0	0.00	9	1.96	2	0.43
2014	491	0	0.00	0	0.00	1	0.20	5	1.02	0	0.00
2015	498	3	0.60	2	0.40	1	0.20	9	1.81	1	0.20
2016	545	2	0.37	1	0.18	2	0.37	11	2.02	0	0.00
2017	594	4	0.67	2	0.34	5	0.84	12	2.02	0	0.00
2018	592	3	0.51	2	0.34	5	0.84	11	1.86	1	0.17
2019	614	2	0.33	2	0.33	10	1.63	17	2.77	3	0.49

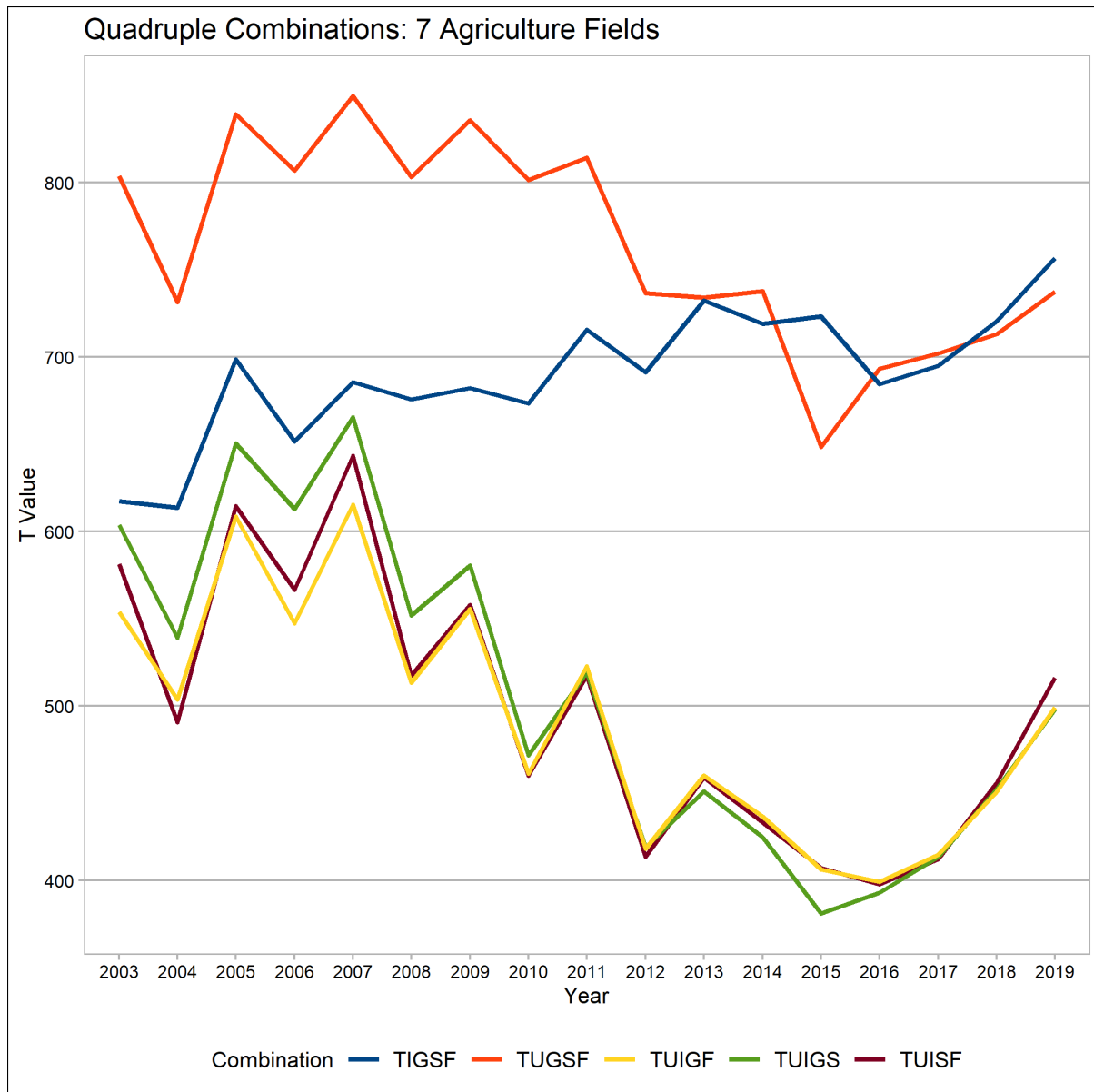
Calculated values derived from Web of Science bibliometric data.

When transferred to the triple helix model to calculate the transmission value, the same patterns can be observed. As the model has reached this increased complexity, the only combination that can contain quadruple combinations is the quintuple combination.

With the collaboration of the most significant magnitude observed in combinations that contain *government, other state/territory, and foreign*, combinations of *university and industry* lead to a declining collaboration and similar magnitudes – reflecting two publications for *university, industry, government, and other state/territory* (TUIGS) and *university, industry, government, and foreign* (TUIGF) in 2019, and the slight uptick for

university, industry, other state/territory, and foreign (TUISF) that resulted in 10 publications in 2019.

Figure 8-11: All quadruple combinations



Calculated values derived from Web of Science bibliometric data.

Whilst the combinations containing *university* declined prior to a rebound in 2015, *industry, government, other state/territory, and foreign* continued to increase at a steady rate above that of neutral.

8.5 Quintuple Helix Combinations

Comprising all elements of the dataset, the quintuple helix reflects the most complex relationships; however, the volume of publications only ranges from 1 to 3 per annum.

Table 8-8: Count and percentage of publications in quintuple combination

Year	Total Publications	UIGSF	
		Count	Percent
2003	321	0	0.00
2004	287	0	0.00
2005	305	0	0.00
2006	333	0	0.00
2007	366	0	0.00
2008	408	1	0.25
2009	347	0	0.00
2010	408	0	0.00
2011	385	0	0.00
2012	383	0	0.00
2013	460	0	0.00
2014	491	1	0.20
2015	498	0	0.00
2016	545	0	0.00
2017	594	3	0.51
2018	592	1	0.17
2019	614	0	0.00

Calculated values derived from Web of Science bibliometric data.

Whilst quintuple combinations are relatively commonplace in the entire research environment, this complex combination is uncommon in agriculture. With a relatively low magnitude, the tendency is for increased independence and the T-values closer to zero. The small increase in the collaboration in 2017–2019 reflects the small number of papers that share this collaboration.

Figure 8-12: Quintuple helix with university, industry, government, other state/territory and overseas



Calculated values derived from Web of Science bibliometric data.

8.6 Conclusions

Examining the roles that the actors can play in research collaborations, the role of drivers for the generation of new collaborations and knowledge can be seen when the role of university is examined. The 2015/16 turning point that impacted the changes in all collaborations that involved universities from New South Wales is visible.

Furthermore, the target of an industry worth \$100 billion by 2030 was announced by the National Farmers Federation (2019). . Reflecting a consultative process undertaken since

2017, the driver of examining the opportunity for new applied knowledge will be captured following this target.

Whilst the total annual production volume from all sectors grew at a near exponential rate, agriculture-related research followed a significantly different trend, with an increase of just over 50% in publications from 2003 to 2019. Representing an increasing collaborative approach to publication, the volume changed in the composition of combination rather than the level of total output. Differing to publish or perish, choices about collaboration reflect the need to transfer applied knowledge through specific collaborations (such as industry or government extension) that ensure engagement with the research. If there are policy changes required to alter collaborative structure, these will need to be different to the volume incentive (publish or perish). The increasing sophistication of the structures can be considered a proxy for knowledge capital creation and diffusion.

What can be considered as the ‘internationalisation’ of research from New South Wales – the transferability to *Other State and Overseas* – reflects the attractiveness of New South Wales’s knowledge and application to overseas and international partners. However, Gingras (2016) states that the nature of localised applied or empirical research can limit the appeal to international journals (which may attract higher citations, and therefore, ‘better’ performance in a measurement metric). Furthermore, described as the exportable nature of research, some subjects are more relevant on a global (or Australia-wide) scale than others. This difference may result in applied knowledge, such as changes in practices at a local level, being delivered outside of the research publication sectors. These flaws in the current system can potentially reduce research output relevant to local problems as high-level journals prefer less specificity and more internationally relevant data (Gingras, 2016, p. 55).

Finally, this data has not captured the role of international researchers (both students and academics) within the university ecosystem. If their research has been of an overseas nature, then there is the same challenge as above – the question of whether this new knowledge is importable into Australia and whether the research addresses the need of the local community. Gingras (2016, p. 79) identified the role of international students in addressing universities' budgetary constraints and the risk of straying from locally relevant research – 'neglecting their local duties'.

The following sections address what these local duties may be, based on the measurement of industry specialisation and the geography of collaboration, again remaining focused on the role of agriculture.

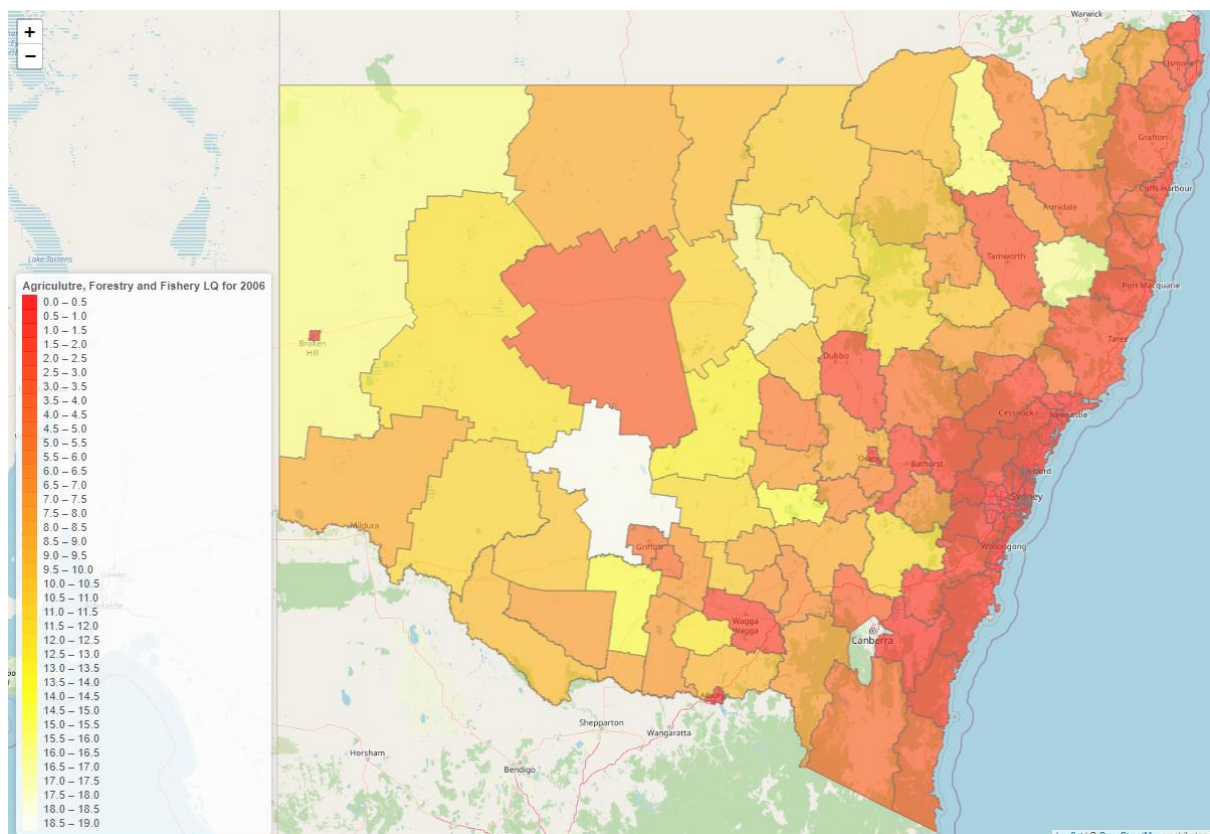
Chapter 9: Measurement of Industry Specialisation

As identified in Chapter Two, two approaches were used to measure the specialisation in agriculture, forestry, and fishery industry activities. Firstly, the location quotient is applied and analysed to examine the extent of specialisation. Secondly Shannon's Entropy is used to examine the diversity of industry.

9.1 Location quotient

The maps showing the results can be found in Appendix iv, as there is little variation between the location quotient year on year. Figure 9-1 depicts the location quotient for 2006.

Figure 9-1: Location quotient for the agriculture, forestry, and fisheries industries, 2006



Location quotient for the agriculture, forestry, and fisheries industries by local government areas in 2006, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

As identified by Pominova et al. (2021), the challenge presented by using location quotients for low population numbers is clear in the case of Carrathool, where there is a very high

location quotient value (18.73). This value indicates that the Carrathool area has 18.73 times the state average employment in the agriculture, forestry, and fishery industries. Analysis that utilises location quotients often requires setting a limit to define when clustering appears.

O'Donoghue and Gleave (2004, p. 421) state that values as low as 1.25 can be used to signify industrial clusters but again recognise the impact that small (total) labour forces can have on skewing the industrial clusters.

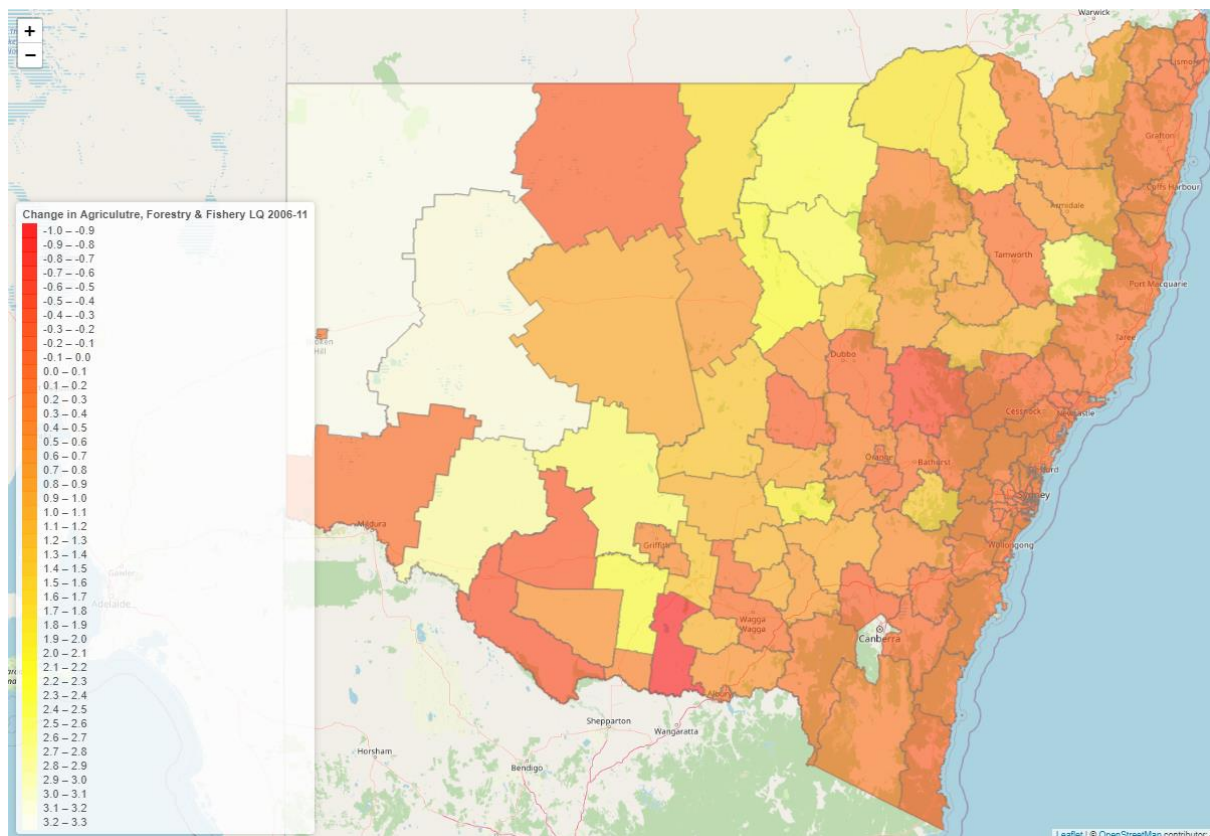
As the change in the location quotient is more noticeable, this is focused upon instead. This reflects the changing nature of the industrial composition when an indicator that loses granularity is utilised. Rather than focusing on the values in each census year, the trends and behaviour between census periods are more relevant and applicable.

9.1.1.1 2006 to 2011

Measuring absolute increases in the location quotient minimises the size of the existing location quotient and subsequent specialisation of that region – the small changes become apparent.

Both increases and decreases in the location quotient can be observed; increases can be seen in many inland regions, whilst the coastal areas show lower (or decreased) changes in the location quotient value.

Figure 9-2: Change in location quotient for the agriculture, forestry, and fisheries industries, 2006 to 2011

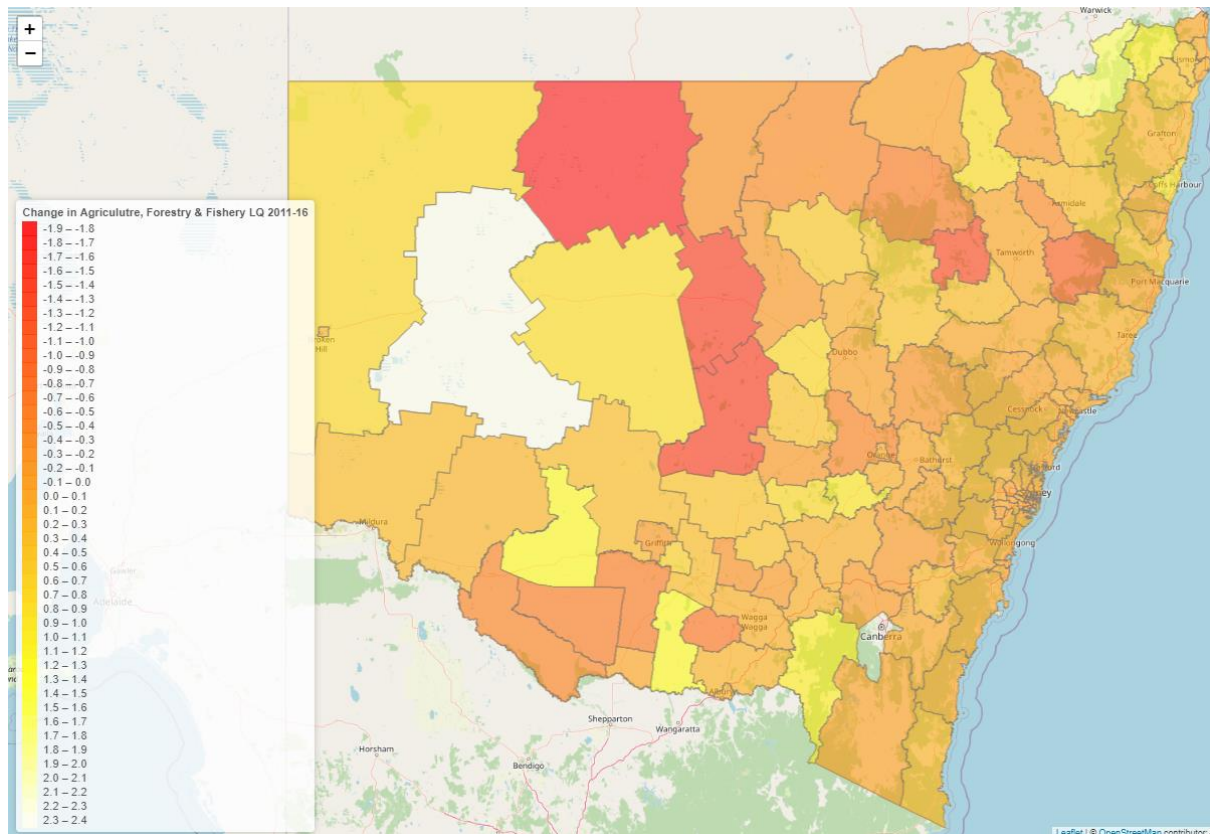


Change in location quotient for the agriculture, forestry, and fishery industries by local government areas between 2006 and 2011, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet

9.1.1.2 2011 to 2016

Whilst the 2006-2011 period showed increases in the location quotient, some of these trends are reversed (e.g., Walcha and Narrabri). Continued increases are visible in the state's west, apart from Bourke, Bogan, and the Lachlan LGAs.

Figure 9-3: Change in location quotient for the agriculture, forestry, and fisheries industry, 2011 to 2016



Change in location quotient for the agriculture, forestry, and fisheries industries by local government areas between 2011 and 2016, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

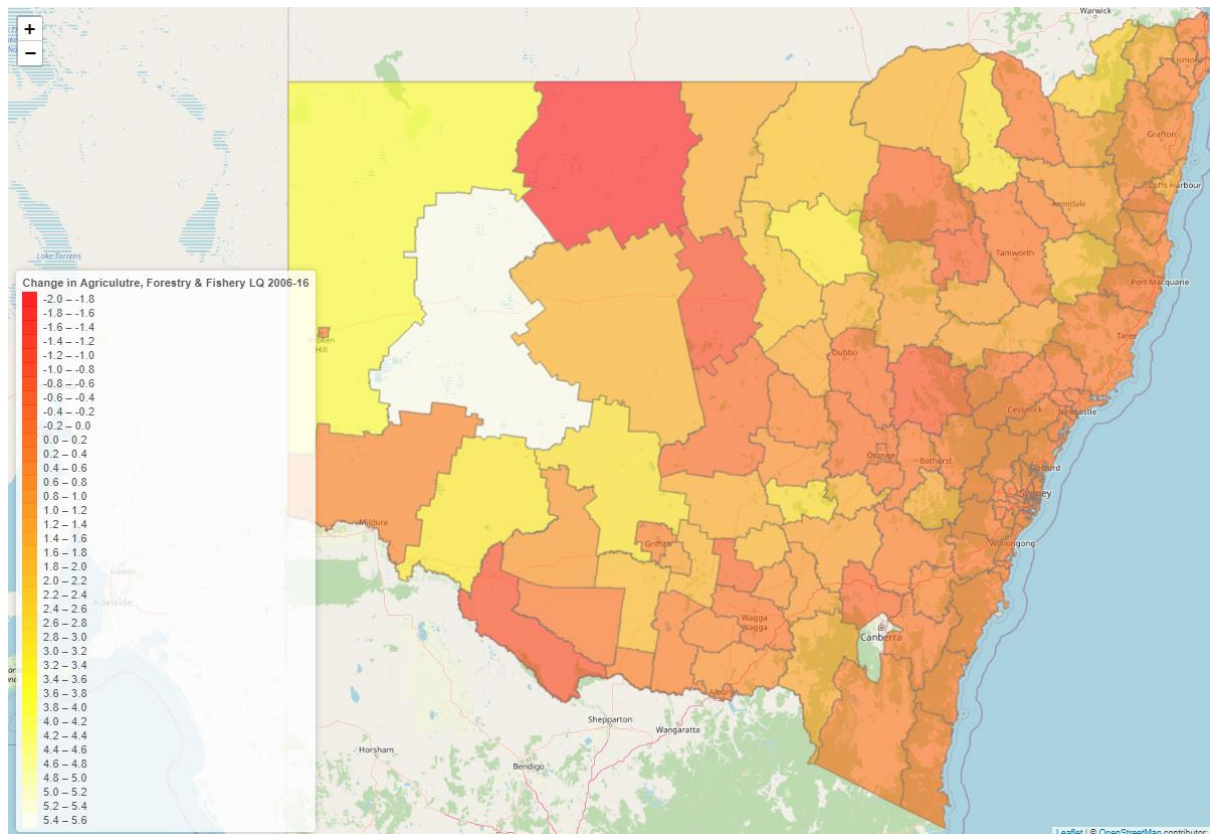
What is visible is that the changes are often minor and gradual rather than major and sudden.

Reflecting labour and industrial mobility challenges, changes within a five-year period are limited. Many coastal regions have little or no change, whereas the inland regions are much more likely to see change. In part, this can be driven by a small change in the industry of employment in a region where there is only a small labour market.

9.1.1.3 2006 to 2016

Considering the longer term, the change between 2006 and 2016 yields similar observations to the previous years. However, what is more noticeable is changes in the location quotient values along the coastal regions. These are often around the zero bracket, reflecting the small size of those regions' agriculture, forestry, and fisheries industries.

Figure 9-4: Change in location quotient for the agriculture, forestry, and fisheries industries, 2006 to 2016



Change in location quotient for the agriculture, forestry, and fisheries industries by local government areas between 2006 and 2011, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

With these changes, the scale of the location quotient at a regional level is such that examining the (absolute) change is more beneficial than examining the location quotient at a regional level. This challenge and flaw in the location quotient is well recognised.

The application of a more appropriate measurement tool is crucial. However, exploratory analysis can be performed quickly using the location quotient to provide indicators of the degree of specialisation. This is where defined cut-offs are important, although there is a challenge in defining the cut-offs.

9.2 Shannon's Entropy

The Shannon's Entropy value calculation for the LGAs was undertaken in R and R Studio (R Core Team, 2022; RStudio Team, 2022), using data from Australian Bureau of Statistics (2017a).

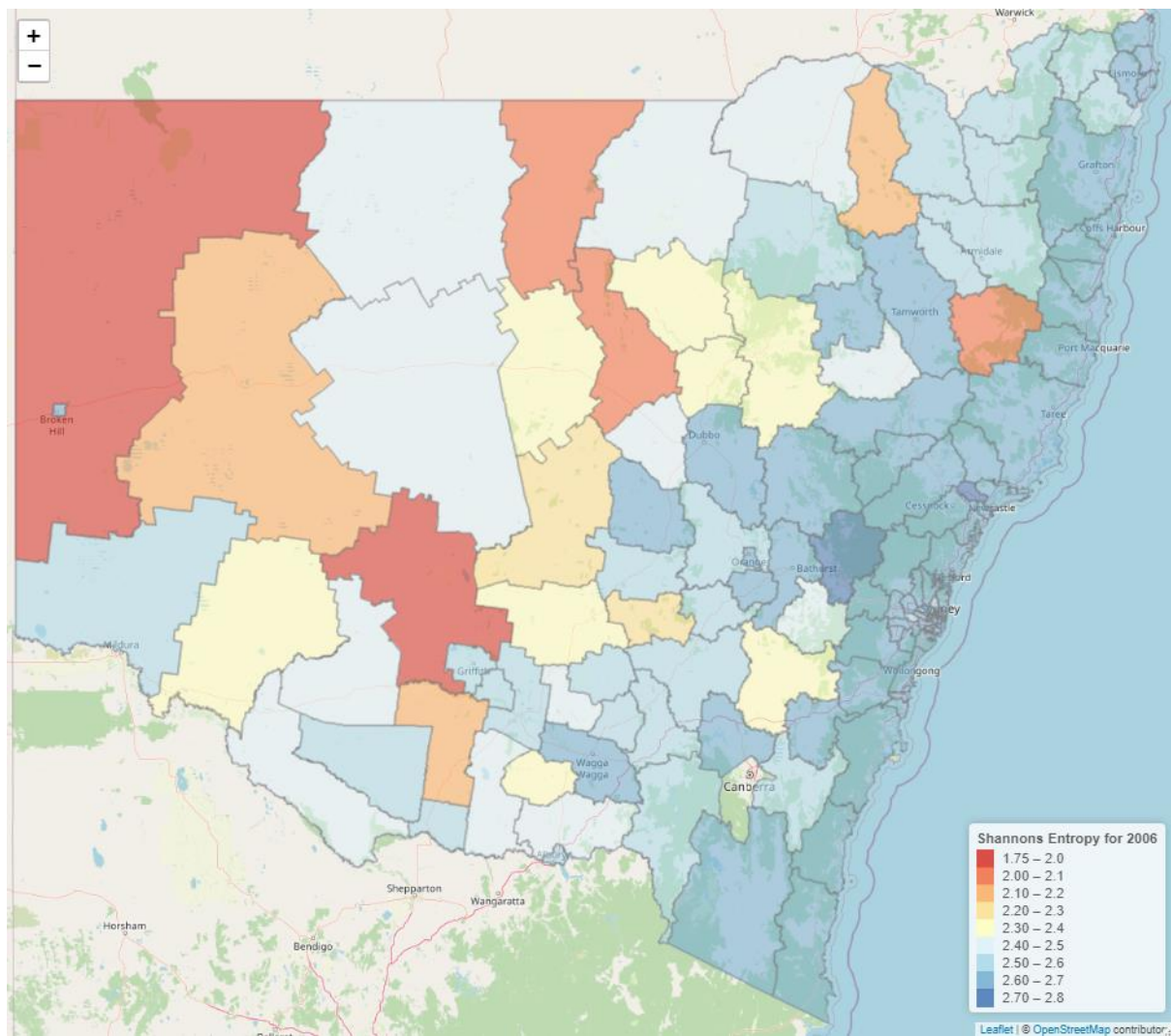
Applying the equation from Equation 6-23, the results (mapped to the LGA) can be seen in the following sections. In each case, the overall Shannon's Entropy is shown for all states – the maximum value of 2.944 reflects a distribution of industries with the maximum diversity. In contrast, a value of zero gives the maximum concentration of industries. With the knowledge of the concentration captured on a 5-yearly basis, the broad changes can be examined for each census period.

The adoption of Shannon's Entropy Index allows for the assessment of the observed values as a share of the maximum value of entropy, as discussed by Theil (1967, p. 293). The ability to measure the industrial concentration and diversity within an LGA facilitates the measurement of the specialisation within that region. Subsequently, it is possible to identify the role that agriculture plays in the composition of Shannon's Entropy value for a given region.

9.2.1 2006

The distribution of industrial activity across New South Wales reveals regions where the dominance of one industry is greater, along with more diverse areas. With a reliance on a few industrial sectors for employment, regions such as the Unincorporated West (the area surrounding Broken Hill), Walcha on the edge of the Northern Tablelands, and Carrathool (northwest of Griffith) are areas that have a low entropy value, representing an increased concentration of employment in a few industries.

Figure 9-5: Map of Shannon's Entropy by local government area, 2006



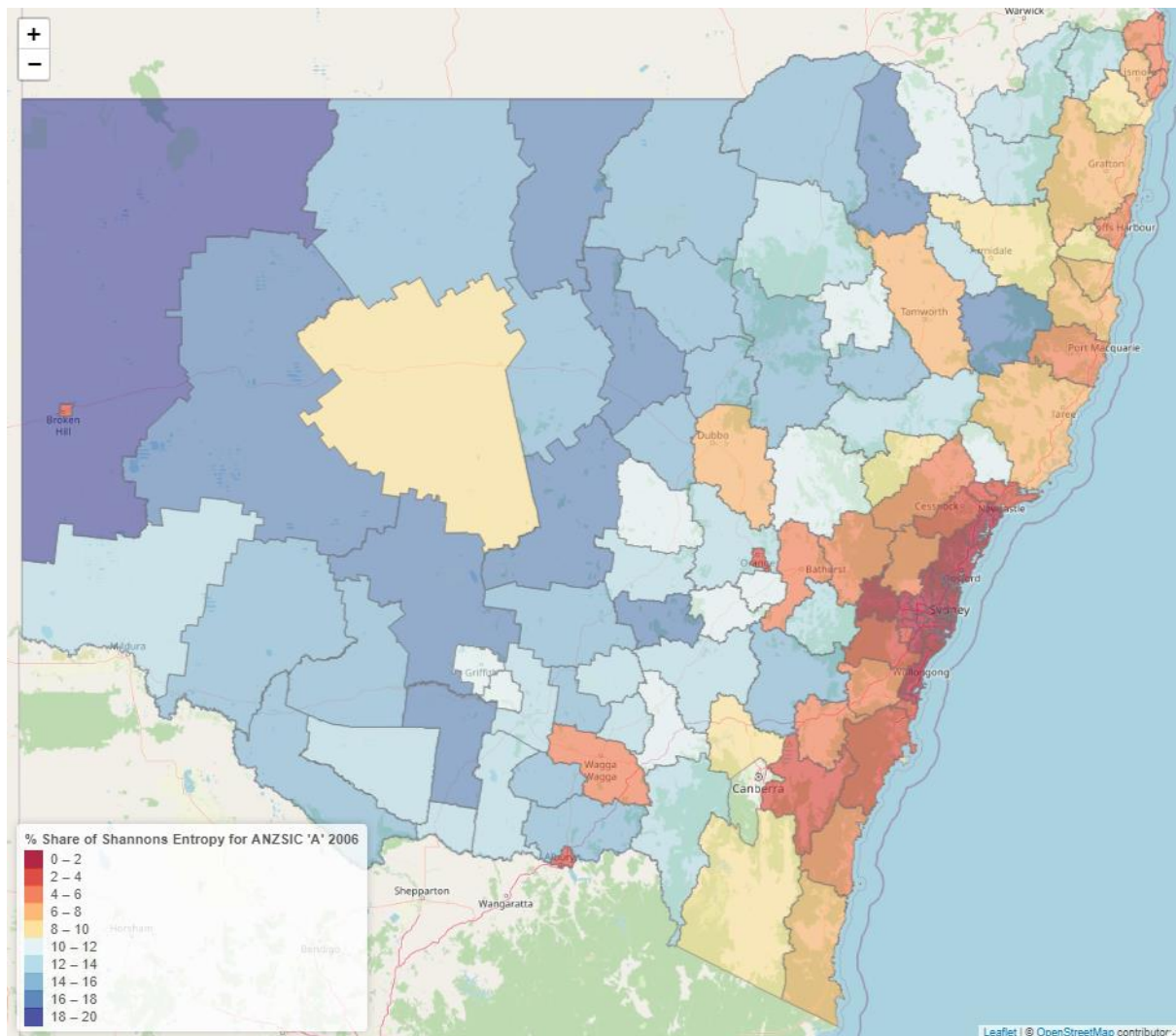
Shannon's Entropy Value for local government areas in 2006, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

The maximum value is 2.944, and the observed maximum is 2.724803 (Lithgow), representing 92.5% of the maximum; 1.9122 for Carrathool is the minimum (64.9%) – a much lower level of diversity.

9.2.1.1 Agriculture, Forestry, and Fisheries in 2006

In a similar approach, the contribution of the Group A sector (agriculture, forestry, and fisheries) to the entropy value can be expressed as a percentage of the value, as illustrated in Figure 9-4

Figure 9-6: Map of the percentage share of agriculture, forestry, and fisheries employment within the total Shannon's Entropy by local government area, 2006



Share of Shannon's Entropy Value for the agriculture, forestry, and fisheries industries by local government areas in 2006, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

By examining the value of the contribution of an individual sector to the overall entropy value, the measurement of equalness (or unequalness) can be identified. Unsurprisingly, areas with a high diversity exhibited a low share of employment in the agriculture, forestry, and fisheries industries. However, the share within regions with a similar entropy value is distinctly different. For example, Tamworth and Gunnedah share similar entropy values (in the range of 2.5 to 2.6) yet have a different composition of values (Tamworth had 6–8% of the entropy value contributed to by those employed in agriculture, forestry, and fisheries, whilst Gunnedah had 10–12%).

9.2.2 2011

Five years later, in 2011, subtle changes were apparent; areas such as Murray River, Walcha, and Inverell became increasingly diversified (changing one band each, respectively), whilst Cobar and Walgett became less diversified, again changing one band.

With changes in diversification in Murray River, Walcha, Inverell, Cobar, and Walgett, these can be expressed as both the absolute value of Shannon's Entropy Index and as a percentage of the maximum Shannon's Entropy Index.

Table 9-1: Share of Shannon's Entropy, 2006 and 2011 for selected local government areas

	Local Government Area	Shannon's Entropy Value (2006)	Percentage of the maximum	Shannon's Entropy Value (2011)	Percentage of the maximum
Increasingly diverse	Inverell	2.57	87.38	2.60	88.14
	Murray River	2.46	83.39	2.55	86.51
	Walcha	2.06	69.97	2.13	72.26
Decrease in diversity	Cobar	2.40	81.58	2.38	80.99
	Walgett	2.41	81.75	2.39	81.10

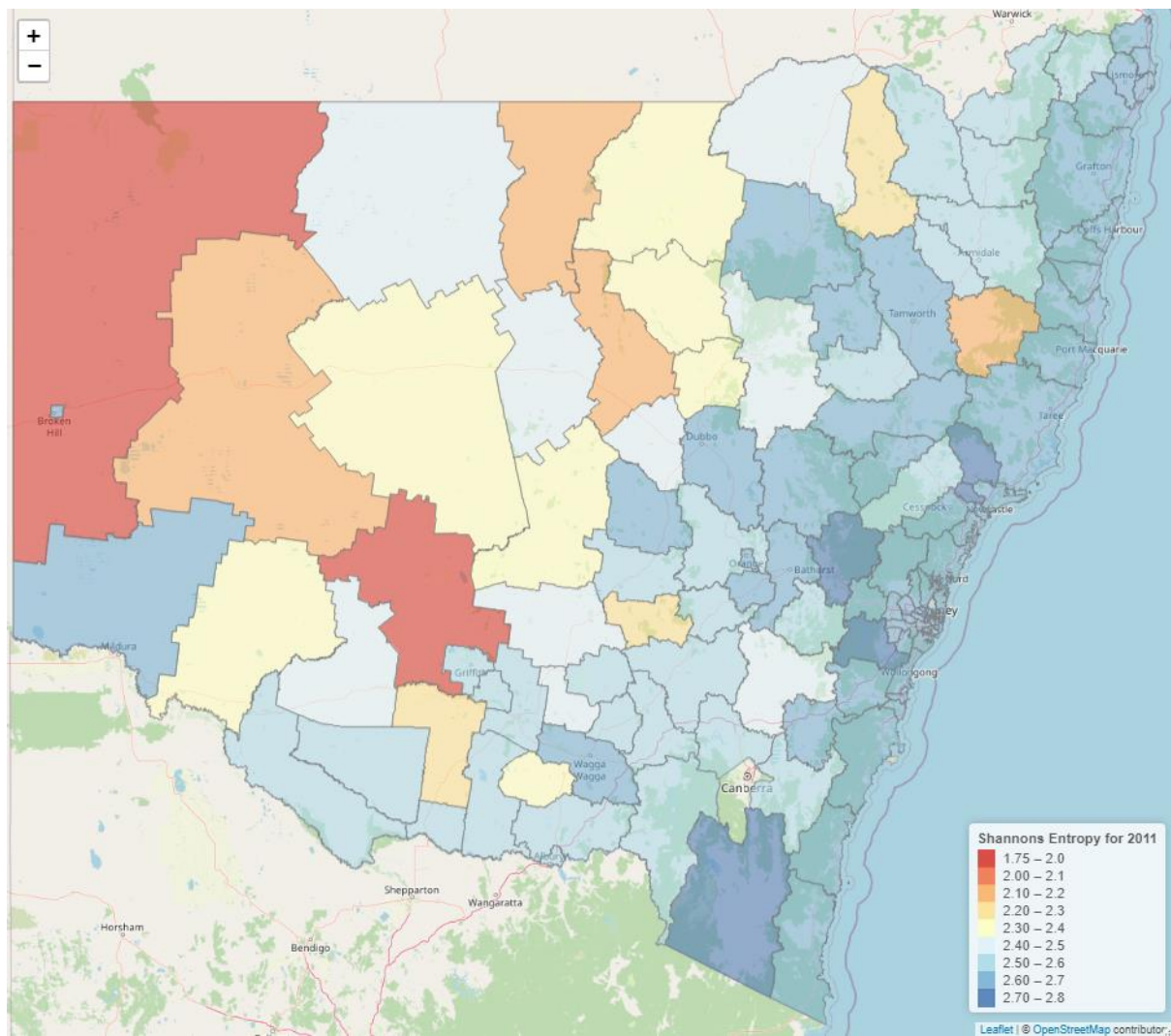
Shannon's Entropy Value for local government areas in 2011, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

With a maximum value of 2.944, the observed maximum in 2011 was Dungog with 2.713, representing 92.14% of the maximum (Lithgow was second, with 2.708 and 91.98%), with an opposite of 1.933 for the Unincorporated NSW region, 65.64%; Carrathool was the second lowest, albeit with an increase in diversity to 1.989 and 67.56%.

Whilst these changes are only small, the change in diversity in the region is clearly visible.

On a short-term basis, these changes in Shannon's Entropy Value and the percentage share of the maximum value allow for comparison on a time-series basis. The maximum value is fixed as the number of industrial sectors does not change.

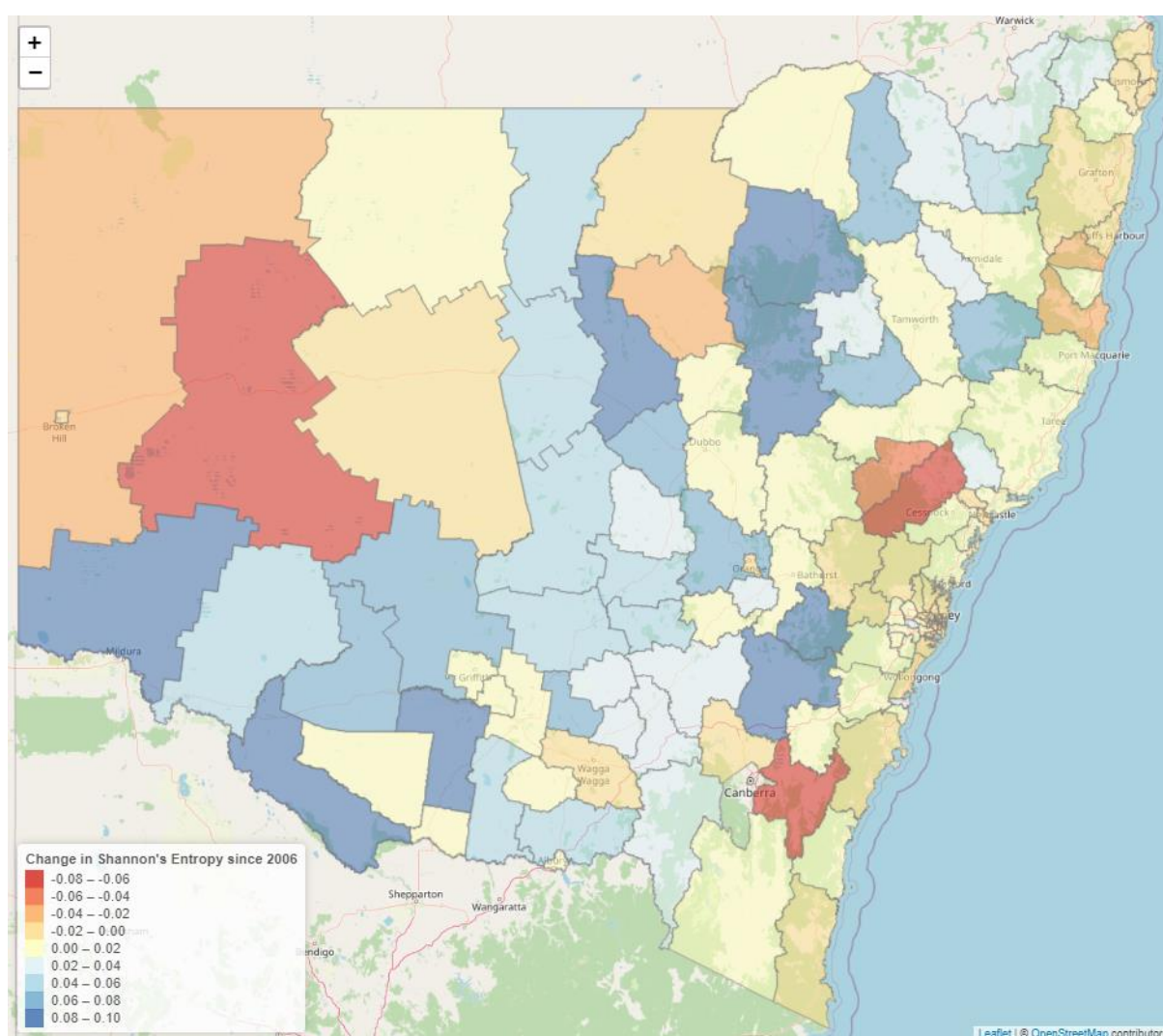
Figure 9-7: Map of Shannon's Entropy by local government area, 2011



Shannon's Entropy Value for local government areas in 2011, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

As can be seen, changes are limited; some areas experience small changes, whilst others exhibit an increase (or decrease) in diversification (blue shades and red shades, respectively).

Figure 9-8: Map of change in Shannon's Entropy Values between 2006 and 2011



Change in Shannon's Entropy Value for local government areas in 2011, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

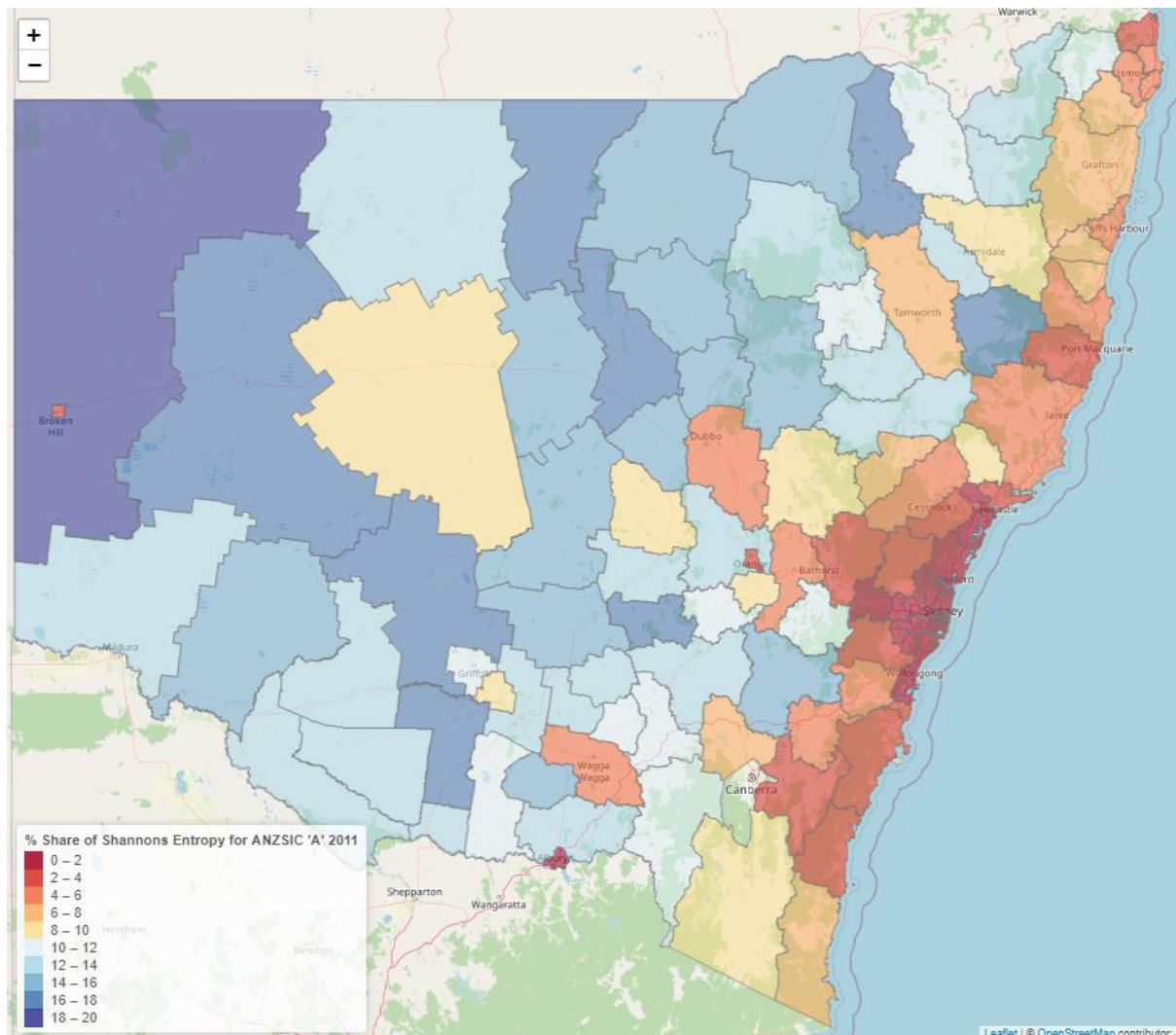
When a change in entropy is negative, it reflects the increase in industrial concentration (fewer industries or increased size of one or more industries). In contrast, the increase reflects a decrease in industrial concentration and a more diverse industrial employment base. With this increased diversity, there is less reliance on one industry for employment and potentially a more resilient (but less clustered) region.

9.2.2.1 Agriculture, Forestry, and Fisheries in 2011

In line with 2006, the low share of the agriculture, forestry, and fisheries industry is still dominant along the coastal fringe. An increasing share can be observed in inland areas, whilst

the coastal fringe (particularly in the Northern Rivers area) exhibited a decrease in the agricultural contribution to Shannon's Entropy Value. This trend continued southwards to Taree and the Mid-North Coast region. Slight decreases in concentration are observable in inland areas such as Bourke, Hay, Federation, and Murray River local government areas.

Figure 9-9: Map of the percentage share of agriculture, forestry, and fisheries employment within the total Shannon's Entropy by local government area, 2011



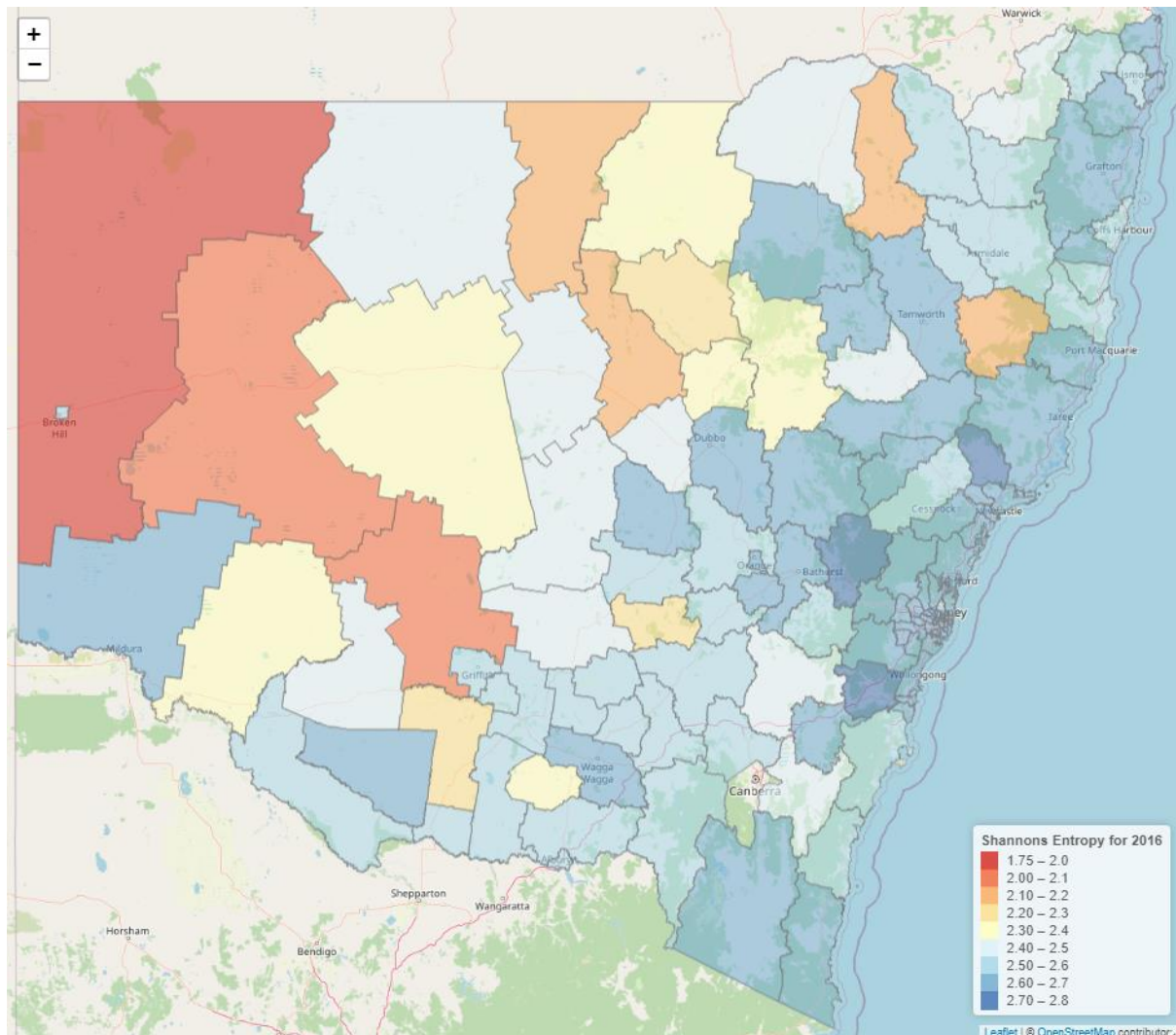
Share of Shannon's Entropy Value for the agriculture, forestry, and fisheries industries by local government areas in 2011, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

Change in employment share can be driven by increasing employment in other sectors that reduces the share (or vice versa) or by an increase in the sector of interest which increases the share (or vice versa). Structural change in the economy or technological change in the industry may change the demand for employment, but this is not known in the data applied.

9.2.3 2016

Compared to 2011, 2016 demonstrates a decreasingly diverse industrial composition in some inland regions, with a more specialised industry base. Coastal areas also demonstrated diversity changes, with the same decreases observed.

Figure 9-10: Map of Shannon's Entropy by local government area, 2016

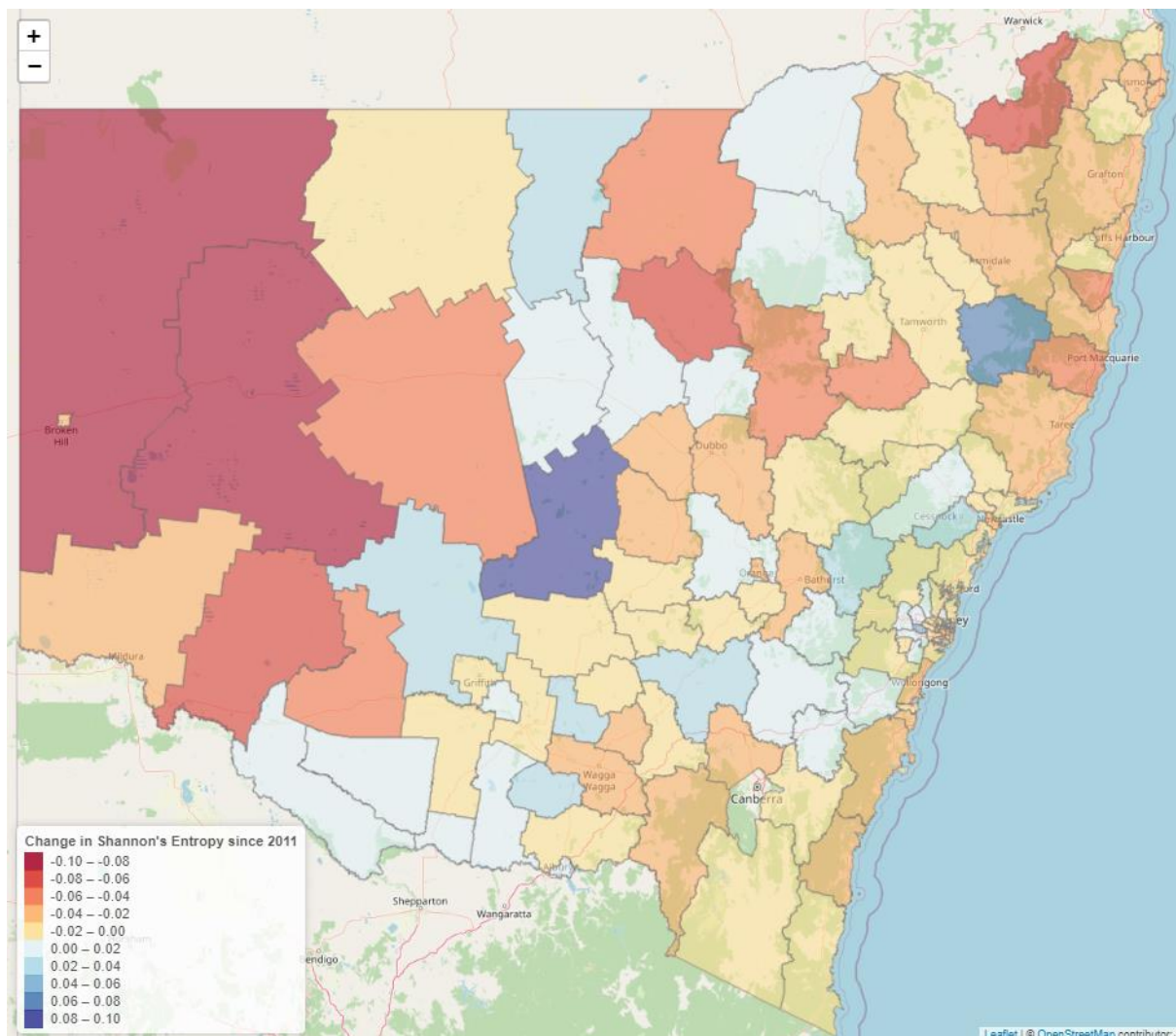


Shannon's Entropy Value for local government areas in 2016, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

Lithgow and Dungog continued to be the leaders in diversity, with 2.734 (92.87%) and 2.706 (91.89%), respectively. Unincorporated NSW and Carrathool remained the least diverse, with 1.845 (62.67%) and 2.019 (68.56%), respectively.

Changes in Shannon's Entropy Value are distributed across the state, with the largest decreases in diversity observable in the west. Many urban and coastal areas exhibit a small change in the diversity of industry, with small decreases visible in some areas. Adjacent areas often move in the same direction, with clear groupings visible between Armidale, Gwydir, Glen Innes, and Clarence Valley, as well as Tamworth, Uralla, Narrabri, and into the Hunter Valley, and then round to the Mid-Western Regional Council. In the south, Forbes, Bland, Weddin, and Temora exhibited similar changes, whilst on the South Coast, Eurobodalla and then north to Wollongong also exhibited this pattern.

Figure 9-11: Map of Changes in Shannon's Entropy by local government area, 2016



Change in Shannon's Entropy Value for local government areas between 2011 and 2016, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

Changes are clearly visible in the Lachlan and Walcha LGAs, as well as Tenterfield and Balranald. The changes can be seen in the absolute values and Shannon's Entropy Index percentage.

Table 9-2: Share of Shannon's Entropy, 2011 and 2016 for selected local government areas

	Local Government Area	Shannon's Entropy Value (2011)	Percentage of the maximum	Shannon's Entropy Value (2016)	Percentage of the maximum
Increasingly diverse	Lachlan	2.33	79.09	2.41	81.83
	Walcha	2.13	72.26	2.19	74.50
Decrease in diversity	Tenterfield	2.55	86.58	2.49	84.41
	Balranald	2.38	80.81	2.32	78.75

Shannon's Entropy Value for local government areas in 2011, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

Walcha became increasingly diverse throughout the three periods, with increases in each period, yet the share of agriculture, forestry and fisheries remained a strong component of its industrial diversity.

The continued role of agriculture, forestry, and fisheries for many economies throughout New South Wales is discussed in the following section.

9.2.3.1 Agriculture, Forestry, and Fisheries in 2016

Whilst 2011 exhibited decreasing shares in the agricultural sector, 2016 reversed this in some areas in the Northern Rivers region, returning towards the ranges observed in 2006.

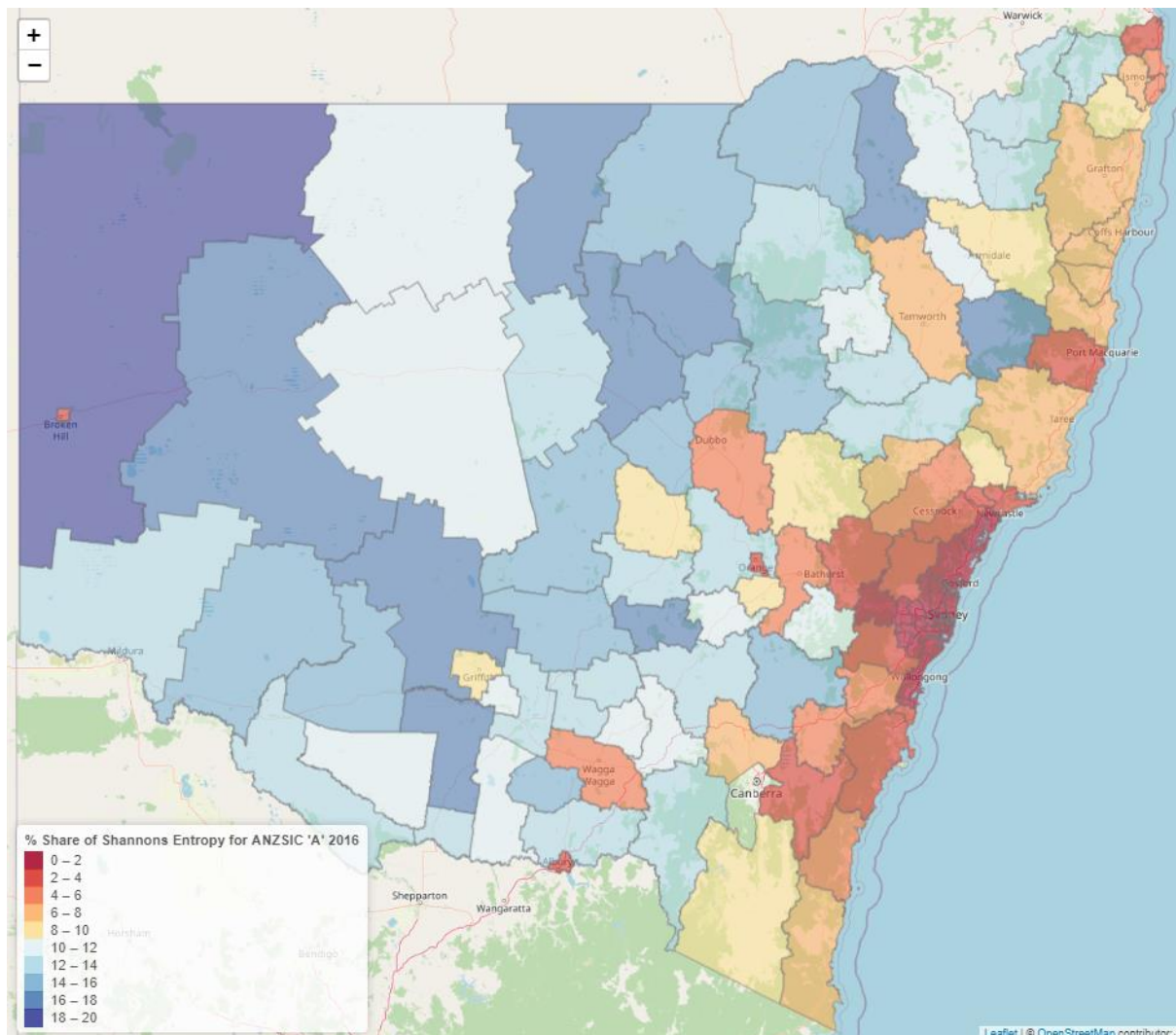
Furthermore, changes in inland regions can be seen: Uralla (between Armidale and Tamworth) became less dependent on agriculture, as did Griffith and Edward River. This is by one bracket in all three cases, so only a small change.

The concentration surrounding Sydney, heading north and south and west through the Blue Mountains, remained low and relatively unchanged, at under 4%.

Moving inland, Bourke and Cobar both tended to the same share of the entropy value – Bourke decreases and Cobar increases their agricultural, forestry, and fisheries industry share.

Both regions are also involved with the extractive industries, although less than in the Hunter region. Narrabri experienced an increasing share of agriculture, whilst Warren had a decreased share. Trends are not uniform across all regions, highlighting the significantly localised nature of industrial activity and employment.

Figure 9-12: Map of the percentage share of agriculture, forestry, and fisheries employment within the total Shannon's Entropy by local government area, 2016



Share of Shannon's Entropy Value for the agriculture, forestry, and fisheries industries by local government areas in 2016, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

As already identified, Walcha remained within a consistent band throughout the three census periods, reflected in 2006, where agriculture, forestry and fisheries accounted for 17.23% of Walcha's overall entropy value, 16.95% in 2011 and 16.62% in 2016. Whilst there is a small change in the share, the overall value of Shannon's Entropy Index also increased. This may

reflect a static labour force in agriculture whilst other industries have increased their workforce.

The ability to examine each industry group in this manner, as an element of the diversity of the overall industrial mix, is an advantage over the location quotient. Furthermore, when expanded to an Australia-wide model, further comparisons can be made using the within and between sector analysis that is not possible when working within a single state grouping.

9.3 Conclusions

Without decomposing the other 18 employment categories to examine where the changes have occurred, there are limitations to the conclusions that can be drawn. However, the diversity and concentration of industries reflects a specialisation of industrial activity. This can be observed in the location quotient for the regions that showcase the specialisation in an alternative metric. However, due to the range of values within the location quotient, expressing the share within Shannon's Entropy provides a much stronger tool for measuring the specialisation.

9.3.1 Location Quotient

A simple, readily recognisable, and easy-to-explain tool, the location quotient is useful for exploratory analysis prior to a more detailed data analysis. The use of readily available data and a programmatically simple method may explain its frequency of use. However, the limited functionality and explanatory capability, once beyond the basic premise of exploring the data, restrict the use of the location quotient.

Taking each industry as an element within a region and then comparing it to the other regions, the location quotient can reveal the degree of industry specialisation. At a regional level, this reveals industry-by-industry specialisation but does not reveal the specialisation or

diversity of the regional economy. This diversity or specialisation then leads to the use of Shannon's Entropy.

9.3.2 Shannon's Entropy

The contrast in diversity and specialisation is crucial to understanding economic activity. The ability to have a comparison tool that works across metropolitan and regional New South Wales is advantageous. In contrast to the location quotient, using natural logarithm brings Shannon's Entropy Index into a scaled model within a simple bound comprising the maximum value representing the most diverse structure and a lower bound of zero representing the least diverse structure. Removing the need to set the limits (a criticism of the location quotient), adopting a scale where the concentration can be expressed as a percentage of the most diverse value removes the individual selection of the boundaries.

However, as highlighted by the Australian Bureau of Statistics (2014), Shannon's Entropy value does not imply that a region is a multiple of difference when comparing the value; rather, it is relative to both the upper limit and the zero value.

9.4 Final Comments

A common theme throughout the years is that the more diverse regions outside of the cities are situated along main transport routes, such as the Pacific Highway on the coast, the New England Highway through the Hunter and the Northern Tablelands, and the Hume Highway south to Melbourne passing north of Canberra. As the distance increases from Sydney heading west, the diversity of the economies decreases and becomes increasingly concentrated (white through yellow to dark red) within a few industries (or near complete absence of an industrial group).

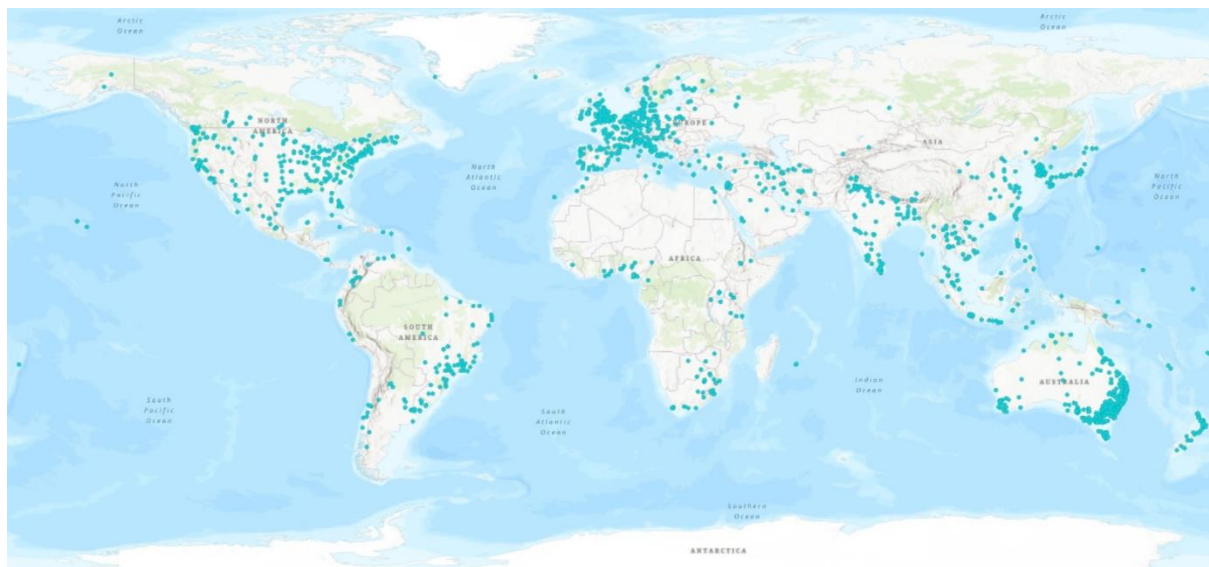
Agriculture, forestry, and fisheries employment is concentrated in regional New South Wales; dispersed through inland and coastal New South Wales, there are regions with concentrations that are higher (or lower) than the state-wide proportion (captured within the location quotient) but also visible within the contribution to Shannon's Entropy. Whilst both measurement approaches have their benefits, the use of location quotient and Shannon's Entropy in conjunction with one another is beneficial.

Moving to the connection between research activity and regional specialisation, Shannon's Entropy, and subsequently, the contribution that the agriculture, forestry, and fisheries employment category makes to a region's Shannon's Entropy Index value is the measurement of choice, supported by the location quotient to highlight any concentrations of specialisation.

Chapter 10: Geospatial Representation and Analysis

With the detailed address information from the Web of Science data for the affiliations found in the agricultural-related research areas, ArcGIS Pro (Esri, 2022) was used to geocode the addresses to generate a global map of the affiliations.

Figure 10-1: Map of author affiliations (by address) for the seven agriculture fields



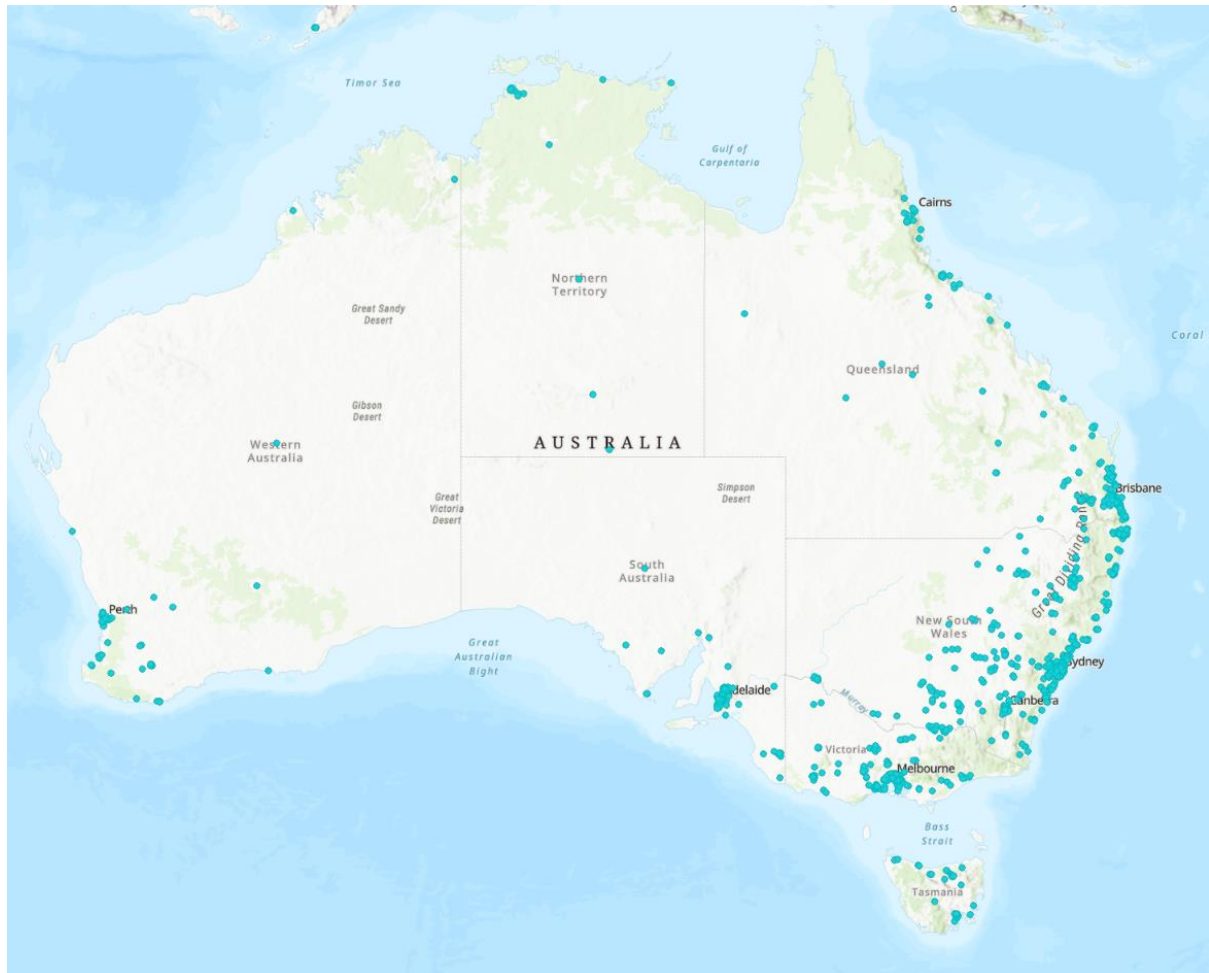
Generated using the ArcGIS Geocoding tool from Web of Science author affiliation data

With almost 13,000 unique author affiliations captured in the seven agriculture fields, these addresses can be found on every continent (except Antarctica). A cursory examination shows the sphere of influence in Southeast Asia, collaboration with English-speaking African countries, and agriculturally dominant economies such as Brazil. The connection with English-speaking countries aligns with Gingras' (2016, pp. 54-55) observation that, in addition to international collaboration, prestige is associated with publication in an English-language journal. Furthermore, this mapping reflects the use of the English language in selecting publications from the Web of Science database.

The distribution can be widespread by bringing the focus from a global to an Australian landscape, specifically New South Wales. With the geographical focus selection of New

South Wales authors, the concentration can be seen in New South Wales and into Queensland and Victoria, with fewer collaborations in the Northern Territory and Western Australia.

Figure 10-2: Map of author affiliations (by address), focused on Australia



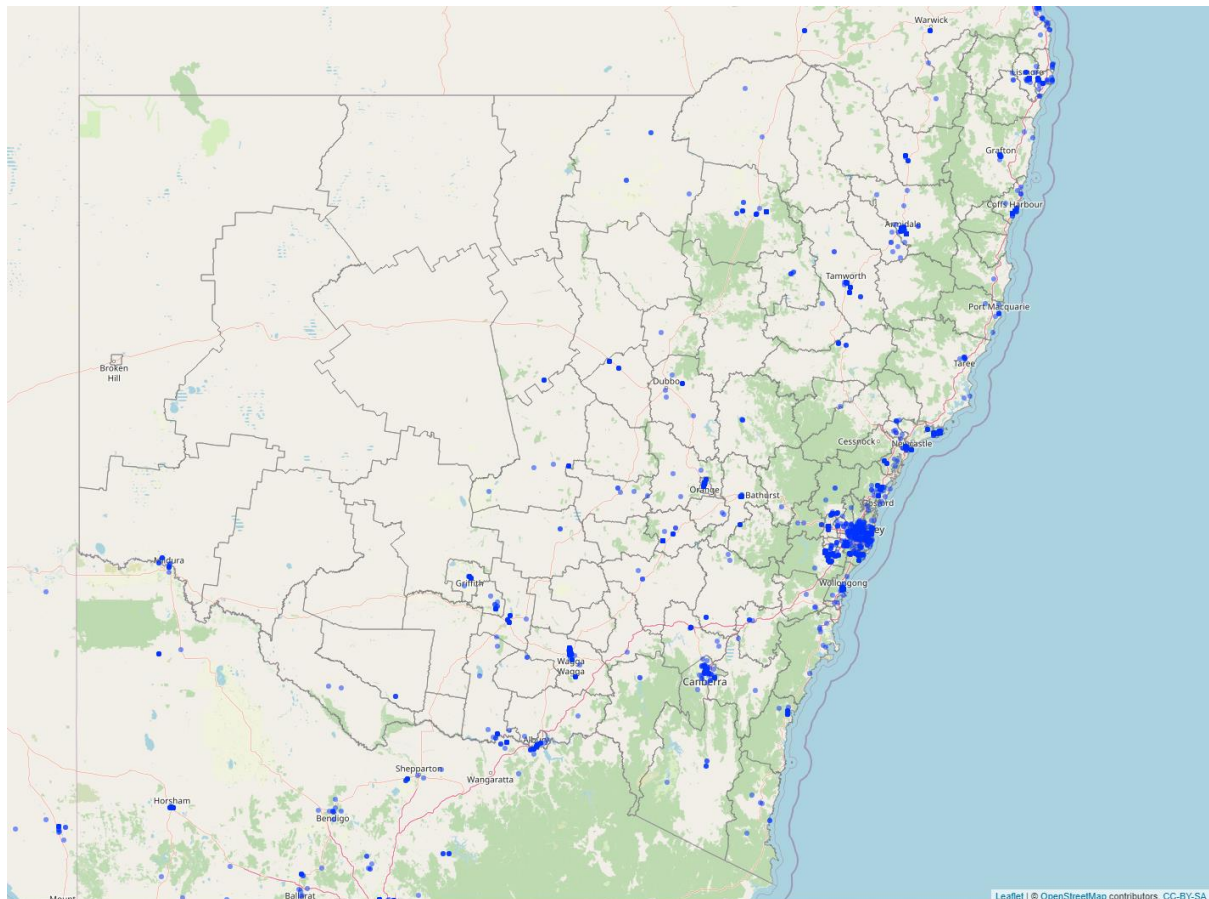
Generated using the ArcGIS Geocoding tool from Web of Science author affiliation data

Further examination of the data leads to the following, now generated within RStudio (RStudio Team, 2022) using ‘leaflet’ (Cheng et al., 2022) and overlaid with the New South Wales 2016 LGA boundaries (Australian Bureau of Statistics, 2018b).

With this geospatial representation, it is possible to see that there are dominant areas of clustering of research output and a broad spread of organisations. Concentrations around Armidale, Wagga Wagga, Canberra, Griffith, and Lismore represent university connections, whilst Tamworth, Orange, and Grafton capture government interests in land agriculture, and Nelson Bay captures fisheries.

However, neither the interconnections of these relationships nor the nature of the connections are shown. Of particular interest are the connections from Sydney and their outbound connections.

Figure 10-3: New South Wales geolocated addresses



Generated from ArcGIS Geocoded Web of Science author affiliation data, rendered using RStudio and Leaflet with ABS LGA boundaries.

The following analysis takes two forms: firstly, that of the interconnections of the points, and secondly, an overlay of industrial specialisation.

Applying an overlay that details the interconnections will show where research collaborations occur. Applying the industrial specialisation data to this map leads to a greater understanding of the role of industry concentration in the distribution of research activities. The latter is discussed in Chapter 12.

10.1 Mapping the Triple Helix Relationships

The previous figures show that the triple helix is observable over time. Changes occur in line with policy revisions, modification of targets and goals, or actors substitute one collaborator for another, choosing whom to work with to achieve their goals. In addition, the location may play a role. The tyranny of distance occurs in Australia due to its size. With a large proportion of the population located in the coastal zone, hemmed in by the Great Dividing Range and further dominated by the major cities near Sydney (Newcastle to the north, Wollongong to the south, and, to a lesser extent, Orange to the west), economic activity can be concentrated in these areas. However, agriculture is concentrated outside of this north-south region surrounding Sydney.

Within the data, the triple helix calculation contains the sets that denote the combinations that form each collaboration. Expressing this data geographically allows examining changing trends both spatially and temporally. This highlights the breadth and depth of how research organisations evolve over time.

Using geospatial data shows the complexity of the relationships but not their frequency. In contrast, the T-value does not capture the range of the complexity of the relationship as, in line with Abramo et al. (2014, p. 185), fractional counting of the number of authors was not used. This means that, even if multiple authors from the same organisational type (e.g., university) are co-authors, it is only counted as a single organisational type.

Of the 32 sets available, 15 are focused on the period from 2003 to 2019. Once imported into ArcGIS, the data from R was converted into points and lines to demonstrate the relationships.

Table 10-1: Selected combinations mapped geospatially

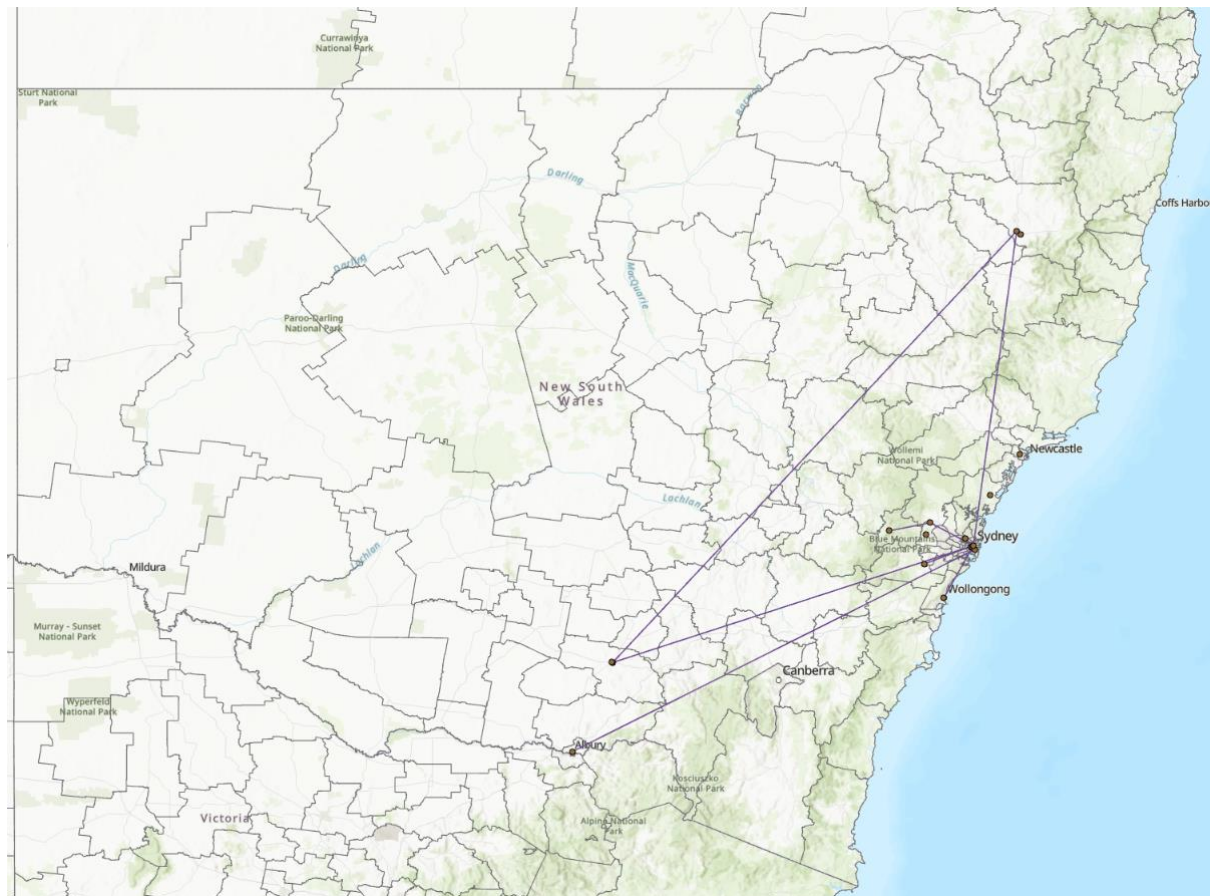
	U	G	UI	UG	US	UF	IS	IG	GS	UIG	UGS	UGF	UGSF	UIGS	UISF
2003	76	59	2	27	24	24	4	4	32	1	13	5	2	0	0
2004	81	47	2	31	24	24	4	1	26	1	6	6	0	0	2
2005	63	47	4	21	30	34	8	0	34	0	14	6	2	3	0
2006	63	47	2	36	38	31	10	1	33	4	17	2	4	0	0
2007	73	36	3	42	20	35	16	3	57	2	15	11	1	1	1
2008	86	38	3	41	39	53	5	2	50	2	22	8	5	3	3
2009	60	35	1	36	38	57	8	1	37	2	20	6	0	1	0
2010	78	28	2	28	52	79	10	2	36	3	30	6	5	0	0
2011	77	23	4	33	33	73	9	0	35	2	19	9	4	1	1
2012	77	20	1	37	47	79	10	0	19	4	29	7	1	3	1
2013	93	14	4	35	7	112	10	3	29	6	27	10	9	2	0
2014	77	13	6	44	36	125	5	1	24	3	41	14	5	0	1
2015	90	10	12	35	50	135	12	1	18	3	22	25	9	3	1
2016	83	8	4	39	38	153	11	0	27	3	17	44	11	2	2
2017	62	15	11	54	49	175	6	4	23	1	22	37	12	4	5
2018	58	11	6	41	47	171	17	1	26	4	33	40	11	3	5
2019	71	10	8	53	54	172	19	1	26	1	27	23	17	2	10

Counts of combinations, derived from the calculated sets.

In contrast to the T-values, in these cases, there are multiple actors within the combination.

For example, the measurement of university in the geospatial context demonstrates the connections between universities. As illustrated in Figure 10-4, whilst these would represent a single organisational type in the triple helix model, in a geospatial representation, the connections between the University of New England (Armidale) and Charles Sturt University (Wagga Wagga) and universities in Sydney can be seen. There were 78 relationships of this nature in 2010. Furthermore, the connections between satellite campuses and main campuses can be observed – for example, the University of Sydney’s Camden research station can be seen in Southwest Sydney.

Figure 10-4: University relationships in 2010



Geospatial location of research institutions, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

These satellite campuses allow the city-based universities to conduct applied research in the relevant areas; similar relationships can be seen with connections to the University of Sydney's Narrabri research institute.

Whilst these observations can be seen in New South Wales, when examined for all of Australia, the *university and other state/territory* collaborations follow a clear divide in terms of collaborations. Reflecting the environment that exists in New South Wales, very few collaborations are observed in Far North Queensland or the Northern Territory, with more relationships with the southern states, including Tasmania.

Figure 10-5: University and other state/territory relationships in 2010



Geospatial location of research institutions, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

With limited connections between New South Wales universities and organisations in other states or territories, the connection with institutions such as in Townsville is clear.

As with the T-value results, the results of the geospatial representation are grouped by the organisation.

10.1.1 University

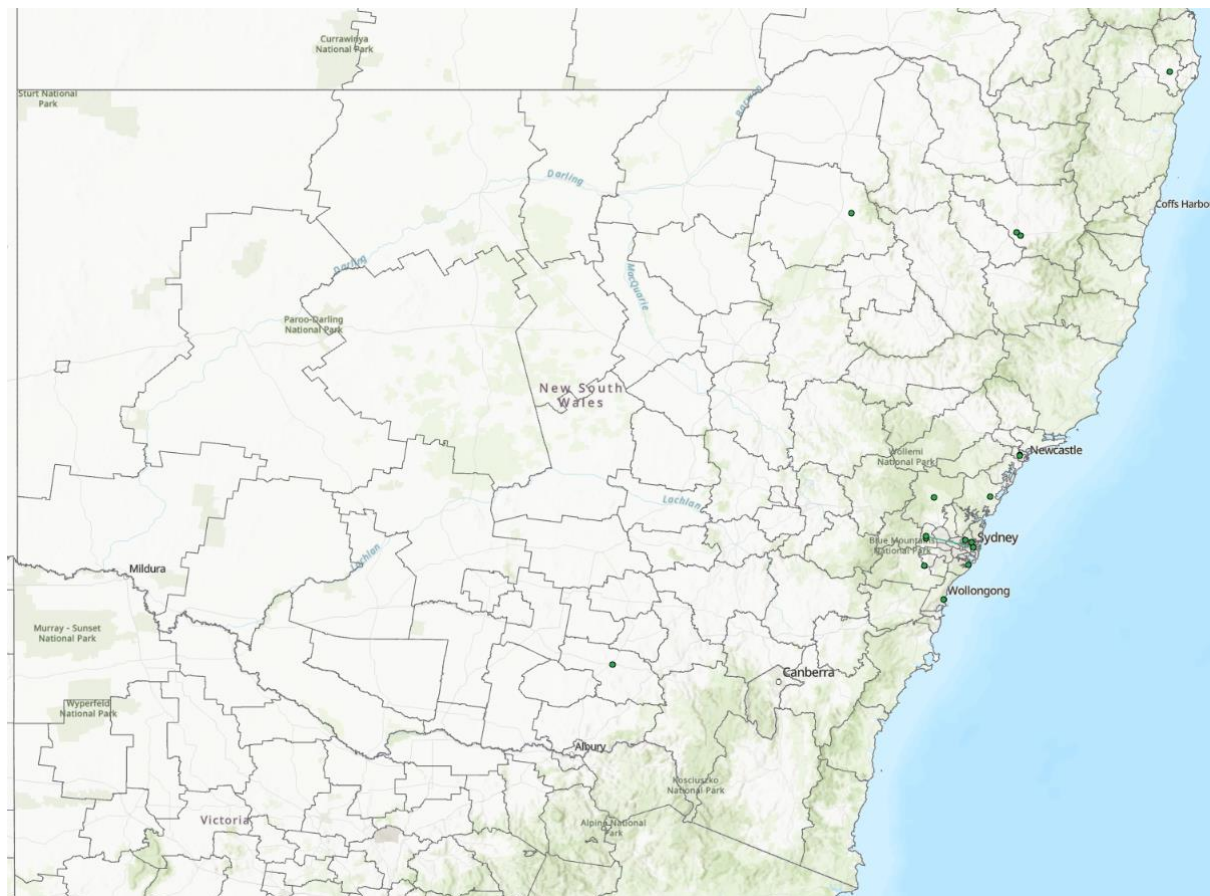
Representing the collaboration where universities are involved, this group is the main originator of research within the sampled data.

10.1.1.1 University Only

The smallest total annual figure of publications occurred in the first year of the data used – 2003 – and the dominant authorship at this time was university. The visualisation of the data results in the ability to see the collaboration within the university sector, something not captured in the T-values of the triple helix.

The inclusion of internal collaboration within the sector, and its capture geographically, increases the understanding of the dynamics of the research landscape. Without this, the trends that emerge in later years as authors move to a more collaborative approach would not be as apparent, nor would the areas that need to be addressed to improve collaborative practices.

Figure 10-6: 2003 University locations for co-authorship

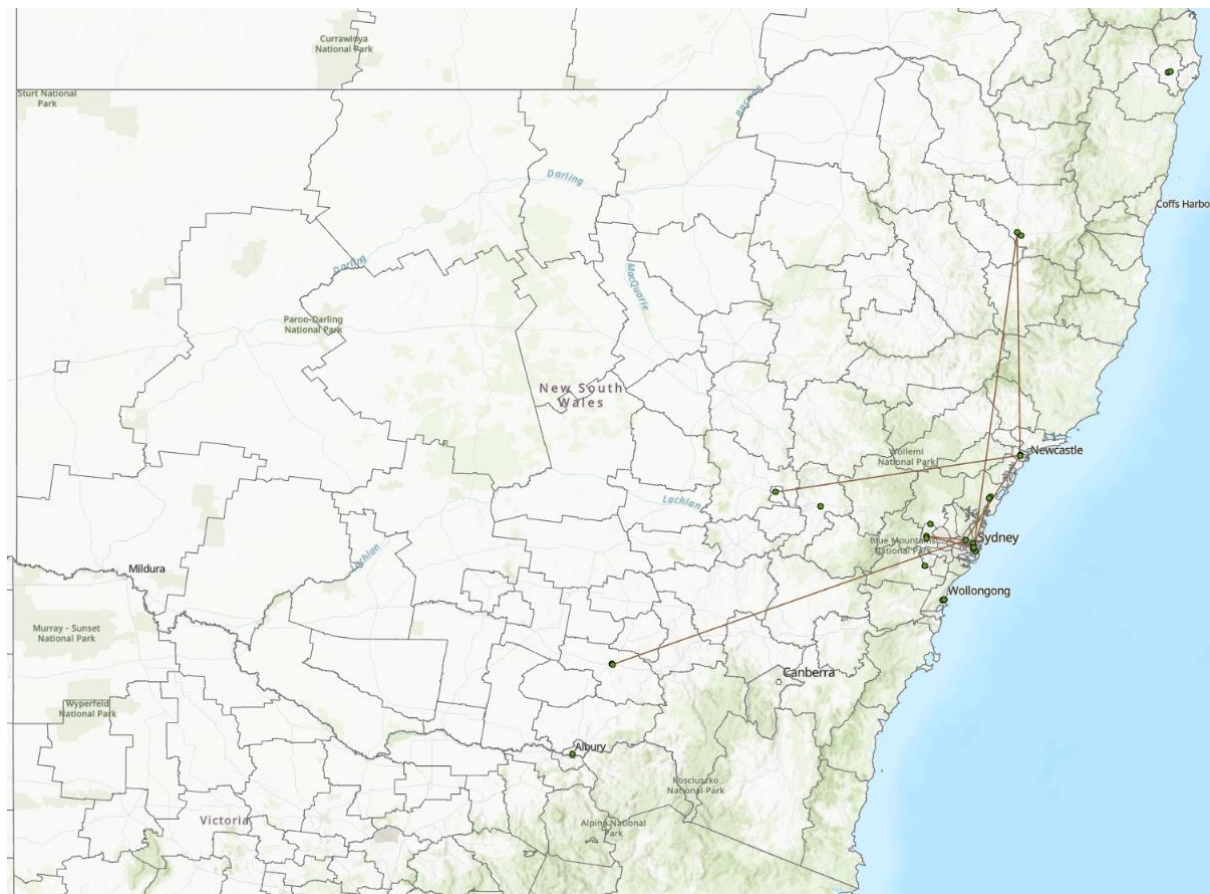


Geospatial location of universities, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

The independent nature of these organisations is clear, with very few inter-university collaborations. With the regional universities of Southern Cross (Lismore), New England (Armidale), and Charles Sturt (Wagga Wagga) readily identifiable, and the University of Sydney's research stations visible in both Narrabri and Camden, as well as the Ourimbah campus of the University of Newcastle, the universities may have collaborated within their campuses but were (rarely) collaborating across the wider university landscape.

In contrast, the following year (2004) had clear collaborations occurring between universities, often spanning hundreds of kilometres.

Figure 10-7: 2004 University locations for co-authorship



Geospatial location of universities, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

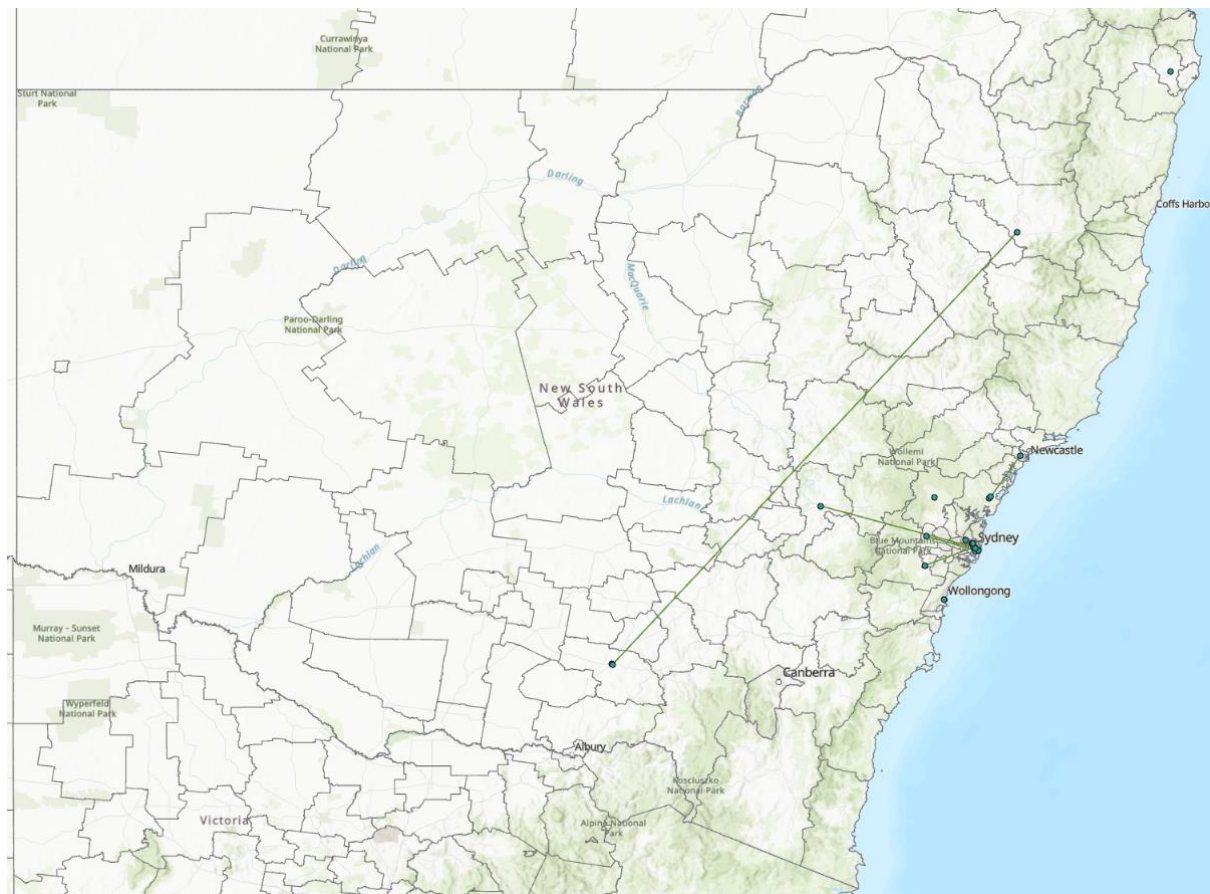
There were clear collaborations between the University of New England and both Newcastle and Sydney universities, and between the University of Newcastle and Charles Sturt

University at Orange, Sydney universities and Charles Sturt University at Wagga Wagga.

However, Southern Cross University at Lismore continued to work independently, as did the University of Wollongong.

Between 2003 and 2006, there was limited collaboration between the regional universities without another actor to influence the collaborations; in 2006, the first occurrence of Charles Sturt University and the University of New England collaborating occurred, whilst Wollongong and Southern Cross continued to operate internally or independently of the other universities in New South Wales.

Figure 10-8: 2006 University locations for co-authorship

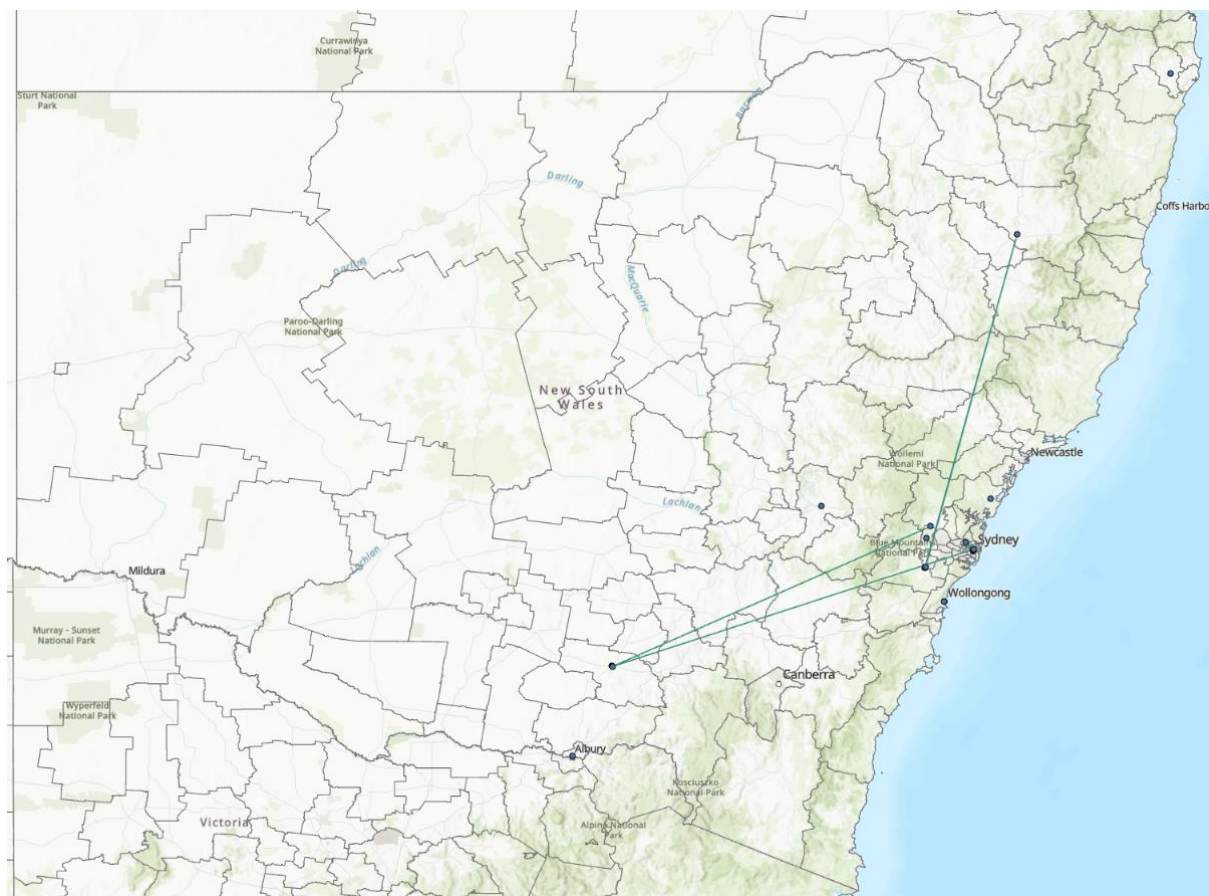


Geospatial location of universities, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

In addition, the intra-university collaboration can be seen in the link within the University of Newcastle campuses. Notably, the universities generally act independently of one another, with limited collaborations between universities but collaboration within the same university.

Changing collaborations occurred in 2009; this time, the University of New England collaborated with the University of Sydney Camden campus. This collaboration reflects the potential for applied research as opposed to foundational research. Furthermore, Charles Sturt University at Wagga Wagga can be seen working with Western Sydney University. Southern Cross was still working independently of the other universities. This may reflect the specific research interests of Southern Cross, as well as closer proximity to the universities in southern Queensland.

Figure 10-9: 2009 University locations for co-authorship

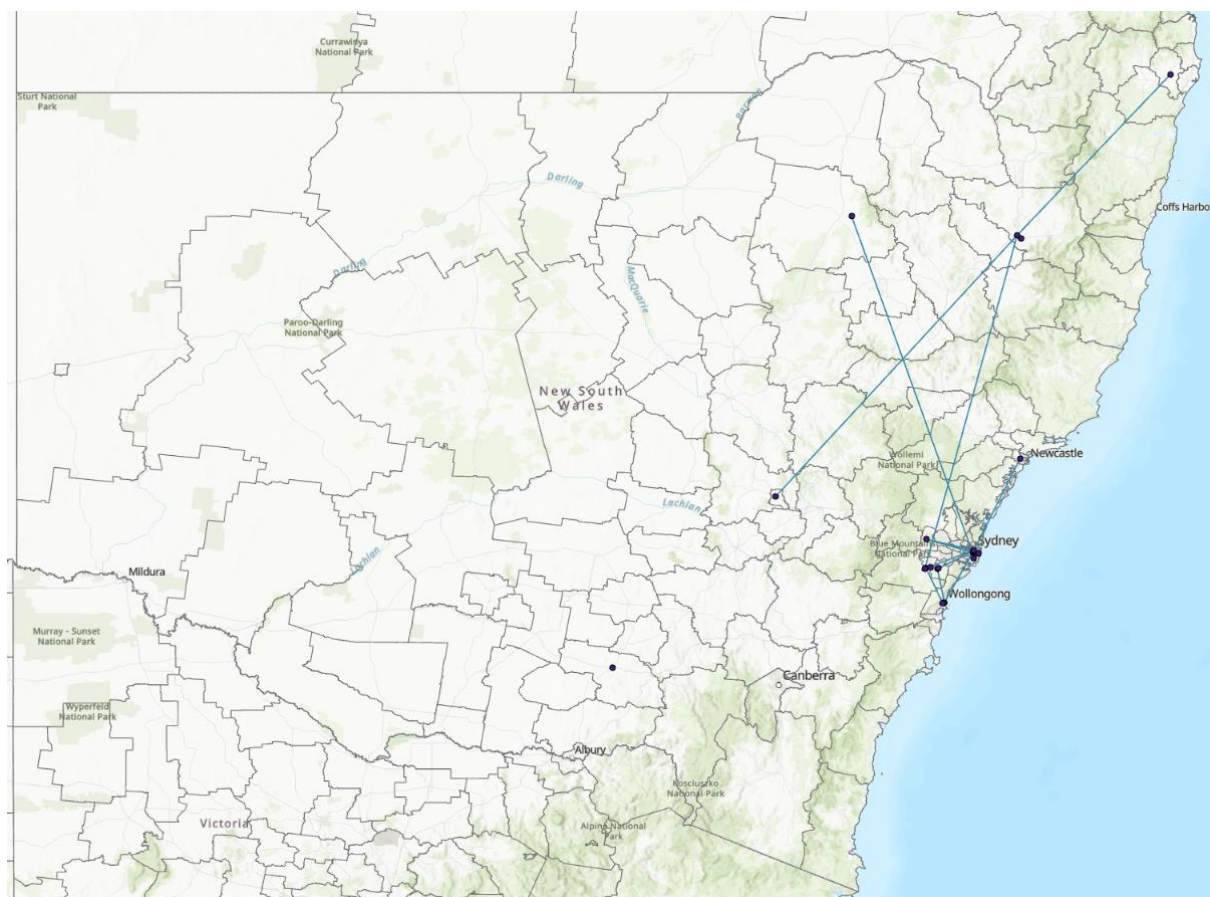


Geospatial location of universities, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

When examining the trends year by year, the changes in research goals, knowledge availability, and collaborations are clearly visible.

Between 2010 and 2019, research policies changed, and this can be seen in the collaborations in 2013 – the first observation of Southern Cross and another university (in this case, Charles Sturt at Orange), as well as the intra-university collaboration with the University of Sydney Narrabri research station. A clear connection between livestock research institutions can be seen with the University of New England and the University of Sydney's Camden campus, which is persistent in many years. Similar common research themes may lead to the collaboration between Southern Cross and Charles Sturt at Orange.

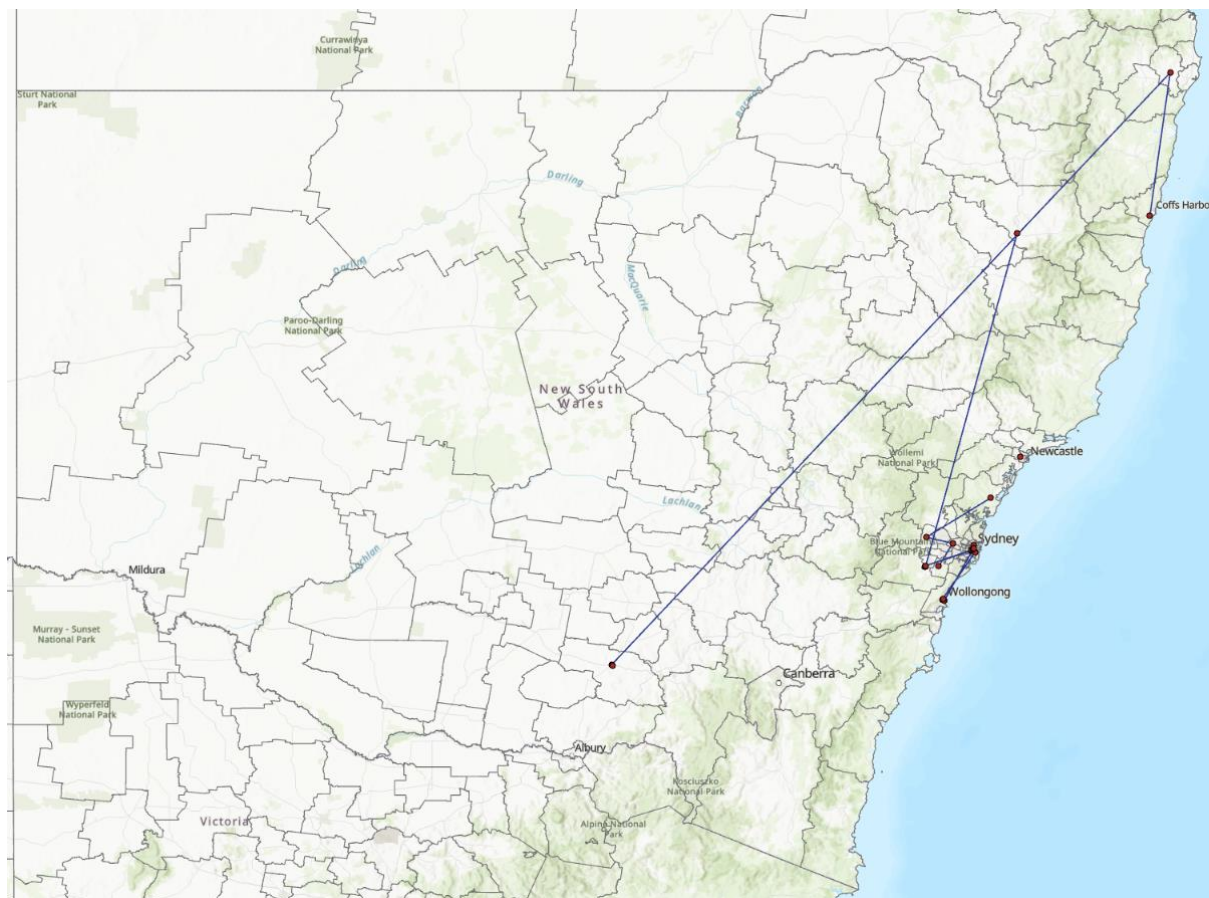
Figure 10-10: 2013 University locations for co-authorship



Geospatial location of universities, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

By 2018, peripheral campuses were increasing their research output. Southern Cross University campus at Coffs Harbour is an example, whilst the main Newcastle campus was undertaking less collaborative research in agriculture. Intra-university collaborations can be seen between the Coffs Harbour and Lismore campuses of Southern Cross University, but rarely any connection between Coffs Harbour and any other university.

Figure 10-11: 2018 University locations for co-authorship

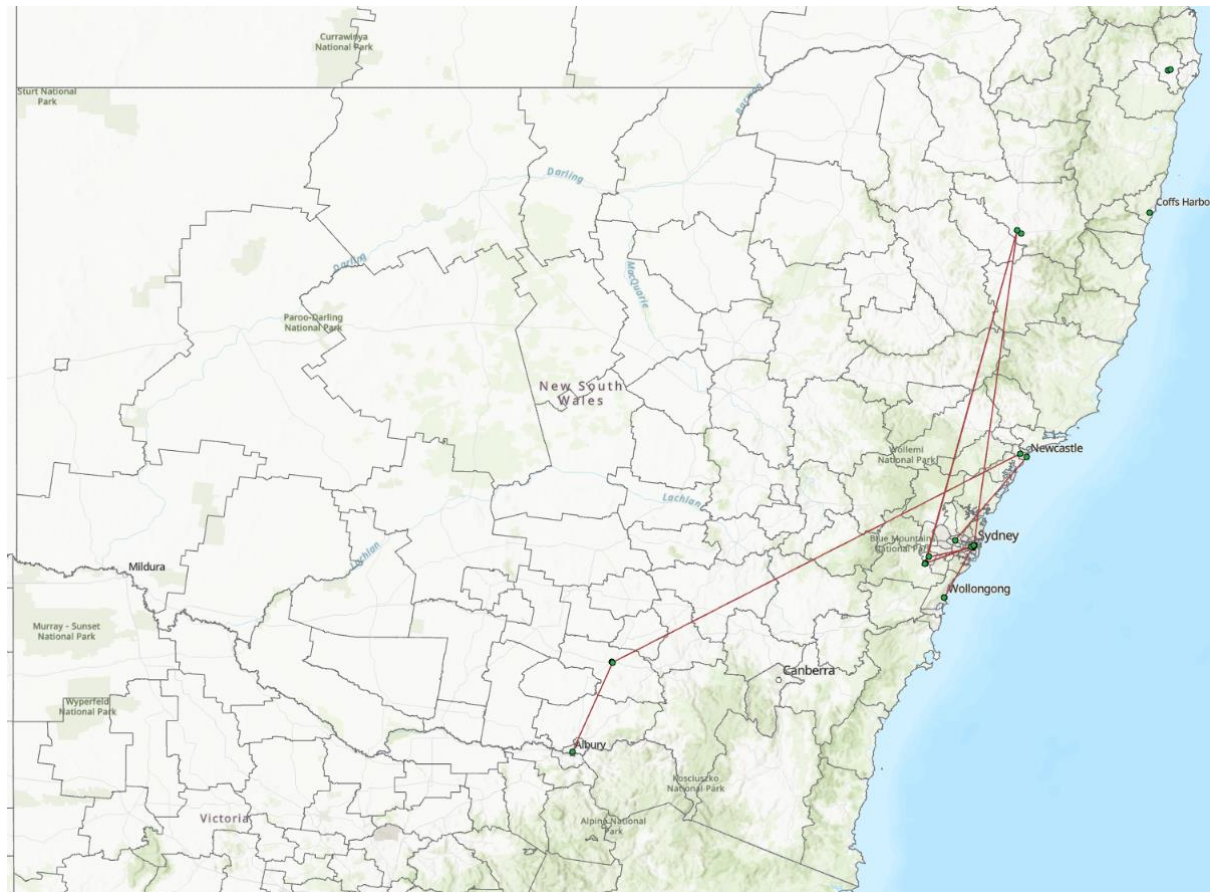


Geospatial location of universities, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

In the final year, 2019, the collaborations changed very little compared to the previous years; the inclusion of Albury/Wodonga in the map reflects the continued expansion of university campuses in regional New South Wales. Charles Sturt's campuses throughout the southern region can be seen in the connections between Wagga Wagga and Albury/Wodonga.

Continued collaborations can be seen between other peripheral campuses, including Newcastle and Sydney University's campuses at Ourimbah and Camden, respectively. However, whilst these collaborations increased between Charles Sturt, Newcastle, and Sydney campuses, Southern Cross continued to work independently.

Figure 10-12: 2019 University locations for co-authorship



Geospatial location of universities, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Whilst absolute numbers remained constant, it must be noted that the overall number of publications increased; thus, the percentage share decreased. This leads to identifying collaborations that have replaced the sole organisational type.

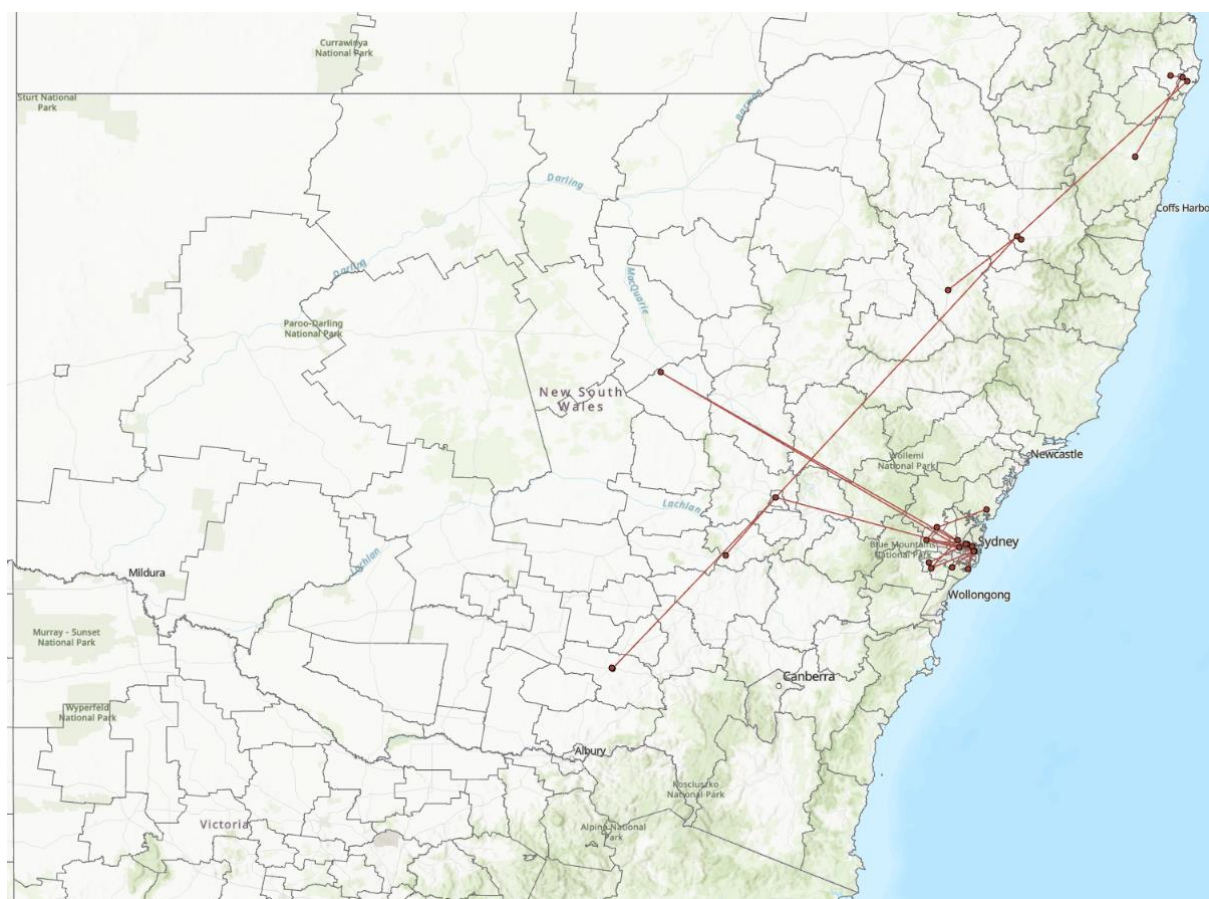
10.1.1.2 University and Government

An important consideration is whether the universities' changed pattern of collaboration within the sector has changed to include government as the actor they choose to work with.

Due to the inclusion of government research organisations, the spread of research activity has increased. With the potential to be of a more applied nature rather than the fundamental research that university-only research may generate, research in partnership with government organisations may be carried out in closer proximity to the appropriate environment.

The inclusion of government allows the collaboration activity of Southern Cross and the local New South Wales Department of Primary Industries stations at Grafton and Tamworth is visible.

Figure 10-13: 2003 University and government locations for co-authorship



Geospatial location of universities and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

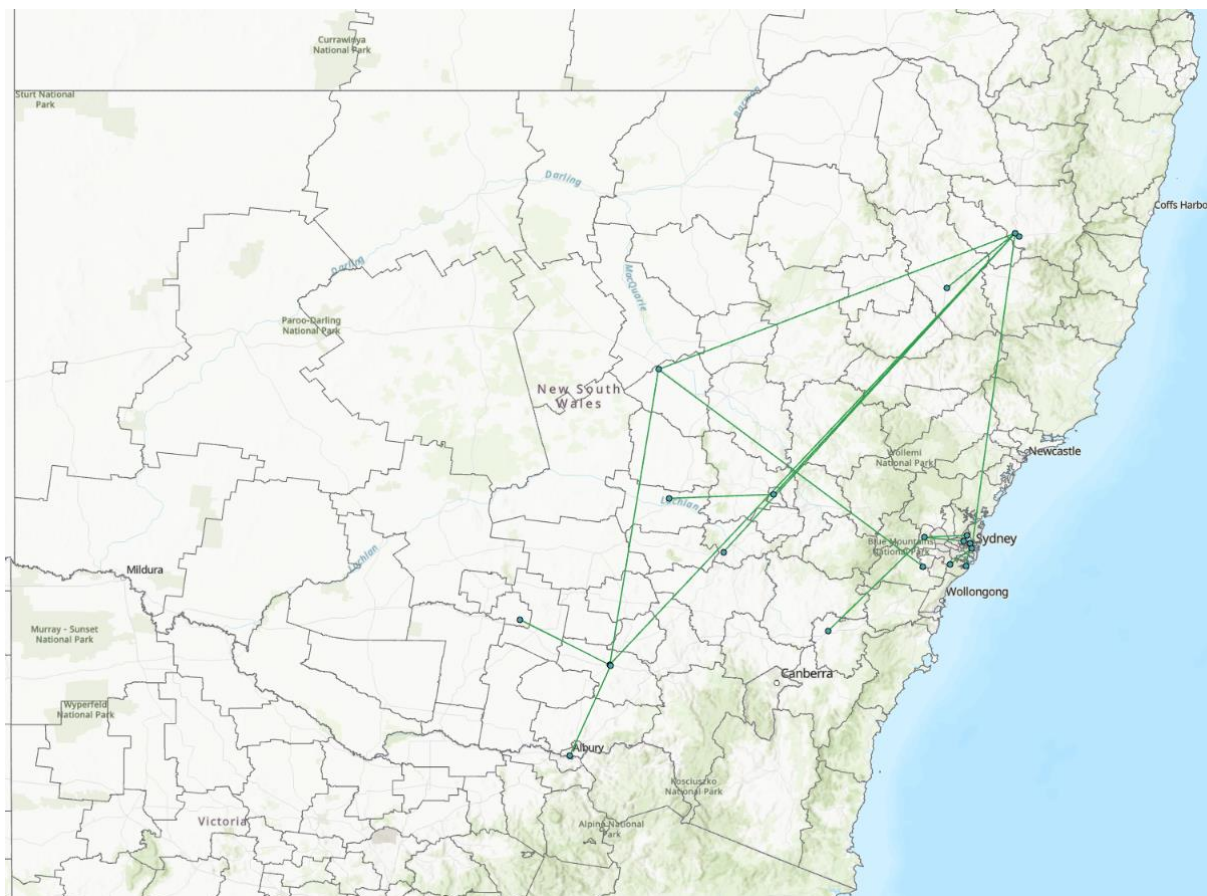
The widespread of collaboration is clearly visible; however, there is limited opportunity to identify when research is carried out locally by universities and government collaborations.

This may be because government research organisations are co-located on university

campuses, which makes identification difficult at a broad state level. Of note is the limited government involvement with Newcastle and Wollongong universities.

In 2004, much more localised collaborations could be observed. The University of New England can be seen to be working with the New South Wales Department of Primary Industries at Tamworth, whilst Wagga Wagga has connections to Albury/Wodonga and out to Trangie. These relationships represent knowledge sharing in similar agricultural regional activities.

Figure 10-14: 2004 University and government locations for co-authorship

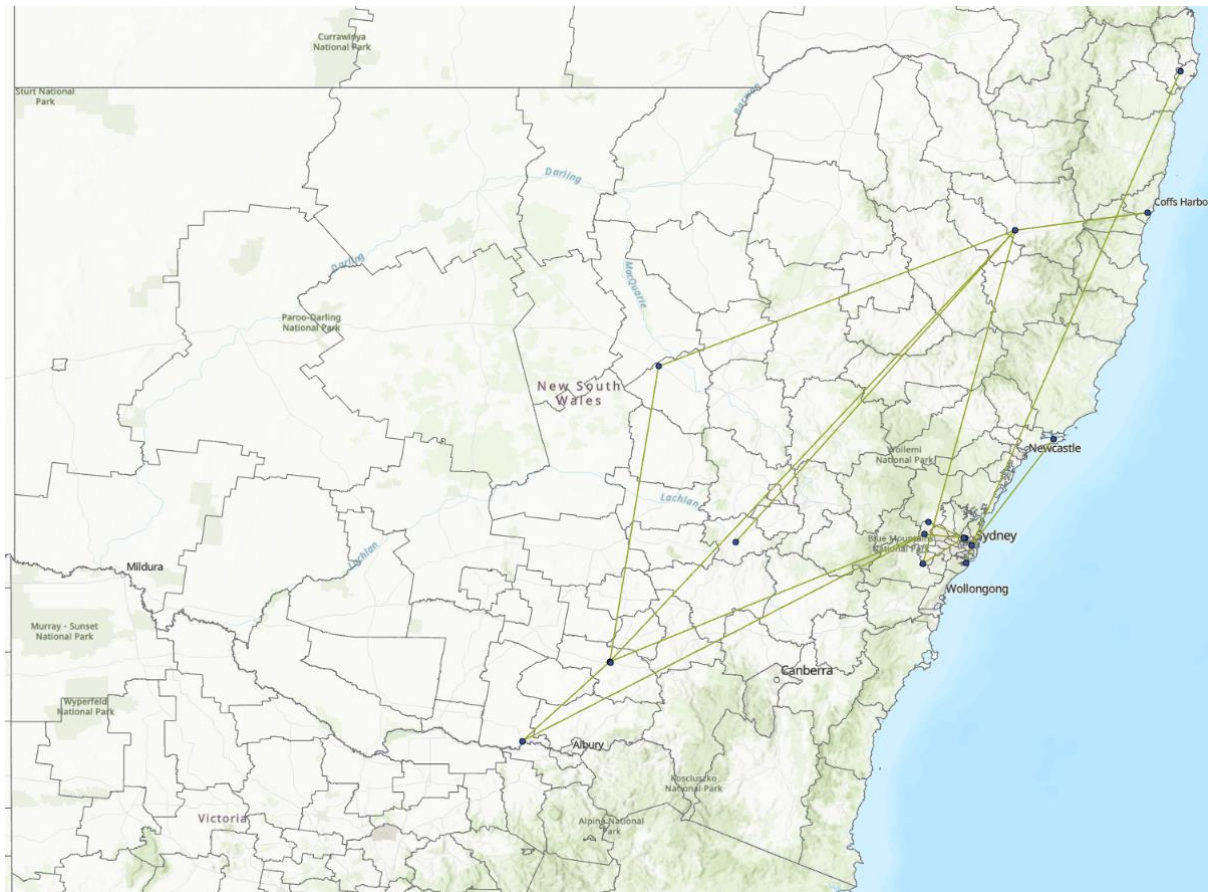


Geospatial location of universities and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

As illustrated in Figure 10-14, there is a continued connection between Sydney research stations at Camden and out to Trangie – a New South Wales Department of Primary Industries research station.

Whilst 2003 and 2004 were focused on agricultural research, 2005 saw the introduction of New South Wales Fisheries, located at Nelson Bay and Cronulla, working with universities in Sydney.

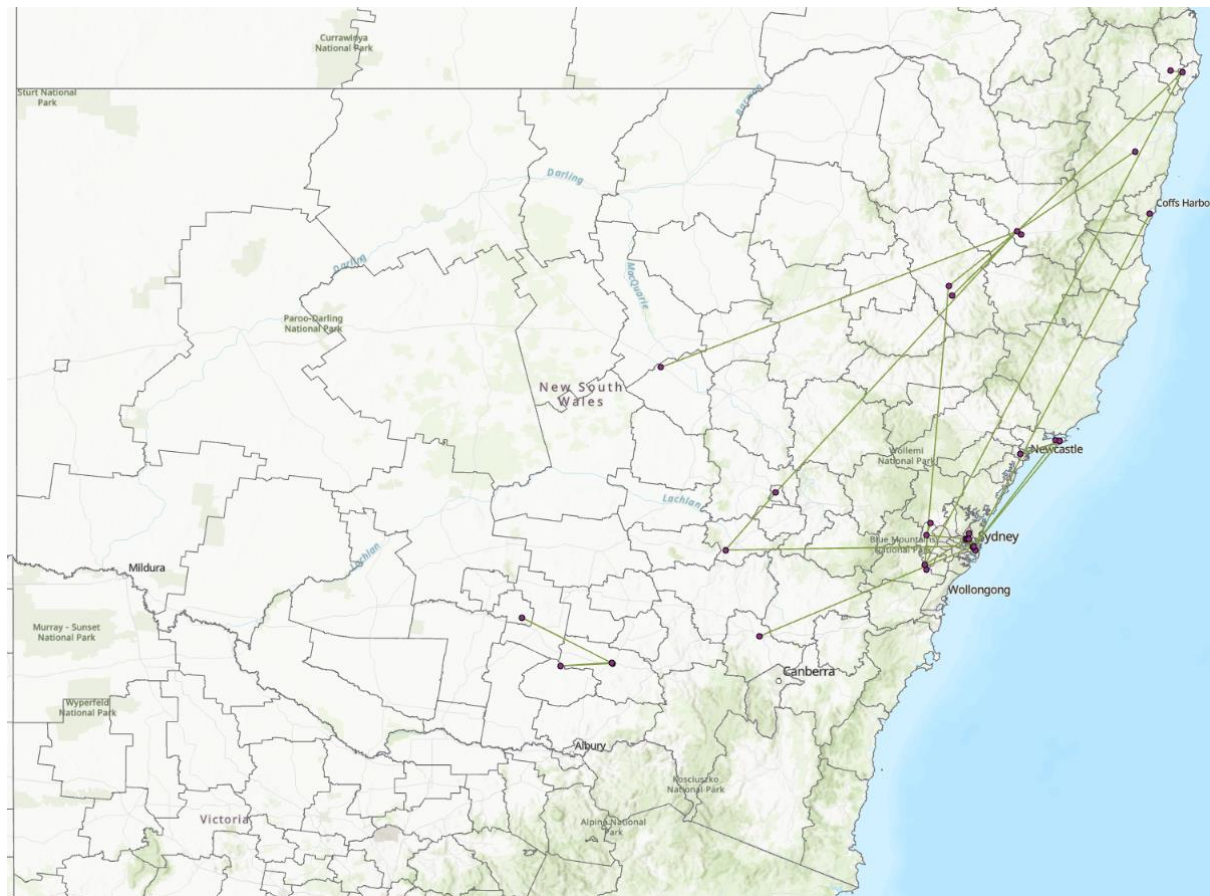
Figure 10-15: 2005 University and government locations for co-authorship



Geospatial location of universities and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

An evolution rather than a revolution led to research activity distribution in 2006. Once again, Cronulla and Port Stephens feature, whilst Charles Sturt and the New South Wales Department of Primary Industries in Wagga Wagga are independent of other research organisations. Cowra and Yass now appear in the data, whilst research from Coffs Harbour is independent of Southern Cross University in Lismore. This implies that the Coffs Harbour research is New South Wales Fisheries.

Figure 10-16: 2006 University and government locations for co-authorship



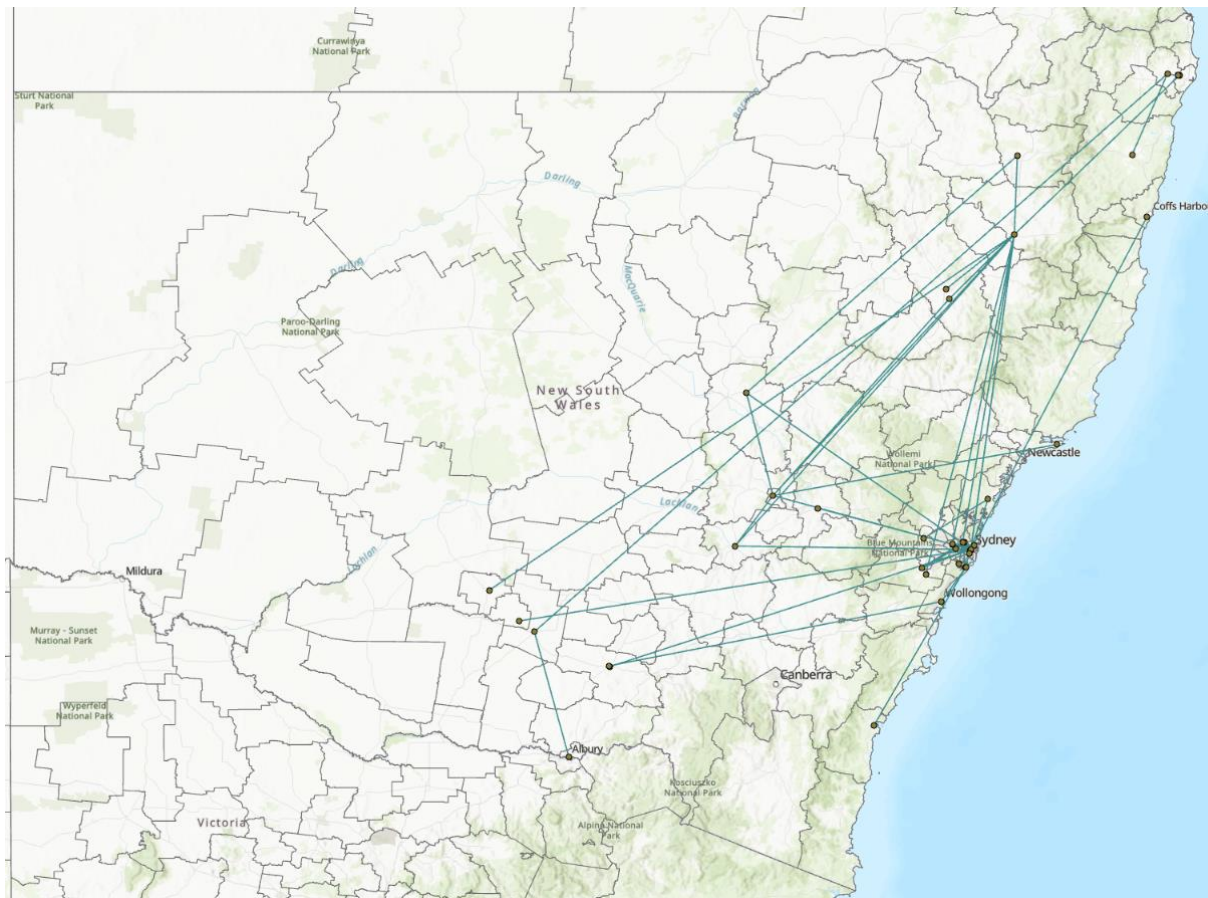
Geospatial location of universities and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

2012 presents increased collaborations, with increased activity west of the Great Dividing Range and along the coast (with Batemans Bay now included). Furthermore, the research around Lismore has an increase in the geographical spread – into the Riverina area.

There is an increase in collaboration research stations, but there is also an increase in the research output from Sydney-based organisations. The regional universities are still active in research collaborations and can be clearly seen to engage across the state.

With the inclusion of Batemans Bay and other New South Wales Fisheries locations, the increasing importance of the fishery sector within the agricultural research ecosystem can be seen.

Figure 10-17: 2012 University and government locations for co-authorship



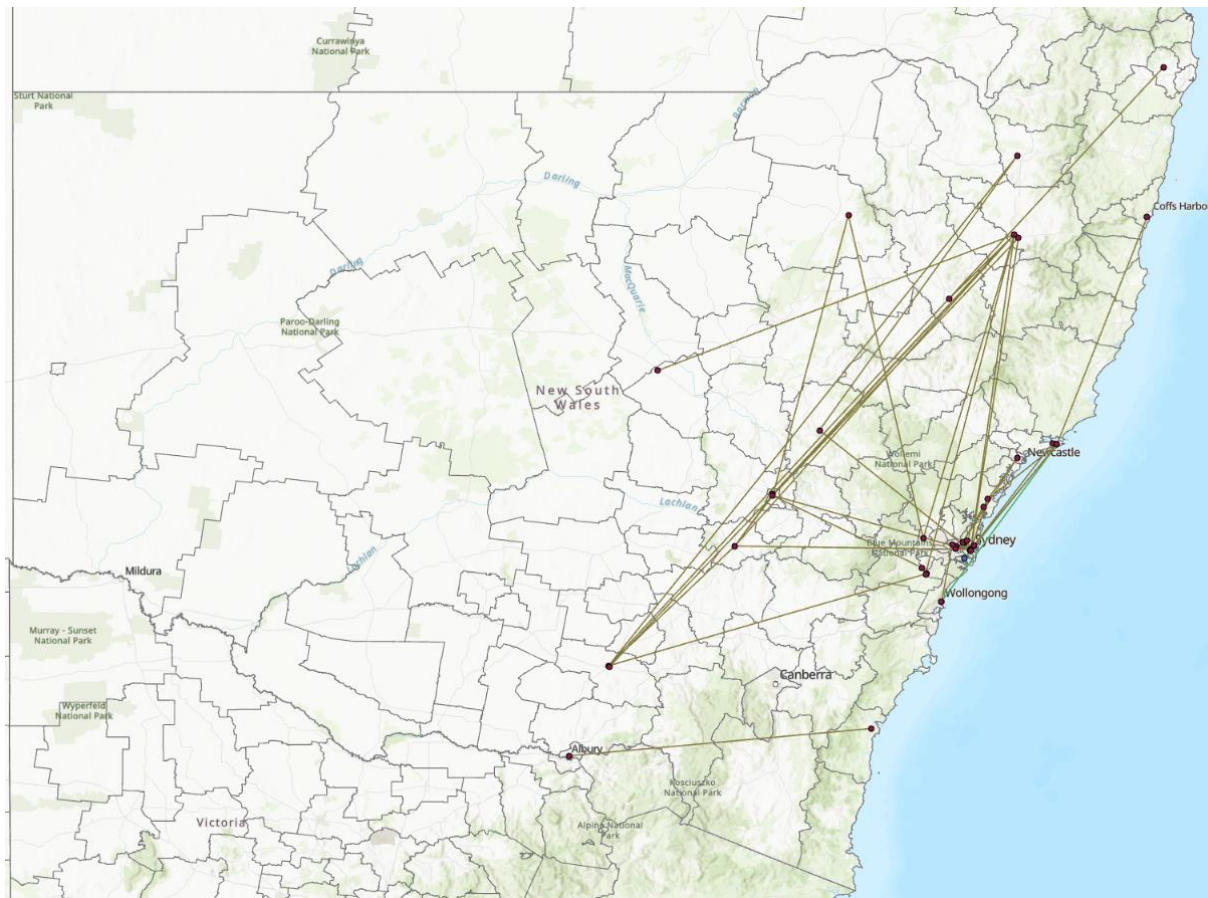
Geospatial location of universities and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Compared to 2006, the relationships in 2012 and subsequent years are increasingly complex.

A shift to increasingly collaborative, as well as applied, research – almost in the extension sphere of the creation of new ideas – may lead to these complex relationships that span the state.

Examples of this increasingly complex relationship can be seen in 2017. The collaborations from Armidale (the University of New England and the New South Wales Department of Primary Industries) are connected to Sydney, Camden, and Wagga Wagga. These collaborations may reflect the early stages of the transition to the National Farmers' Federation's 100-billion-dollar goals.

Figure 10-18: 2017 University and government locations for co-authorship

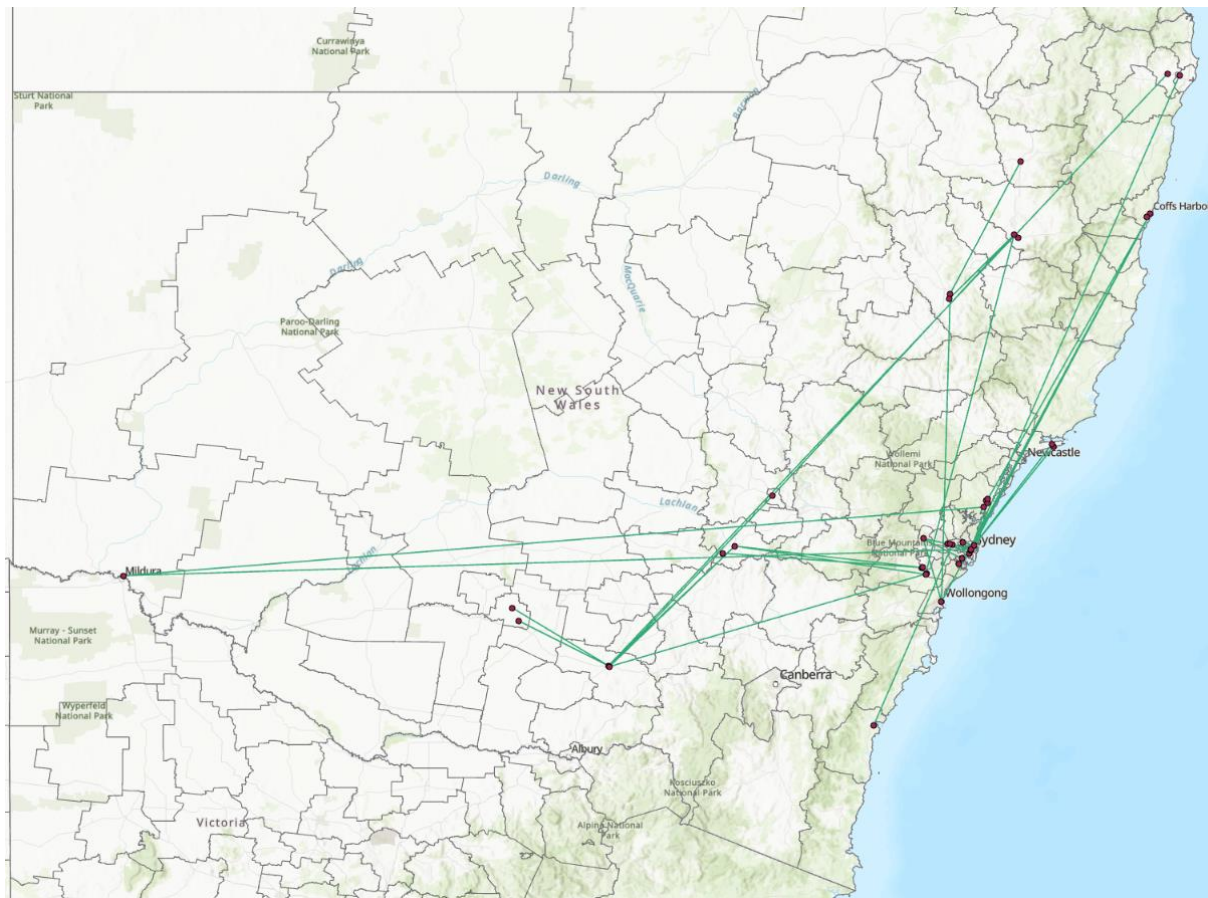


Geospatial location of universities and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

The connection between Tenterfield and Mudgee, and subsequently to Sydney or Wagga Wagga, is of interest in the 2017 map. This reflects the potential of similar agricultural activity in geographically diverse regions.

The trend of similar activity in geographically distributed regions can also be seen in the final year, 2019, where the most complex collaborations can be observed. New connections to Mildura and a continued Tenterfield presence in the research output can be seen. In 2019, Tenterfield-based researchers worked with Tamworth, whilst researchers in Wagga Wagga worked with other similarly close researchers. In contrast, Mildura-based researchers worked with researchers from the Central Coast.

Figure 10-19: 2019 University and government locations for co-authorship



Geospatial location of universities and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Whilst the engagement of state-level government collaborations reflects the local knowledge dynamic, the extension to include partners in other states or territories shows the transferability of the research.

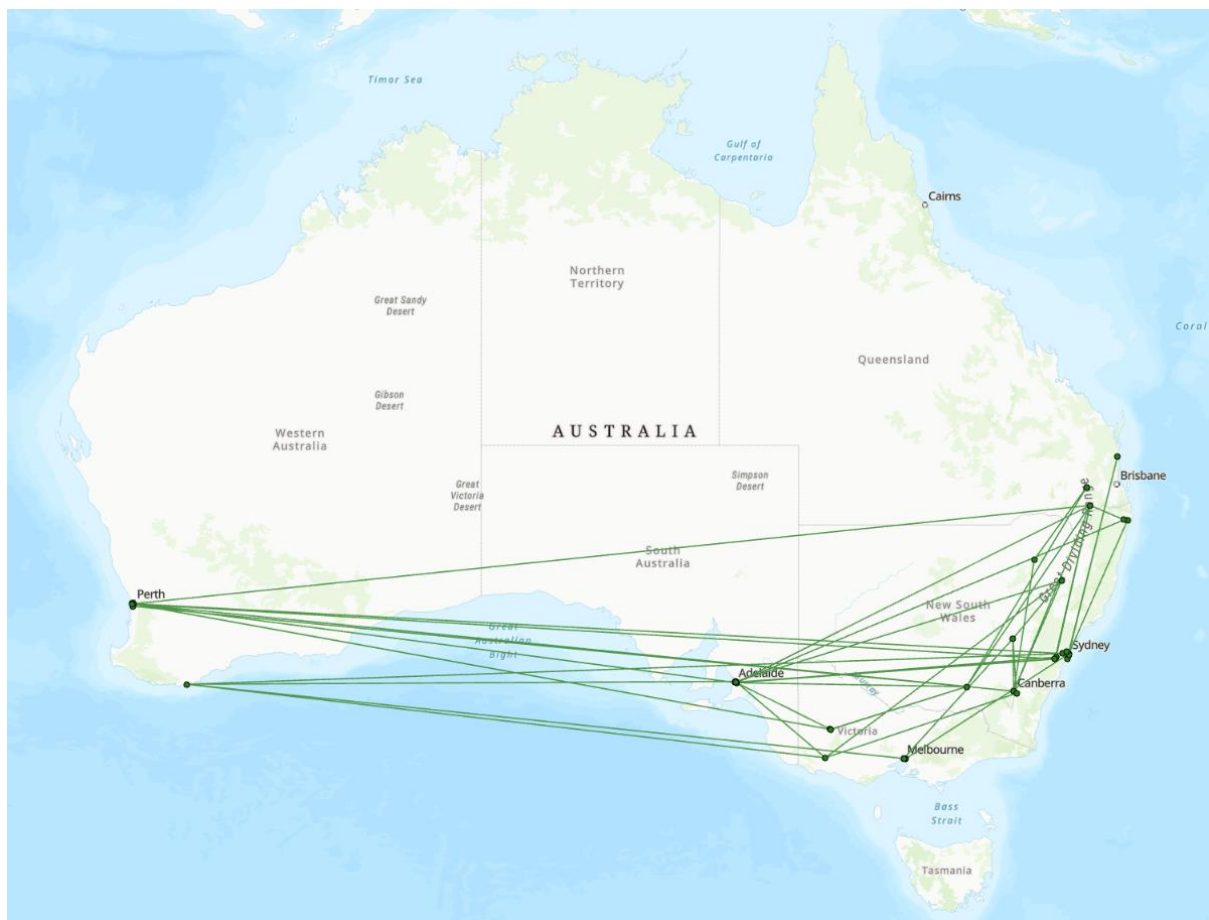
10.1.1.3 University, Government, and Other State/Territory Combinations

When expanding the collaboration patterns, the clear boundary that separates the research landscape is visible, with limited co-authorship between New South Wales-based institutions and those in the tropical north. There is a wide range of biomes and environments, as well as the specialisations of the different agricultural regions.

Clear patterns of collaboration can be seen. Working with Perth, Adelaide, or Melbourne-based institutions reflects both exchanges of knowledge and specialisations and the demand

for relevant knowledge. In 2003, research between universities, governments, and other states was widespread, with many Sydney organisations involved. Furthermore, the concentration of research along the Great Dividing Range at this time is apparent. This can be seen in the collaboration between Armidale and Gatton-based organisations; the similarity in elevation as both are on the Great Dividing Range.

Figure 10-20: 2003 University, government, and other state/territory locations for co-authorship



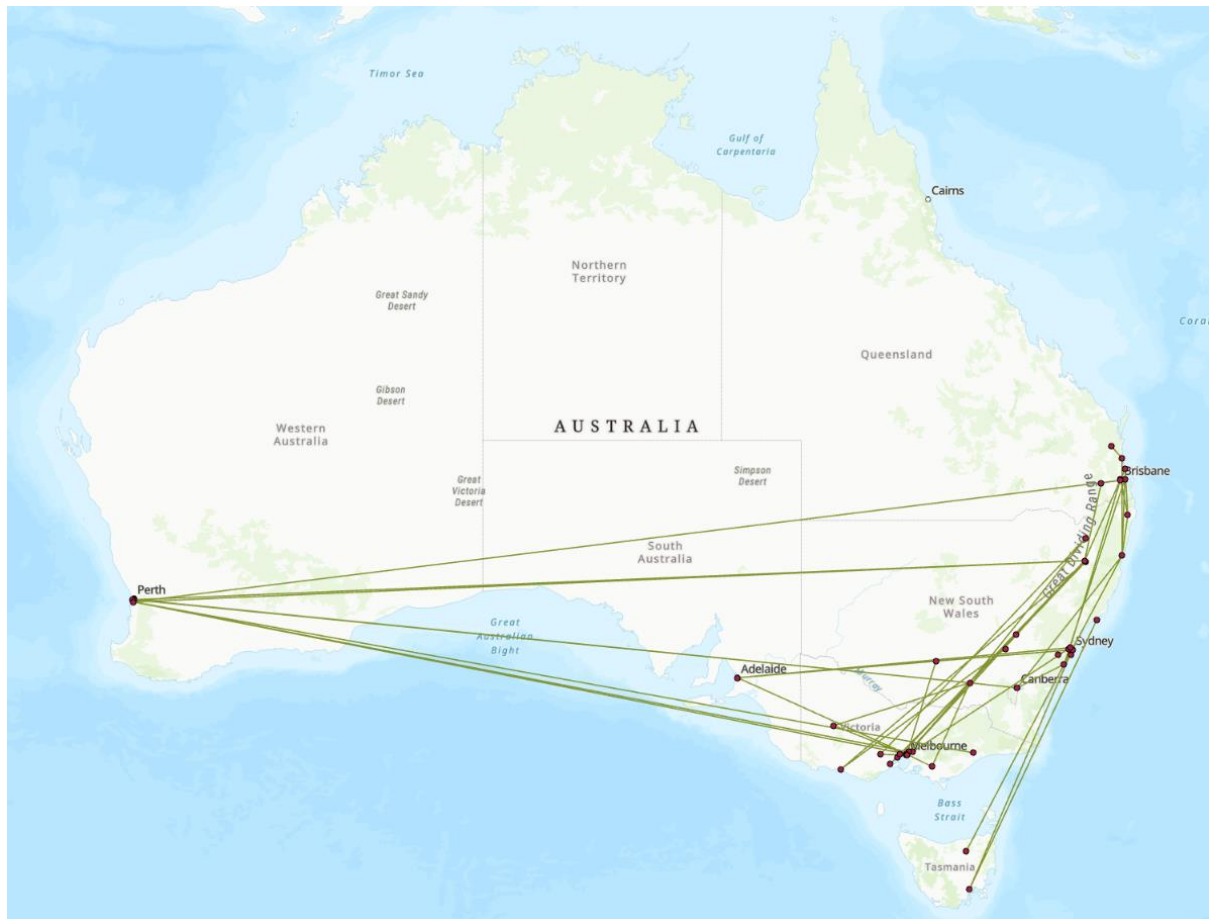
Geospatial location of universities, government, and other state/territory, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

The concentration is unsurprising, with key New South Wales agricultural research locations along the Great Dividing Range (including Armidale, Tamworth, and Orange). Furthermore, this aligns with the Queensland organisations on the Granite Belt.

Retaining the sub-tropical collaboration, the overarching pattern of collaboration was similar in 2012, with collaborations involving Perth, Adelaide, and Melbourne. However, in 2012,

Tasmanian researchers became engaged with New South Wales researchers from Nelson Bay, reflecting the similarity of the fishing industry. Furthermore, the research concentration along the Queensland coast north of Brisbane also increased, often working with Coffs Harbour and Lismore-based organisations or with organisations in Armidale.

Figure 10-21: 2012 University, government, and other state/territory locations for co-authorship

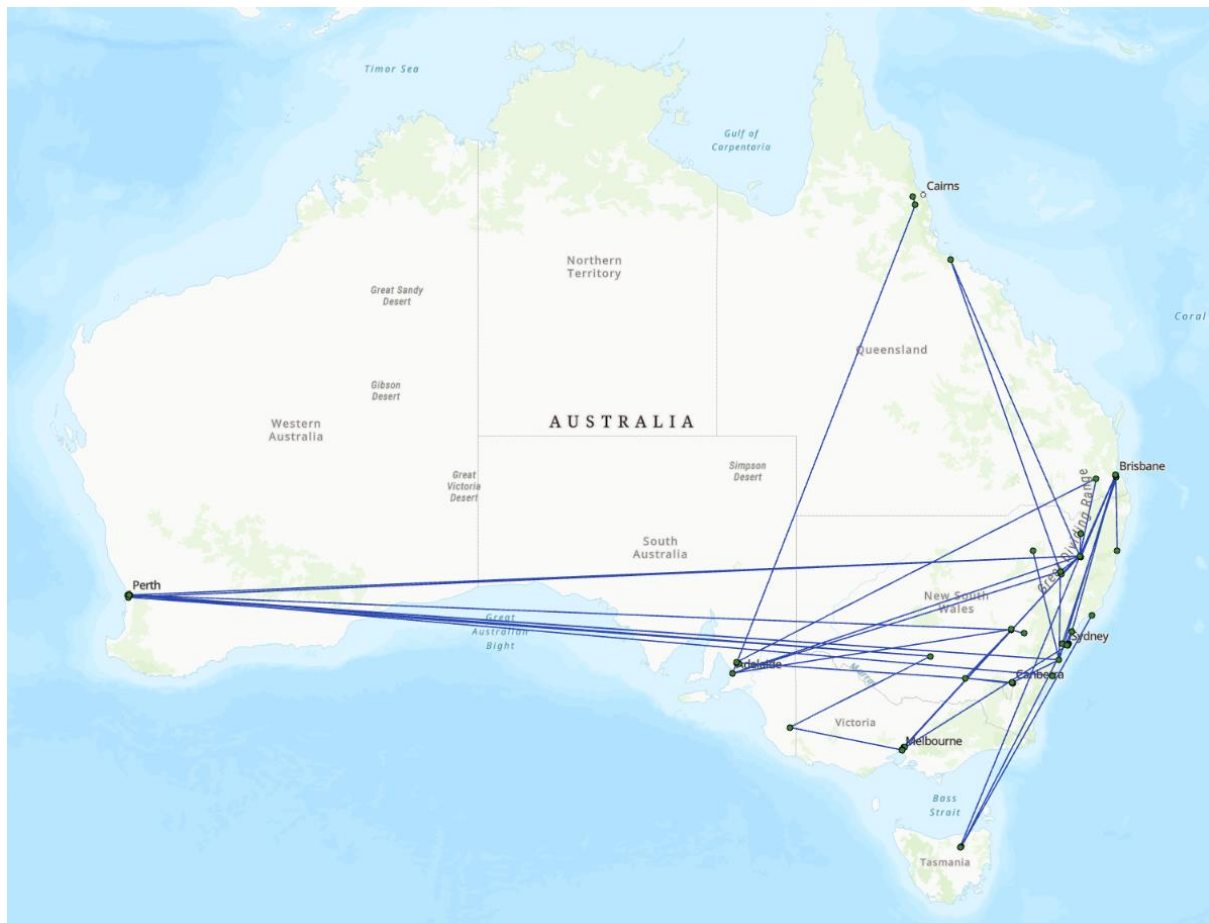


Geospatial location of universities, government, and other state/territory, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

The increase in collaboration visible in the T-value data (Figure 8-8) from 2015 onwards is reflected in the expansion of the network, with an increasing complexity in the relationships between author organisations.

The increasing collaboration began in 2015, and the expansion of the network extends to Far North Queensland (Townsville) and south to Tasmania., with collaborations involving organisations based in Townsville and Cairns, as well as Launceston (Tasmania) occurring.

Figure 10-22: 2015 University, government, and other state/territory locations for co-authorship



Geospatial location of universities, government, and other state/territory, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

The new collaborations connected a wide range of organisations. For example, the Launceston connection with Nelson Bay for the New South Wales Fisheries reflects the specialisation that exists in this industrial sector.

In 2019, an increasing network around Adelaide undertook collaborative research. There is a much wider network, with more collaborations with Tasmania and increasingly connecting with Adelaide and South Australia in the research ecosystem. However, this South Australian concentration differs; in 2015, collaboration was focused on Adelaide (as was 2003), but in 2019 the collaboration shifted further west towards

Port Augusta⁷, as observed in the university, industry, government, and other state/territory.

Figure 10-23: 2019 University, government, and other state/territory locations for co-authorship



Geospatial location of universities, government, and other state/territory, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Whilst *university and government* and *university, government, and other state/territory* capture government involvement in research collaborations and are seen to change, from an academic perspective, the prestige associated with these collaborations may be limited.

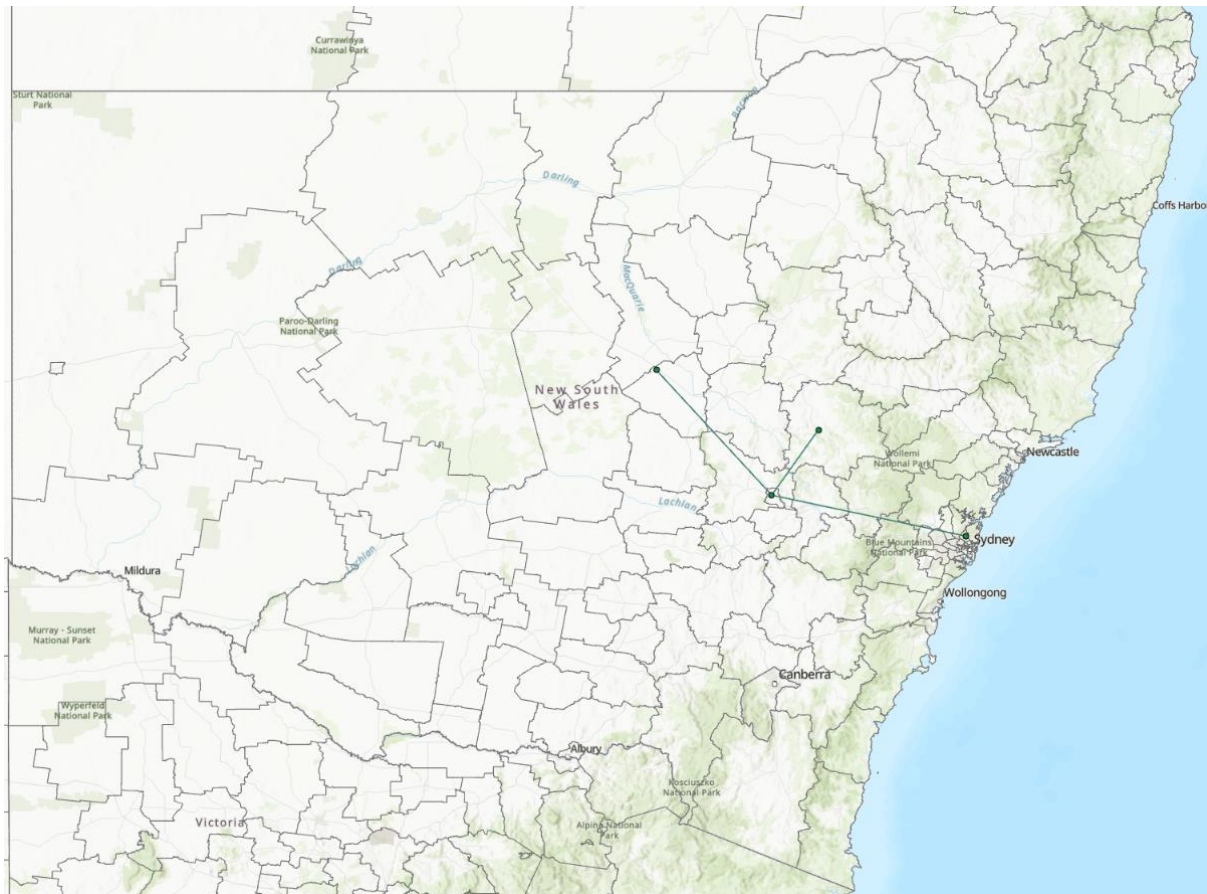
⁷ In 2014, substantial investment in controlled environment horticulture was made in the Port Augusta area. This was predicted to be operational in 2016 (<https://www.adelaidenow.com.au/news/south-australia/sundrop-farms-150mplus-20ha-port-augusta-greenhouse-complex-to-produce-hundreds-of-jobs/news-story/49bc686221d2df928850c4ef18807d4f>), which may explain some of the growth in university, government, and other state/territory collaborations at this point.

10.1.1.4 University, Industry and Government and University, Industry, Government, And Other State/Territory.

Returning to the original premise that university, industry, and government collaboration is beneficial for economic activity, both *university, industry, and government* and *university, industry, government, and other state/territory* are examined in this section. The geospatial representations are much simpler, with very small numbers in some combinations.

In 2003, the *university, industry, and government* collaboration only yielded a single publication, whilst the inclusion of *other state or territory* had none.

Figure 10-24: 2003 University, industry, and government locations for co-authorship



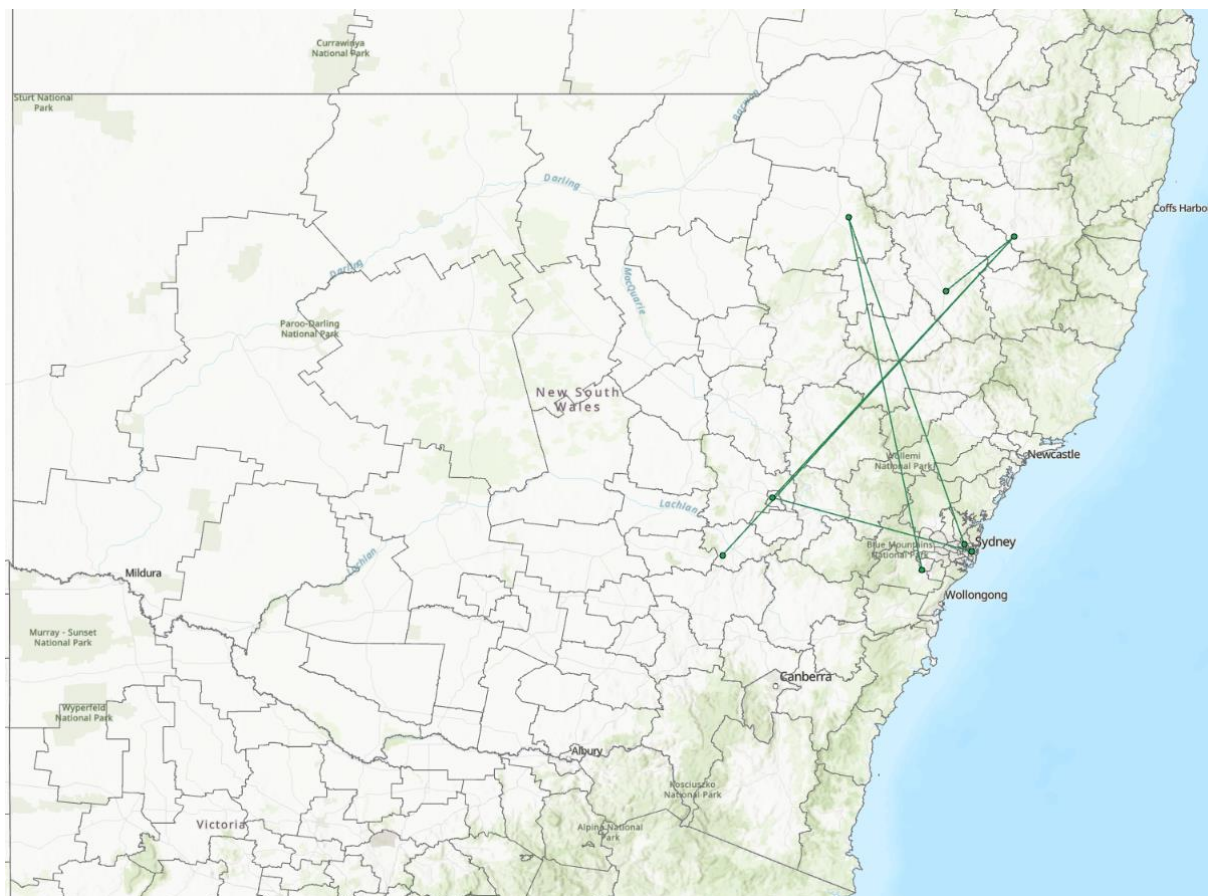
Geospatial location of universities, industry, and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

This single publication can be seen as a collaboration with four actors in Sydney, Mudgee, Orange, and Trangie, with a very distributed collaboration rather than close in proximity,

reflecting the distribution of specialist knowledge within agriculture. Orange is a common location as it houses the head of the New South Wales Department of Primary Industries.

An increase in collaborations in the university, industry, and government co-authorship can be seen in 2006; however, there is still the distributed knowledge within agriculture spread throughout New South Wales. Tamworth, Armidale, and Cowra are all connected, as are Narrabri, Camden, and Sydney – reflecting the expertise of the University of Sydney in some of the cropping activity in Narrabri.

Figure 10-25: 2006 University, industry, and government locations for co-authorship



Geospatial location of universities, industry, and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

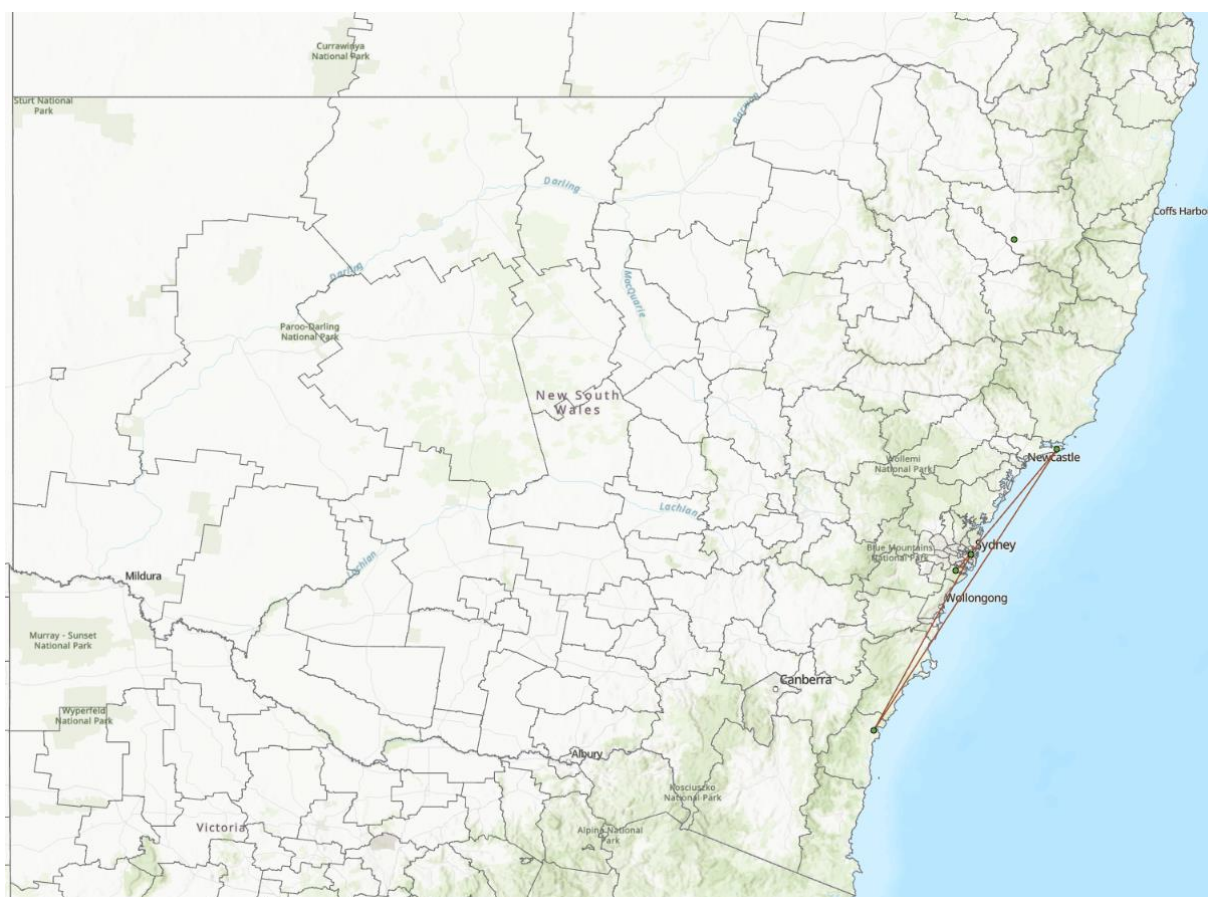
With only a few collaborations of this nature occurring each year, changes can be observed in research areas, denoted by where research is being undertaken. In contrast to 2006, the 2015 university, industry, and government collaboration can be seen to involve the fisheries

industry, with Nelson Bay and Batemans Bay involved in the research collaboration.

Furthermore, the complete concentration of all three actors can be seen in Armidale, where no external links exist to the organisations involved.

Unlike other combinations, *university, industry, and government* remained steady each year; increases in the collaboration identified in the T-values can be attributed to the quadruple helix combinations that include these three actors, as exemplified by the small number of collaborations in 2015.

Figure 10-26: 2015 University, industry, and government locations for co-authorship



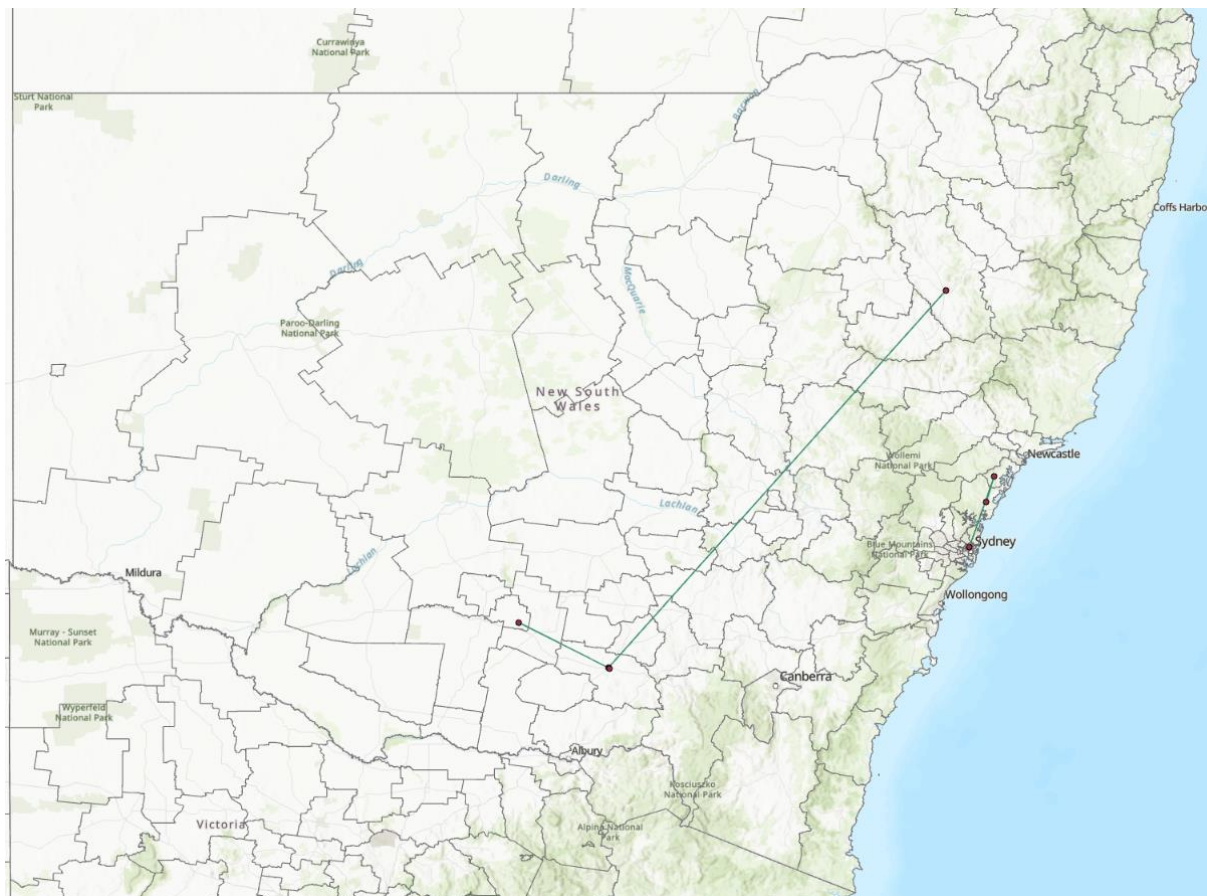
Geospatial location of universities, industry, and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

The year 2015 reflects the low point in many collaboration T-values that involve universities and industry, and this remains true for the *university, industry, and government* collaboration as well. Increasing collaboration after 2015, this small shift can be seen in the mapped

collaborations in 2018. However, it must be remembered that these foundational elements appear in subsequent combinations rather than the absolute values – which remain very low.

There was also a network of collaboration from Tamworth to Wagga Wagga and on to Trangie, as well as a coastal connection between locations on the Central Coast (Ourimbah and Cooranbong) and Sydney.

Figure 10-27: 2018 University, industry, and government locations for co-authorship

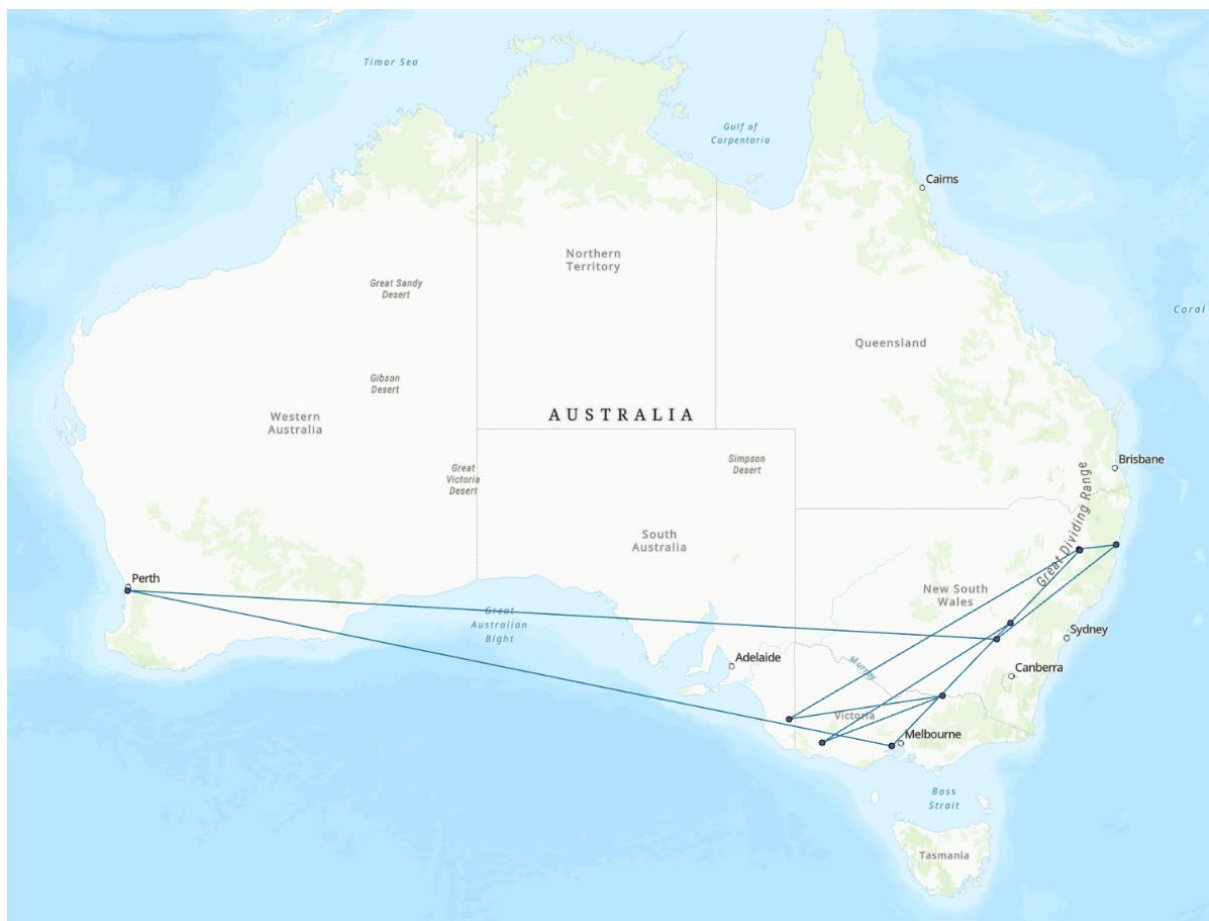


Geospatial location of universities, industry, and government, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

These are components of the larger collaborations and are part of the smaller magnitude group within the university collaboration. In contrast, when other states or territories are introduced, the collaboration changes, not only with the interstate actors but also within New South Wales.

With this change, the nature of collaboration within the state changes significantly. The regional universities no longer seek partners in Sydney or Newcastle; rather, the partners are found further afield. The transfer of knowledge is most likely to similar regions, so there is limited collaboration in Far North Queensland or the Northern Territory. For example, in 2005, the university, industry, government, and other state/territory collaborations involved Coffs Harbour, Armidale and Orange – all potentially university locations in the collaborations, but have no involvement of the major cities of New South Wales.

Figure 10-28: 2005 University, industry, government, and other state/territory locations for co-authorship

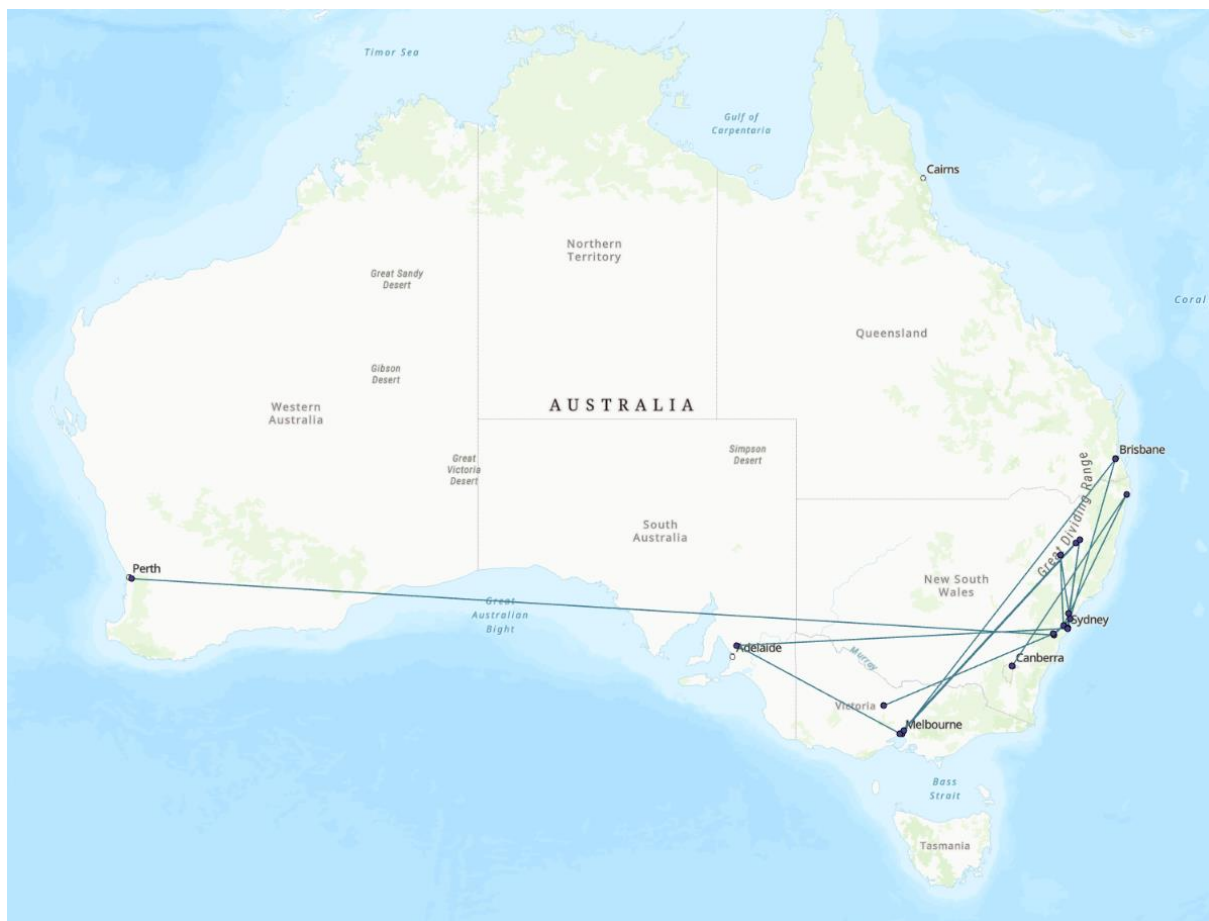


Geospatial location of universities, industry, government, and other state/territory, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Whilst this change in the collaboration showcases changes taking place when other state/territory is involved, the numbers are still very low (a total of 3).

Structural changes occur in the research priorities, and there are subsequent changes in the collaborations. In 2017, there were four publications, which can be seen in the much more complex network of collaboration. Notably, 2017 is after the increase in collaboration in the T-values from the triple helix. Furthermore, the collaborations encompass Brisbane and Adelaide instead of Perth. Within New South Wales, Lismore is involved in the combinations, but (unlike in *university, industry, and government*) there is no connection from Lismore to Queensland; rather, the connection is to Canberra and Sydney.

Figure 10-29: 2017 University, industry, government, and other state/territory locations for co-authorship



Geospatial location of universities, industry, government, and other state/territory, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Whilst the pattern of collaboration within Australia changed, reflecting the recognition of exchangeable knowledge, the international exchange performed differently over the same

time. Having examined combinations that include domestic collaboration, moving to the international landscape is the next step.

10.1.1.5 International Collaborations

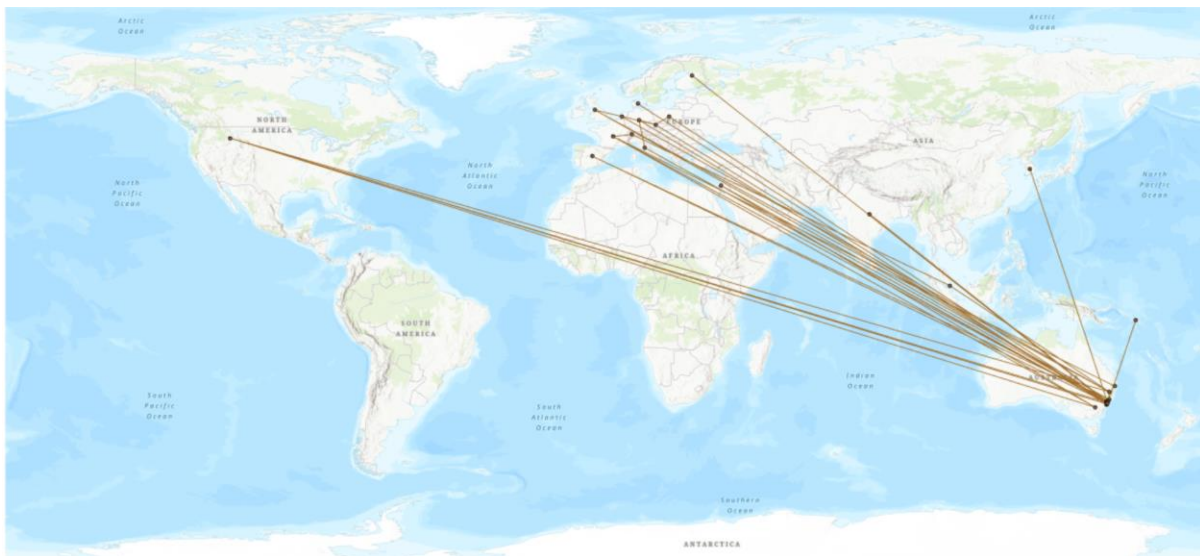
The use of international publications, driven partly by the productivity challenges faced in global agricultural production (an industry that every country has), leads to an expanding collaborative network. A shift to more global issues also results in a more transferable research outcome that increases the prestige for the authors. A change in the areas of collaboration reflects not only changes in the measurement metrics of performance but also a change in government policies (both domestic and international) with the increase in collaboration.

When considering the range of author locations, the connection with anglophone countries is clear, as well as those of Southeast Asia, where a foreign aid program is in place. Very clear changes were visible in where collaborations took place between 2003 and 2019. Whilst 2003 exhibited Euro-centric dominance, there were limited collaborations with Asia (South Korea, India, Singapore, and the Solomon Islands) and none with Africa or South America.

However, it must be noted that there is no distinction between university, industry, or government in these foreign collaborations (without looking at the original data).

These collaborations continue through many subsequent years, but with additional collaborations over time, reflecting the changes in the research goals and demand for the knowledge of Australia.

Figure 10-30: University and foreign collaboration in 2003

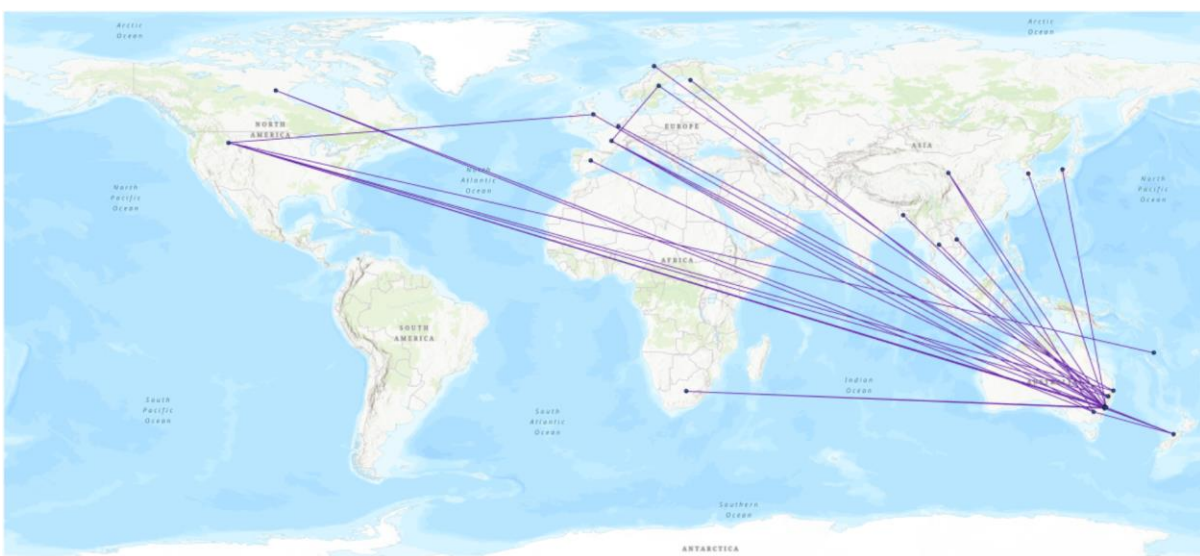


Geospatial location of universities and foreign countries, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Whilst the first year of the period showed limited collaboration within Southeast Asia, the subsequent years demonstrated increasing networks between international and New South Wales researchers.

In 2005, the university and overseas collaborations increased their connections outside Europe, particularly in Asia.

Figure 10-31: University and foreign collaboration in 2005



Geospatial location of universities and foreign countries, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

As this network expanded, the concentration of the connections into Europe decreased, but there were increases in connections into Japan, Bangladesh, Thailand, Vietnam⁸, and South Africa. This initial entry into Africa is reflected in the continued connections into sub-Saharan Africa (anglophone countries) in 2012 and increases in Southeast Asia, including Bhutan, Indonesia, the Philippines, and Sri Lanka.

Figure 10-32: University and foreign collaboration in 2012



Geospatial location of universities and foreign countries, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

These connections also start to enter South America (Brazil and Argentina) as well as additional connections into the Middle East (Iran, Israel, and Jordan).

The T-values showed an increase in collaboration after 2016, which can also be seen in the map for collaboration. As is generally the case concerning a T-value and then the map, the difference is that the *university* and *foreign* in the map represents the combination that only matches this. In contrast, the T-value captures subsequent combinations where this pair exists.

⁸ As the geocoding has been applied to the centre of the country, links to Vietnam appear in Laos. Data confirms no connections to Laos in 2012 or 2016. In 2019 there was connections with both Laos and Vietnam.

With an even wider network of collaboration than in 2012, which was a low point in the T-values, connections now exist with more South American countries and more extensive with countries close to Australia. Furthermore, changes occurred in collaboration with the Middle East, but there was a substantial increase in collaboration with the sub-Saharan African anglophone countries (Kenya, South Africa, and Tanzania).

Figure 10-33: University and foreign collaboration in 2016



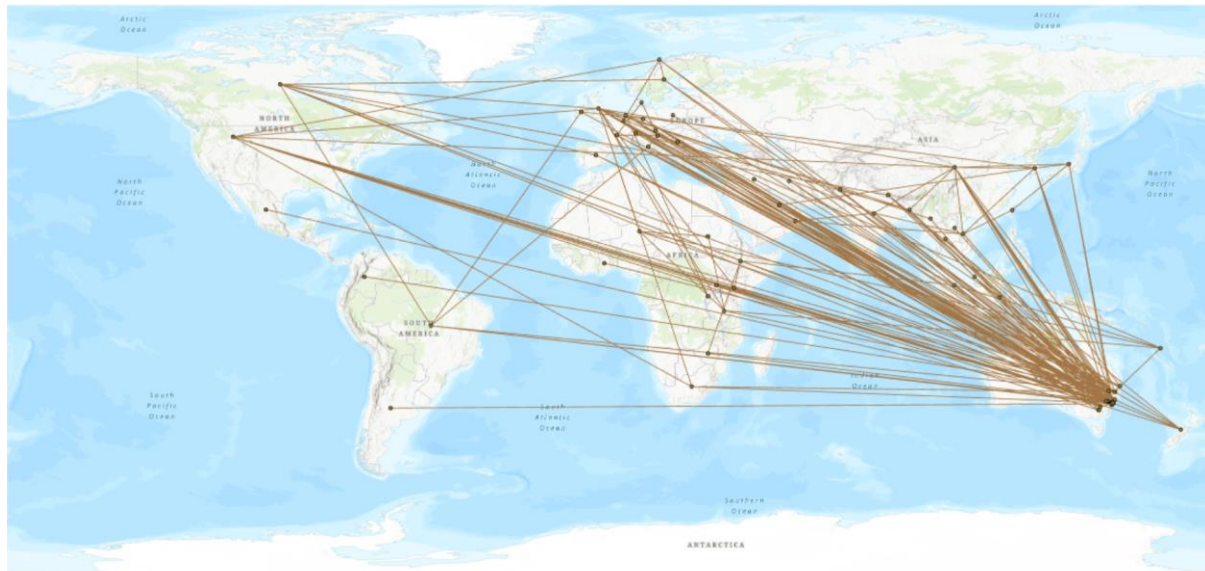
Geospatial location of universities and foreign countries, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Of interest are the increasing connections within Southeast Asia. Previously, the connections terminated in Southeast Asia, but in 2016, the countries started to cooperate. Examples include Taiwan and Vietnam, Taiwan, and Singapore, whilst South Korea collaborated with China. These continental connections can also be seen within South America, with Venezuela and Ecuador, and Chile and Argentina connected.

In 2019, the Middle East (Iraq, Iran, Oman, Qatar) returned, and activity in sub-Saharan Africa increased. Continued activity in Asia included Nepal, India, Pakistan, and Bangladesh, whilst in Southeast Asia, Myanmar, Vietnam, Laos, Vietnam, Thailand, and Indonesia all demonstrated increased activity.

Contrasting previous years, 2019 includes connections between Japan and Southeast Asia. In previous years, the connection was only with Australia. In addition, South Korea was also more connected.

Figure 10-34: University and foreign collaboration in 2019



Geospatial location of universities and foreign countries, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

10.1.2 Government

Historically government had a key role in agricultural research and innovation as either the funder (not captured in this sample) or as a connector of research organisations. Furthermore, government can act where there are no other research organisations and enable the development of relevant research outcomes.

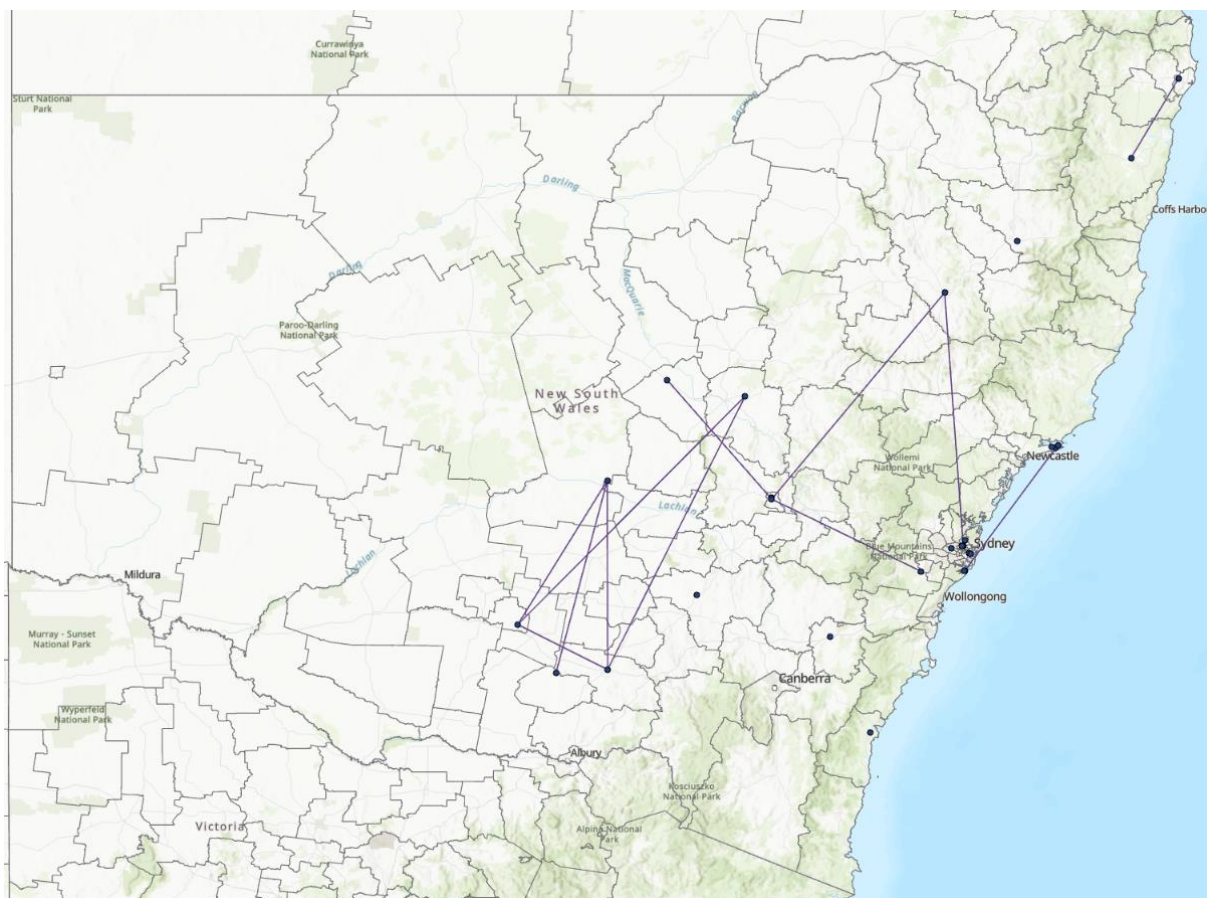
Whilst government can be found to work with other organisations, the different levels also work collaboratively. In this study, all government organisations were treated the same, with no distinction between the different levels – such as federal (CSIRO) and state (NSW Department of Primary Industries) – and therefore, the collaboration of these activities is lessened in the T-values, but visible in the geospatial data.

10.1.2.1 Government Only

As mentioned above, this captures all levels of government in a single measurement; however, the geospatial data allows regional data to be visualised and the collaboration networks to be shown.

In 2003, collaborations were often local or with similar agricultural environments (e.g., the connection between Port Stephens and Cronulla – both New South Wales Fisheries locations). However, whilst many connections are wide and open, there are also pockets of very localised collaboration (e.g., Bateman’s Bay on the South Coast and Armidale on the Northern Tablelands). Totalling 58 publications, the volume is not great, but it was the highest in the sampled period.

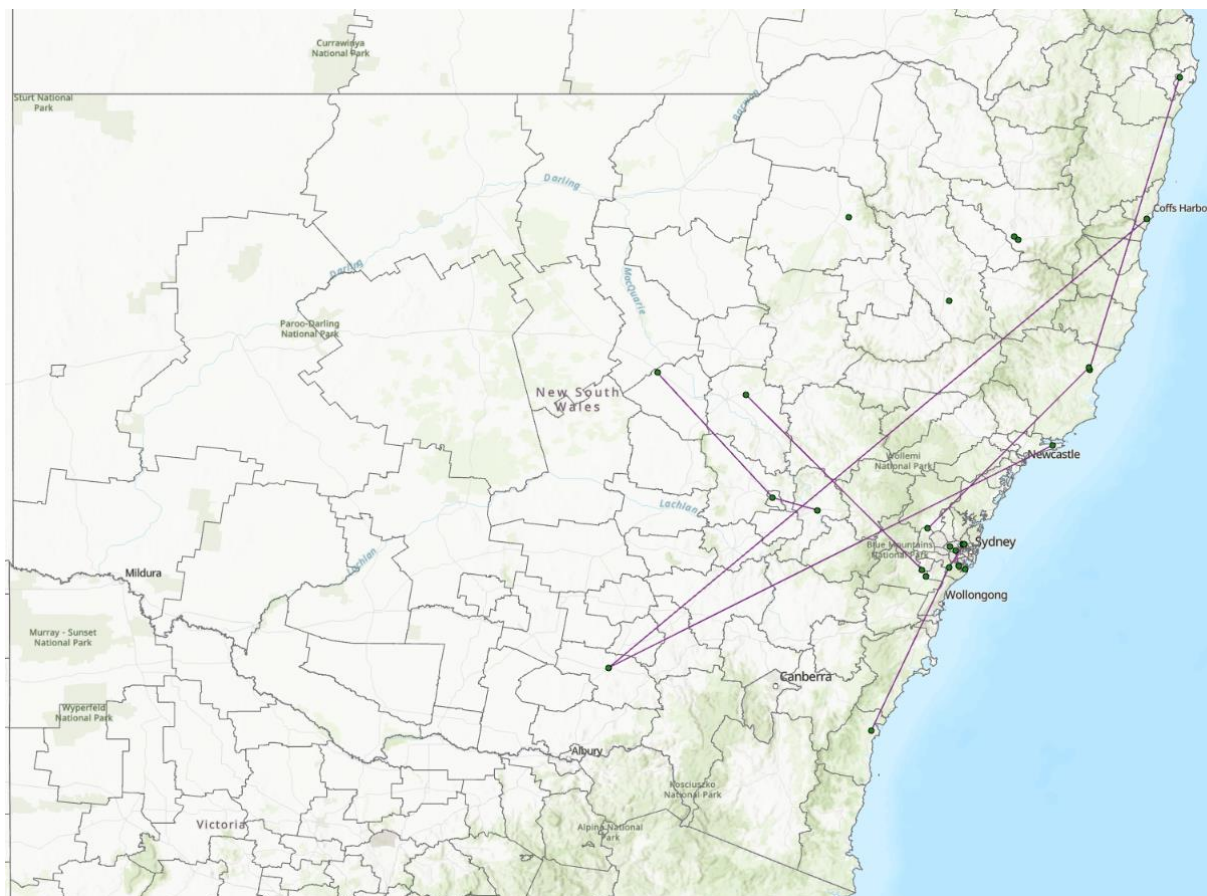
Figure 10-35: Government collaboration in 2003



Geospatial location of government organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Whilst these collaborations were often localised, by 2010, the collaborations were much more open and widespread, although less frequent – only 28 publications. The collaborations ranged across the state, and there was an increased concentration of activity in Sydney. The concentration in Sydney could be explained as CRCs classified as government authors; therefore, if the CRC address was listed as Sydney, they would appear there in this case. Connections began to appear where there were none previously and vice versa. Tamworth was no longer collaborating on a wider scale, but a new appearance from Narrabri represents the emergence of research stations in areas where they were previously not present.

Figure 10-36: Government collaboration in 2010



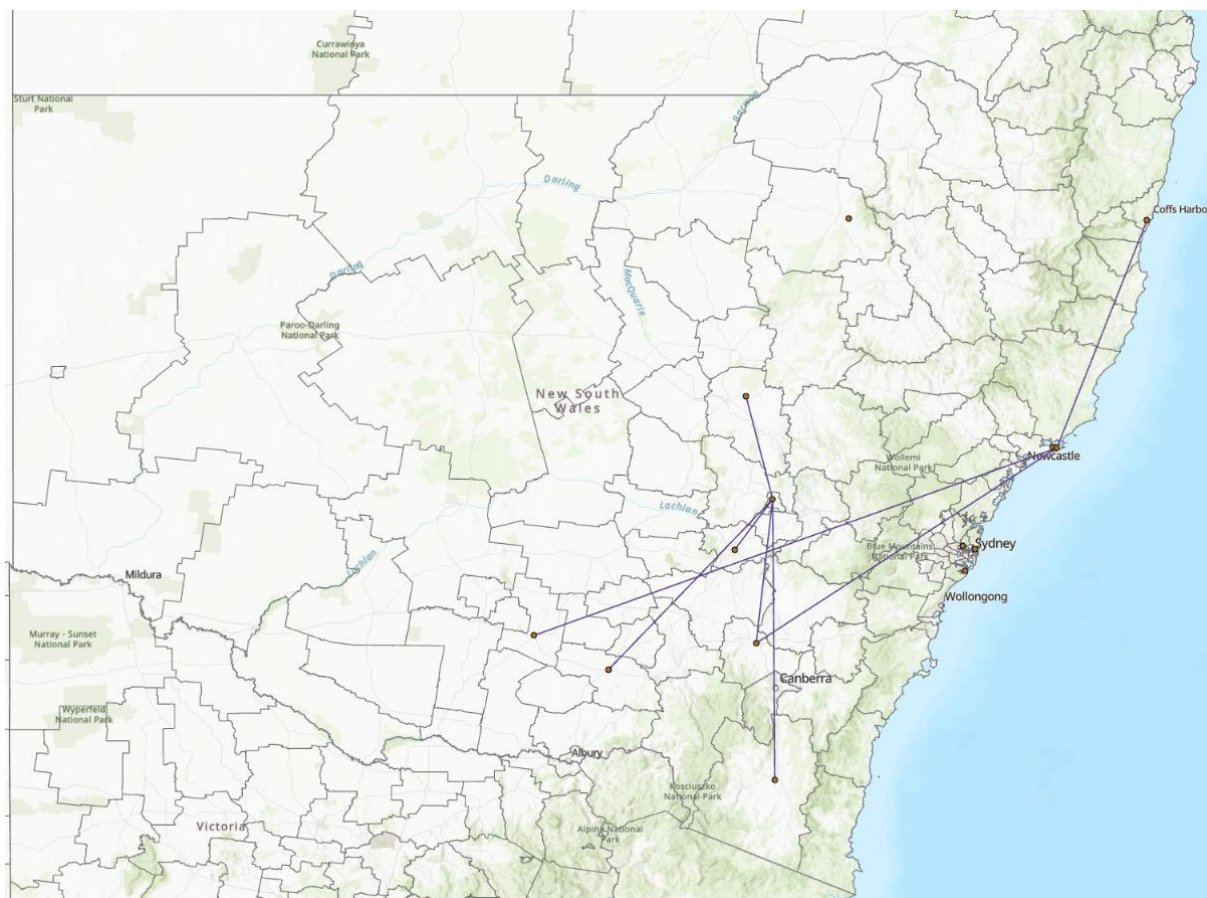
Geospatial location of government organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

The decline seen in 2010 continued in 2013 (14 publications). While government agencies may not be involved in fundamental research at an organisational level (they may act

collaboratively to achieve these goals), they focus on applying the new fundamental knowledge.

With this decline in publication, the networks widened and covered more of the state, frequently connecting to Orange. Whilst many connections focus on Orange, there are still independent research activities taking place within Sydney and Narrabri, as well as strong connections from Port Stephens (north of Newcastle).

Figure 10-37: Government collaboration in 2013



Geospatial location of government organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

The decline in publication numbers started to plateau after 2013, with a slower rate of decrease in subsequent years (even an increase in one year). In 2015, 10 publications were produced. This low number was concentrated in four locations: Orange, Wagga Wagga,

Sydney, and Wollongong. Orange worked locally with Cowra, but otherwise, there was very little reach into a wider area.

Figure 10-38: Government collaboration in 2015

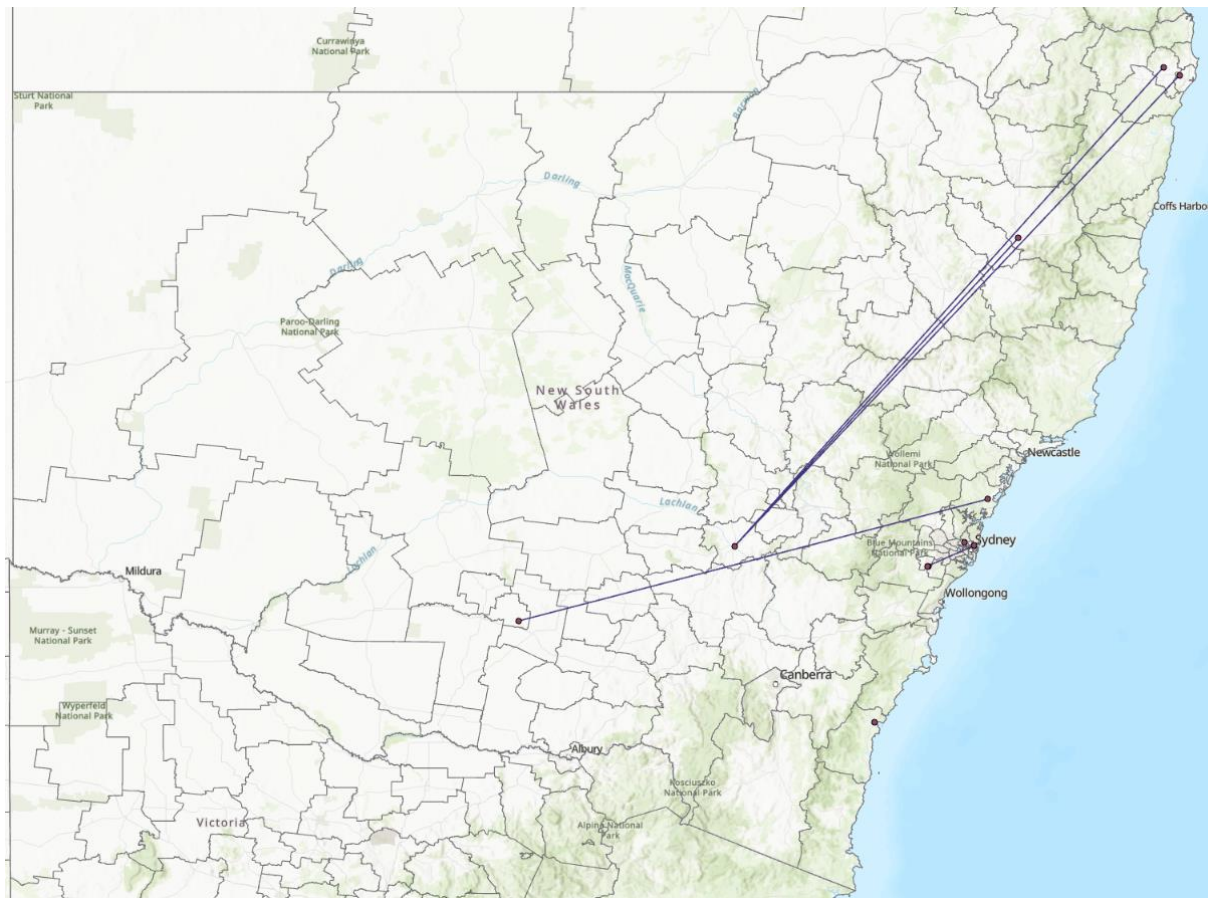


Geospatial location of government organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Whilst 2015 represents a low point, in the final year of the sample (2019), government was author for 10 papers. Still concentrated on Orange, the collaborations were equally distant and spread across the state.

When contrasted with the range of collaborations between the university sector and government in the same year, the change can be seen in research activity preferences (or expectations). Clearly identifiable in Figure 10-19, this shift demonstrates the changing research practices of both university and government actors.

Figure 10-39: Government collaboration in 2019



Geospatial location of government organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Culminating in a large decrease (from 58 to a low of 10), the change in government authorship may be accounted for by the addition of partners from *university* (as examined above) or from *other state or territory* (to be examined), as well as overseas or industry.

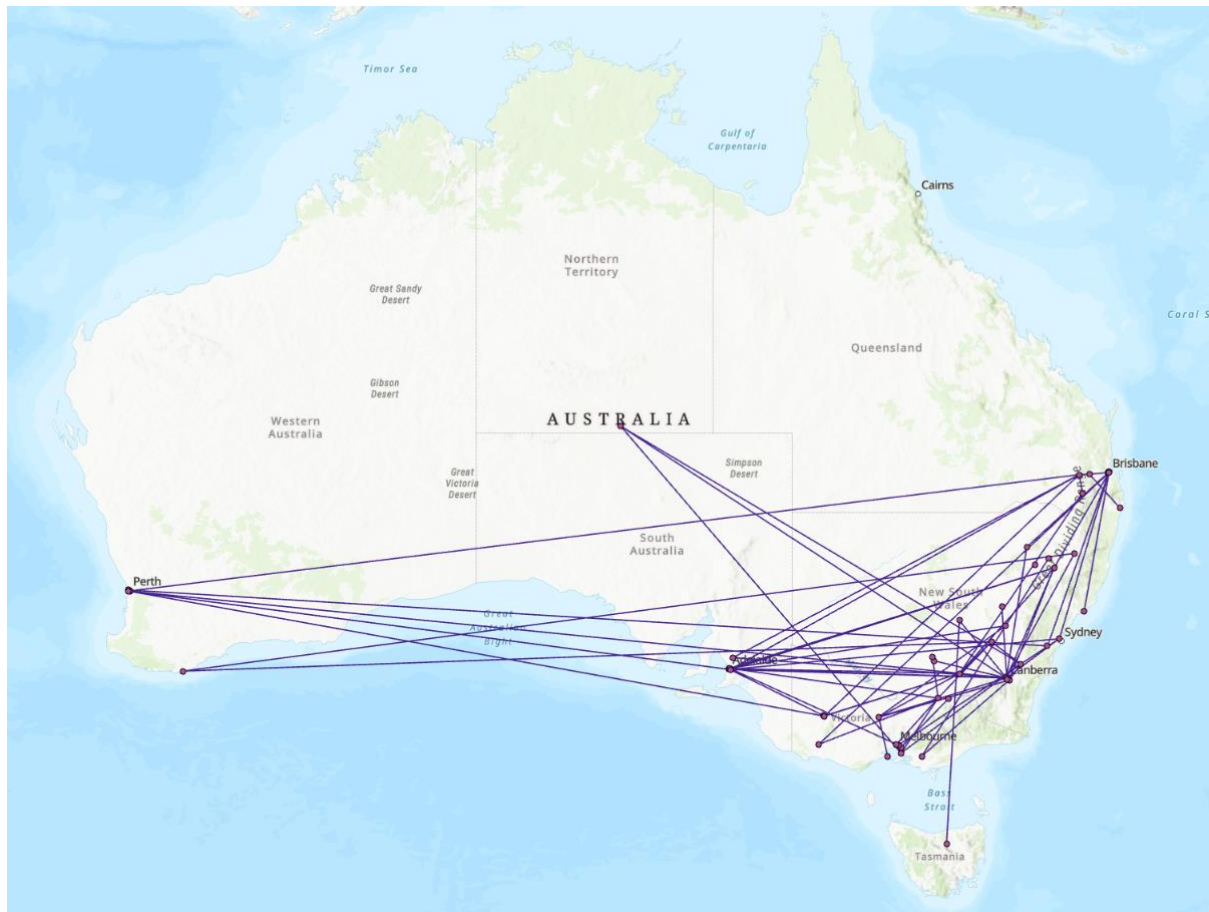
10.1.2.2 Government and Other State/Territory

The adoption of collaboration with universities in New South Wales is clear, but the option of collaboration with interstate universities is captured within the *other state/territory* classification, along with *industry* or *government* agencies located within those states.

Reflecting an increasing collaboration in the T-values of the triple helix, the *government and other state/territory* combination also exhibited an increase in absolute numbers from 32 to 57 before falling to 26.

Starting at 32 publications in 2003, the *government and other state/territory* combination is much more active than just the *government* author. As with other combinations that include other state/territories, limited collaborations exist north of Brisbane, whilst the concentration in Victoria and South Australia reflects similar agricultural conditions and activity.

Figure 10-40: Government collaboration with other state/territories in 2003



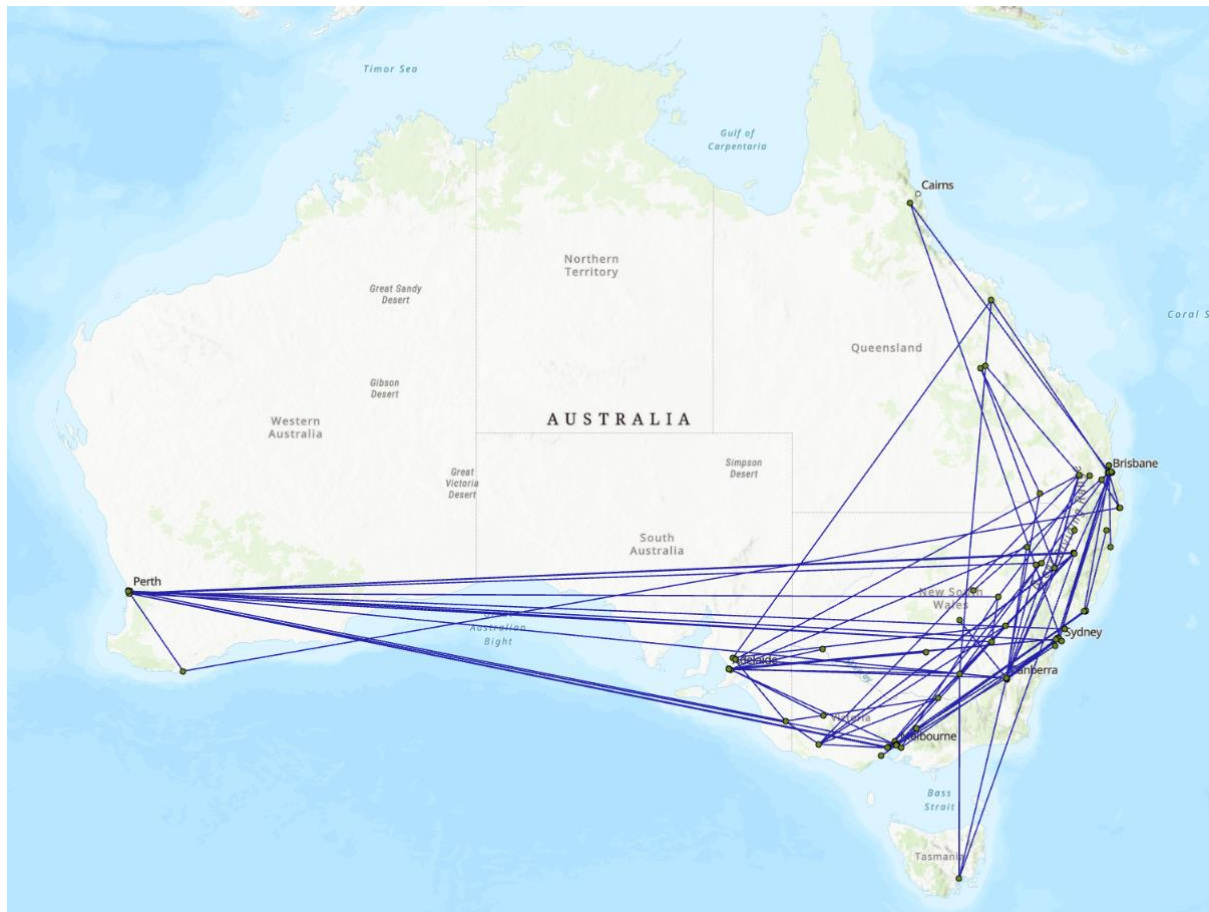
Geospatial location of government organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.⁹

Where multiple connected locations within New South Wales exist, many did not exist in the internal government connections within New South Wales; instead, these connections required the catalyst of an external actor to create the connections.

⁹ The location of points in the centre of Australia represents erroneous geolocations that defaulted to Australia.

This trend continued in 2007 (the peak year, with 57 publications). However, in contrast to 2003, there are connections into northern and central Queensland and more complex relationships with Western Australia. In addition, multiple connections with Tasmania are visible.

Figure 10-41: Government collaboration with other state/territories in 2007

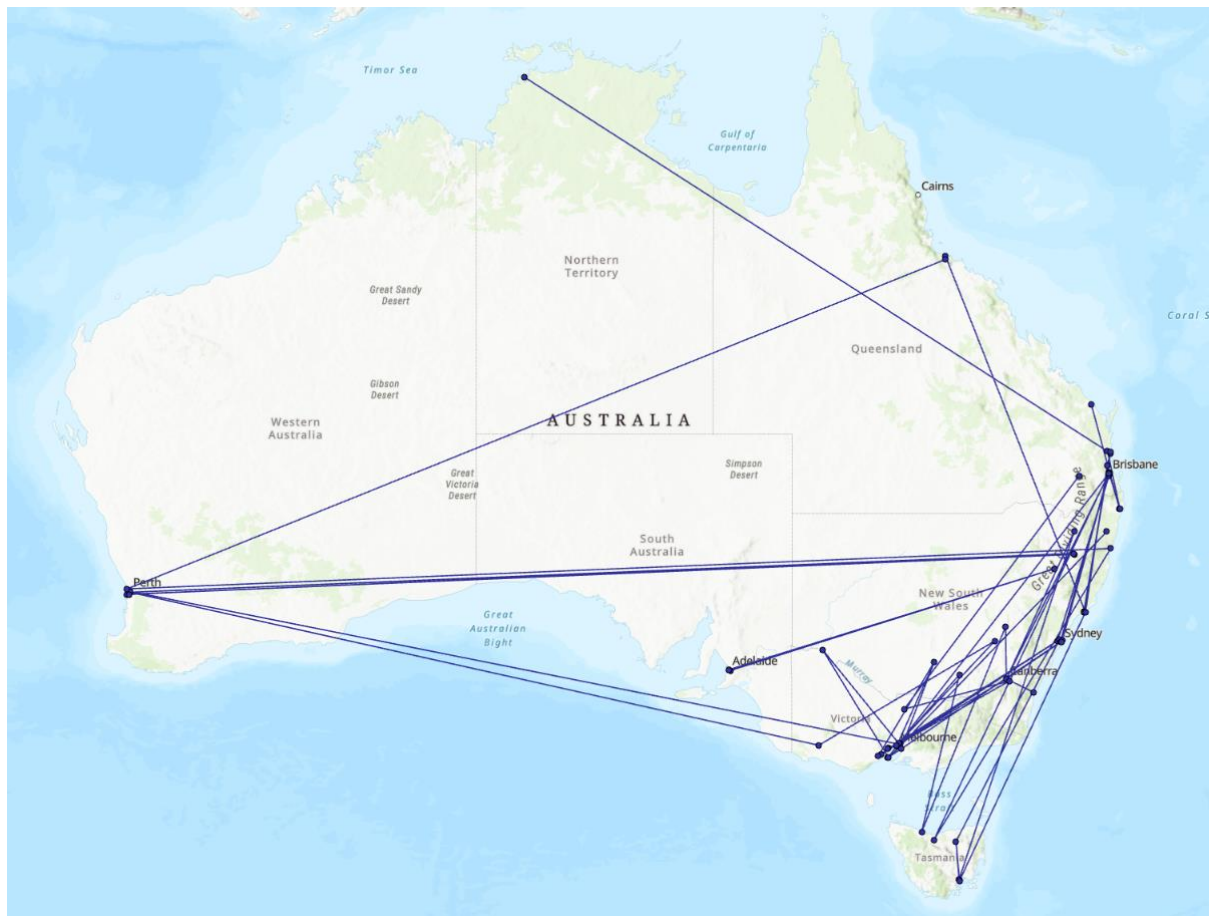


Geospatial location of government organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

This increasingly complex relationship (in terms of co-authorship and interconnectedness of authorship) captures the collaboration between multiple actors external to New South Wales, as well as the actors within New South Wales.

The final year, 2019, has the lowest number of publications but has some of the widest collaboration coverage.

Figure 10-42: Government collaboration with other state/territories in 2010



Geospatial location of government organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

In contrast to other combinations, there is a decrease in collaborations in South Australia, with no concentration around Port Augusta that was observable in the *university and other state/territory* data. However, one of the few connections to the Northern Territory is visible in this data. In addition, the connection between the Lismore area and Queensland is again apparent. Furthermore, there is an increase in locations within Tasmania.

Government and other state/territory suggests that a decrease in publications may result in an increase in collaborators, potentially reflecting an increased complexity of not only the research collaboration but also the complexity/quality of the research, which requires a lower publication rate.

10.1.3 Industry

Ending this analysis, the final grouping is that of industry collaboration. With very low numbers of industry-only activities, the analysis focuses on *government and industry* and *industry and other state/territory*, as *university and industry* has been addressed previously.

10.1.3.1 Government and Industry

Whilst there is an increased collaboration of the industry and government pair measured in the T-value results of the triple helix, the absolute numbers of publications remain small, with a maximum of four and a minimum of one publication.

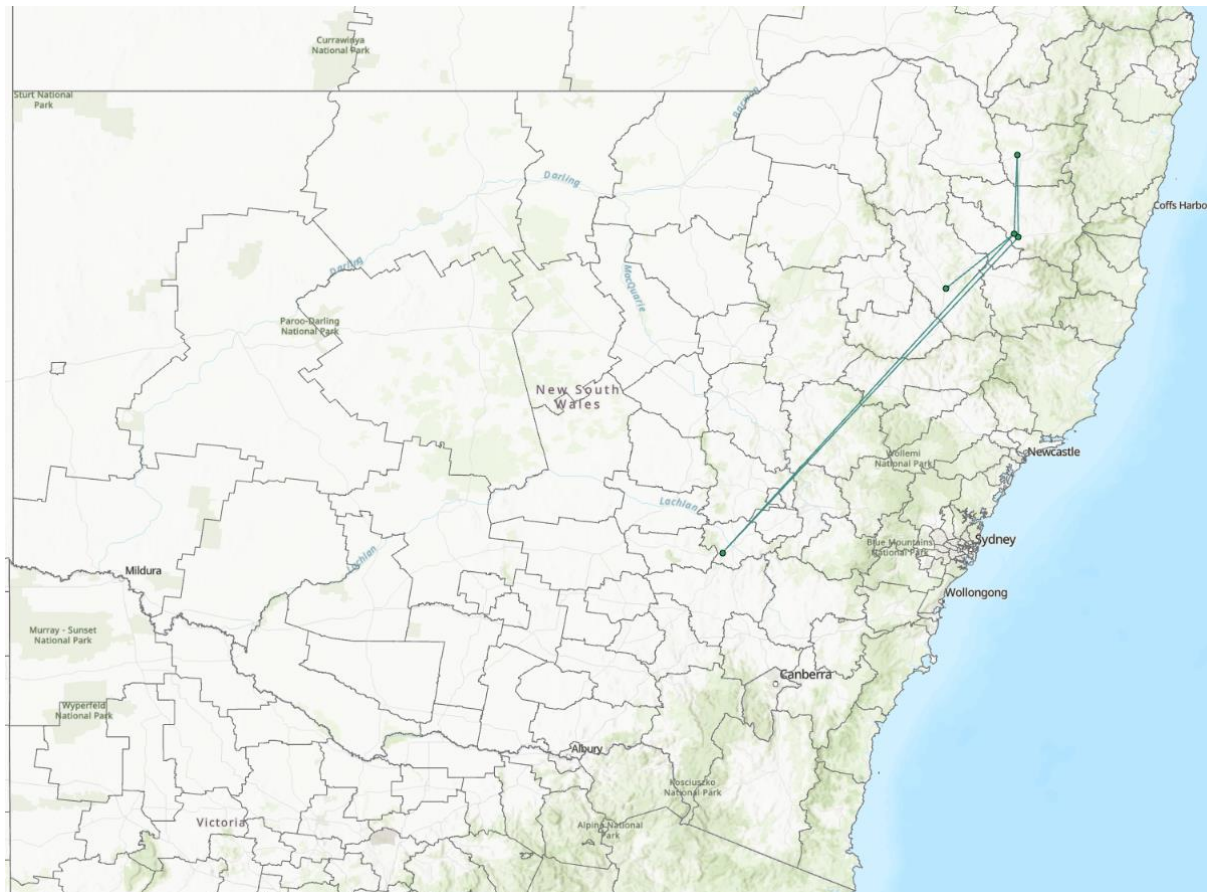
Figure 10-43: Government collaboration with industry in 2003



Geospatial location of government and industry organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

As can be seen, in 2003, the limited activity was concentrated in the Newcastle to Sydney area; in contrast, in 2006, the collaborations moved west and north, working with Orange, Armidale, Tamworth, and Tenterfield.

Figure 10-44: Government collaboration with industry in 2006

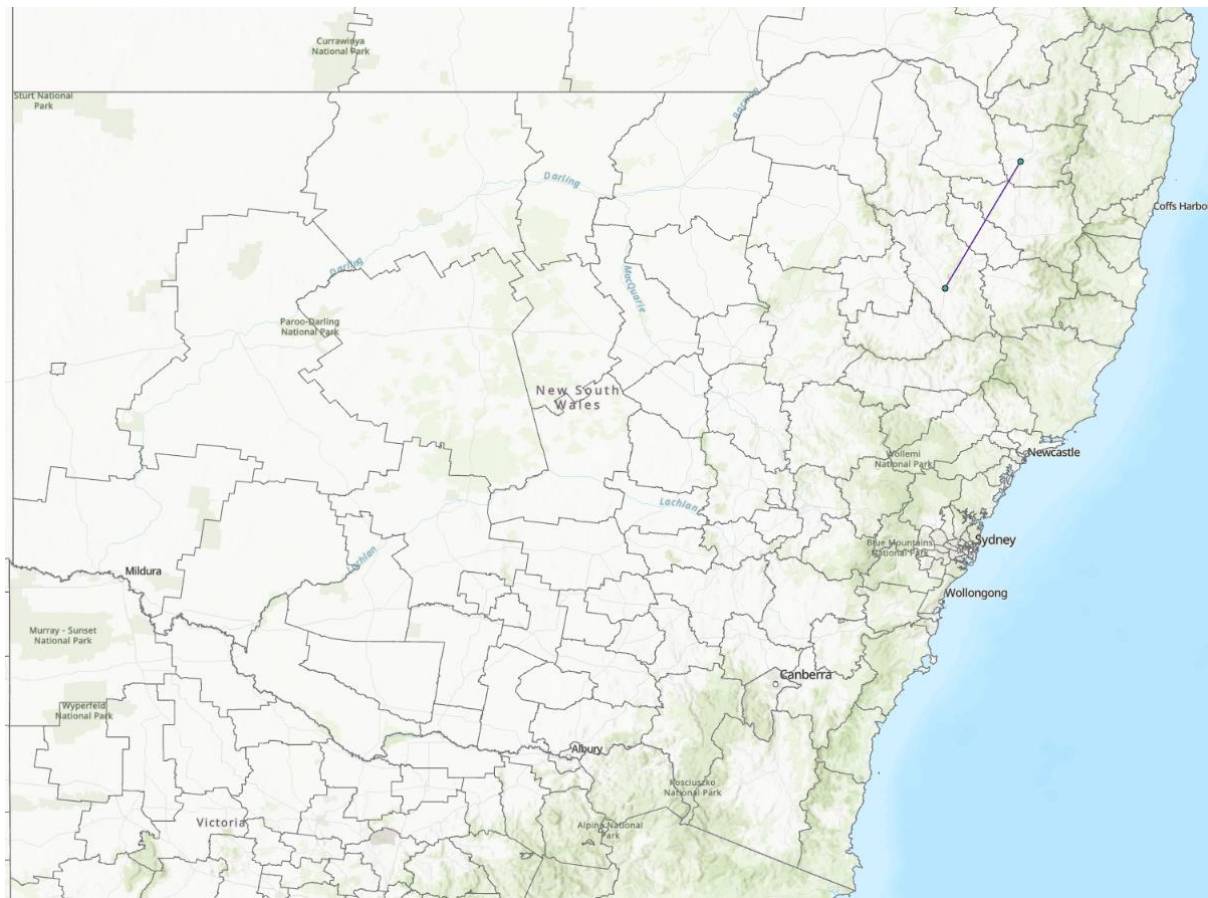


Geospatial location of government and industry organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

This has the potential to demonstrate the applied nature of government research, where industry drives the adoption of new technologies and research outcomes, or present the issues that drive the development of these new technologies and research questions.

By the end of the sample period, contrasting the trends seen elsewhere in the data, the collaborations were much simpler and localised, with only one combination identified between Armidale and Tamworth. Reflecting a more localised problem and collaboration, this combination is one of the simplest observed.

Figure 10-45: Government collaboration with industry in 2019



Geospatial location of government and industry organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

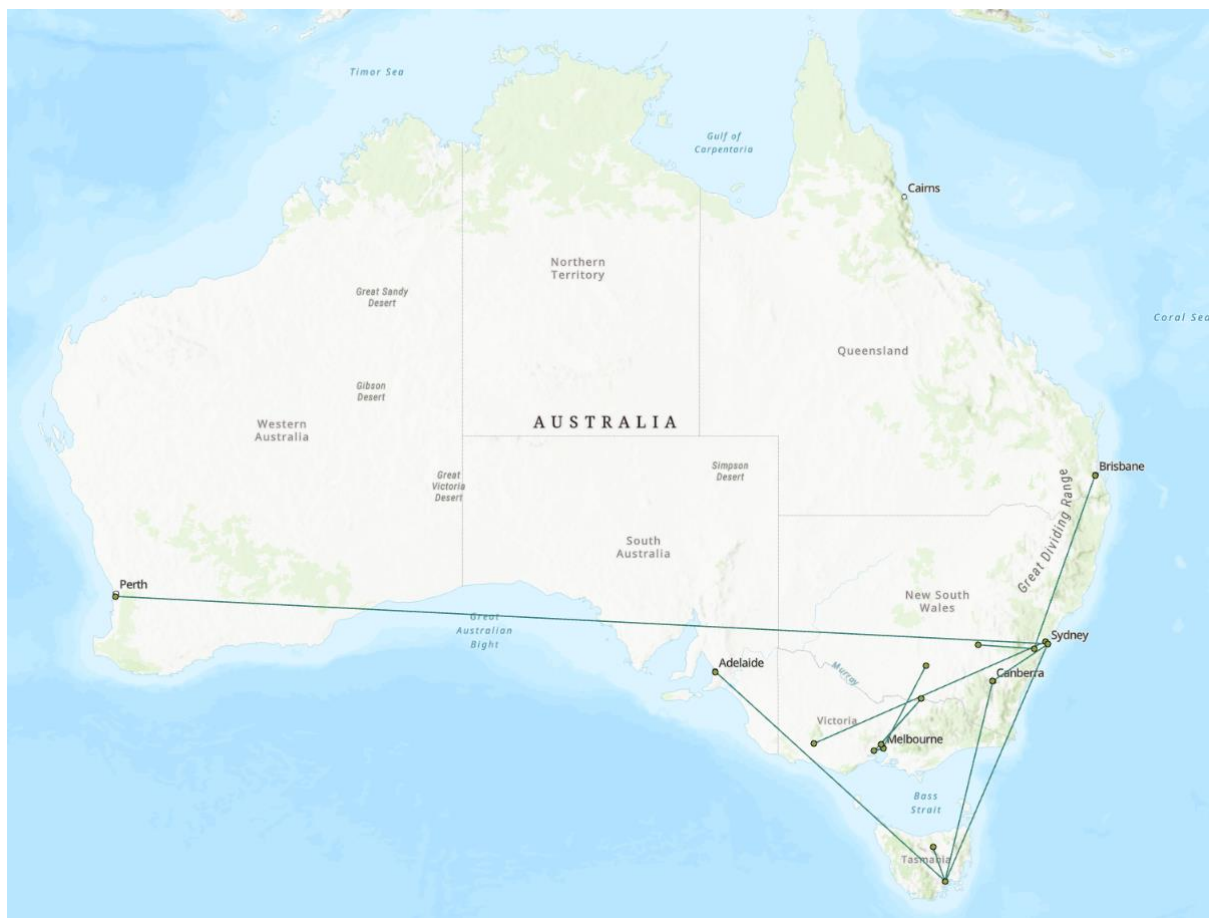
10.1.3.2 Industry and Other State/Territory

Contrasting the spread of the *industry and government* combination, or that of *industry and university*, the *industry and other state/territory* combination increased substantially, from 4 to 19 over the sample period.

With 2003 and 2004 exhibiting the same location in the centre of Australia due to geocoding, 2005 is the first year to be examined. This collaboration produced eight publications.

With a range of connections, but often only a small number of collaborators, the *industry and other state/territory* combination exhibits a city-centric perspective, with most collaborations engaging with a major city in both New South Wales and the other state/territory.

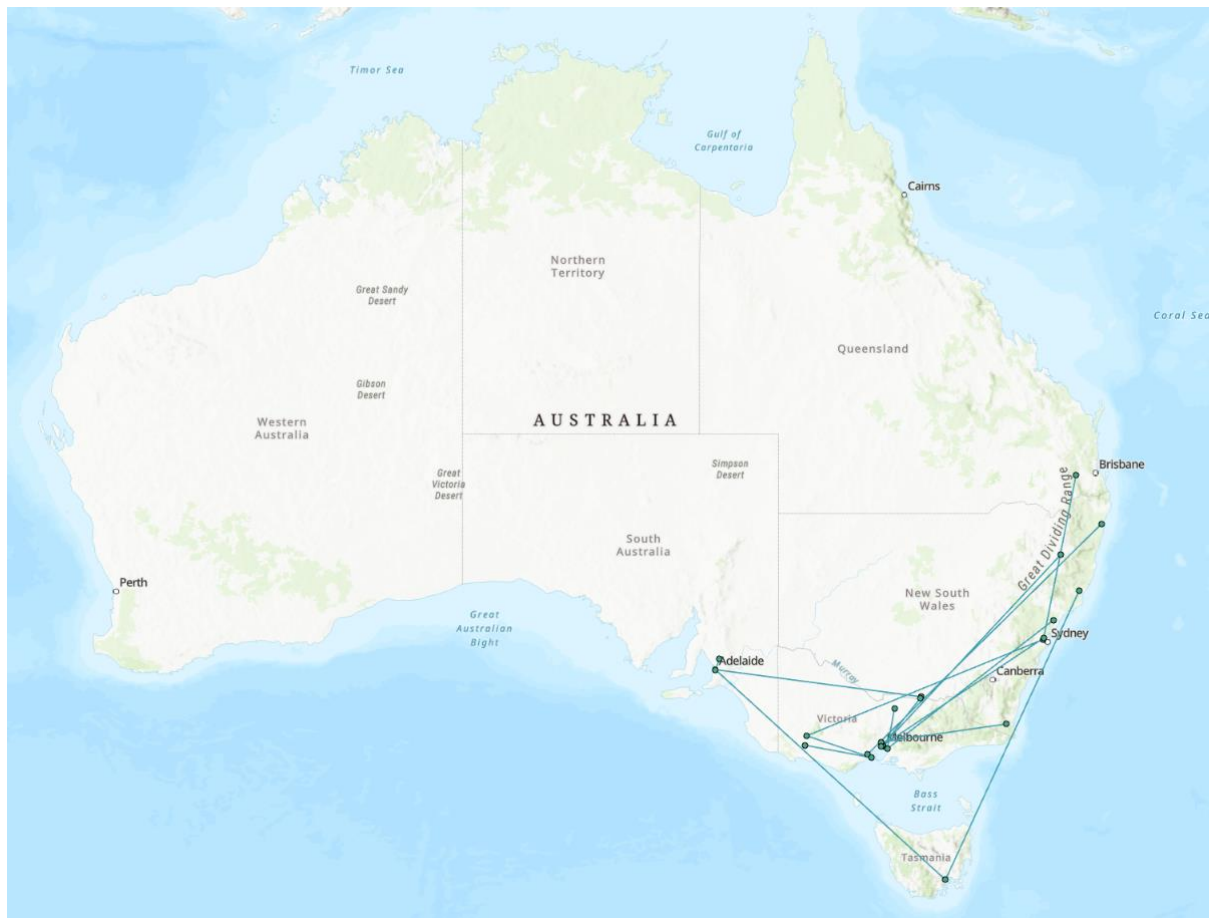
Figure 10-46: Industry collaboration with other state/territories in 2005



Geospatial location of industry and other state/territory organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

By 2010, publications reached 10 per year and remained at this rate for some years. However, they were more locally concentrated, with the collaborations predominantly occurring in the southeastern states (or, in the case of Queensland, the southeast of the state). Furthermore, the collaborations captured activity in an increasing number of regional areas; Armidale and Lismore are both visible in New South Wales, whilst an increasing number in Victoria (Shepperton and the Hamilton area) can also be seen.

Figure 10-47: Industry collaboration with other state/territories in 2010



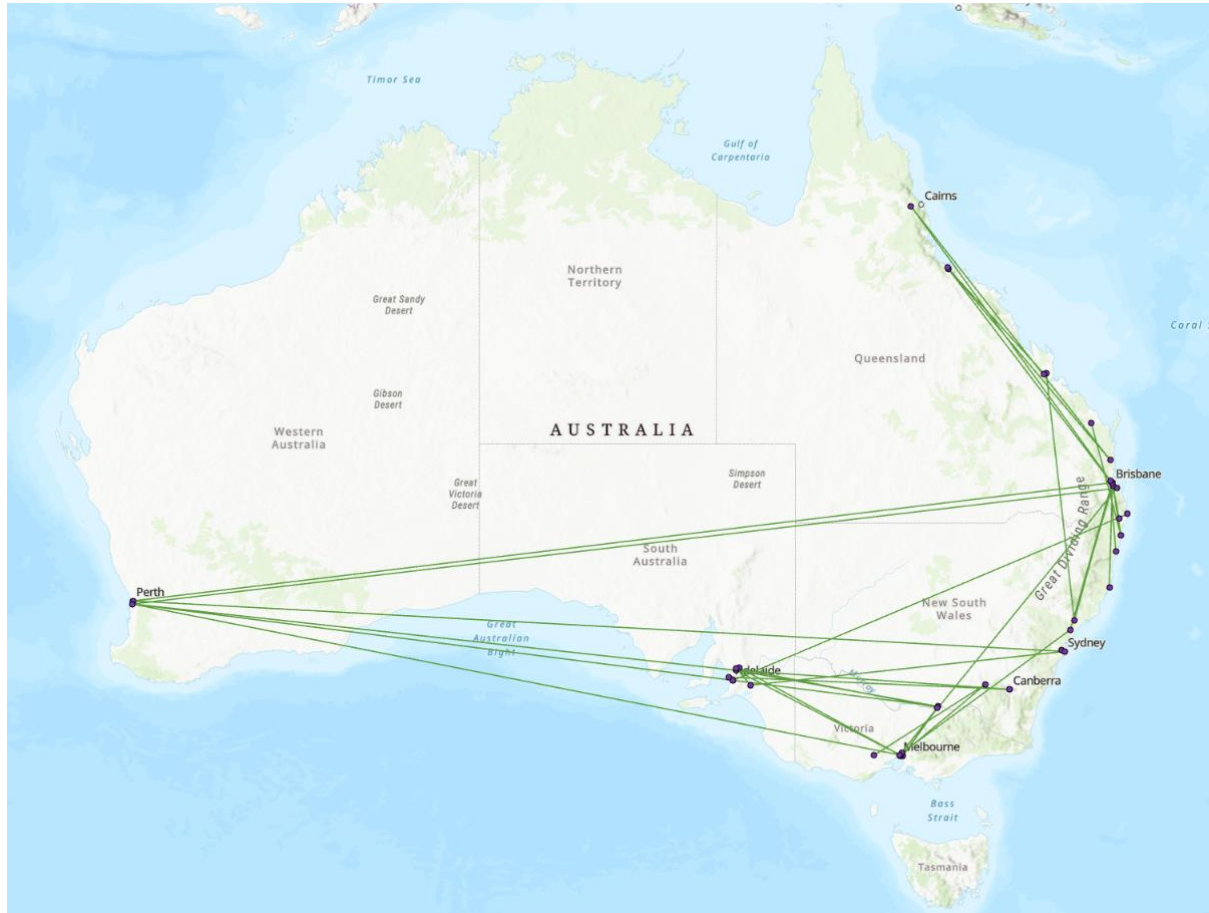
Geospatial location of industry and other state/territory organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Finally, the highest number was seen in 2019, when there were much more complex connections across Australia. However, whilst these connections were more widespread, the concentration was particularly city-centric in Victoria, South Australia, and Western Australia, with Queensland and New South Wales concentrated on the coastal fringes. This shift in location may reflect the changes in the research objectives between industry and other state/territory, with a shift from broadacre or livestock to more coastal activities – as evidenced by the inclusion of Coffs Harbour, Port Macquarie, and other coastal locations.

Whilst the focus is along the coast, particularly with the Queensland collaborators, the connections are increasingly complex with multiple collaborators. There is an increasingly

complex series of connections north of Port Macquarie along the coast. In contrast, Sydney had simpler northward connections, directly to Brisbane or Rockhampton.

Figure 10-48: Industry collaboration with other state/territories in 2019



Geospatial location of industry and other state/territory organisations, based on extracted addresses from Web of Science, geocoded and visualised in ArcGIS.

Finally, the increasing role of Adelaide in the agricultural landscape can be seen with the concentration of connections in the Adelaide and surrounding area.

10.2 Number of Affiliations per Local Government Area

A different metric that can be applied is the number of affiliations per LGA. This captures both the number of organisations and the number of publications per LGA on an annual basis.

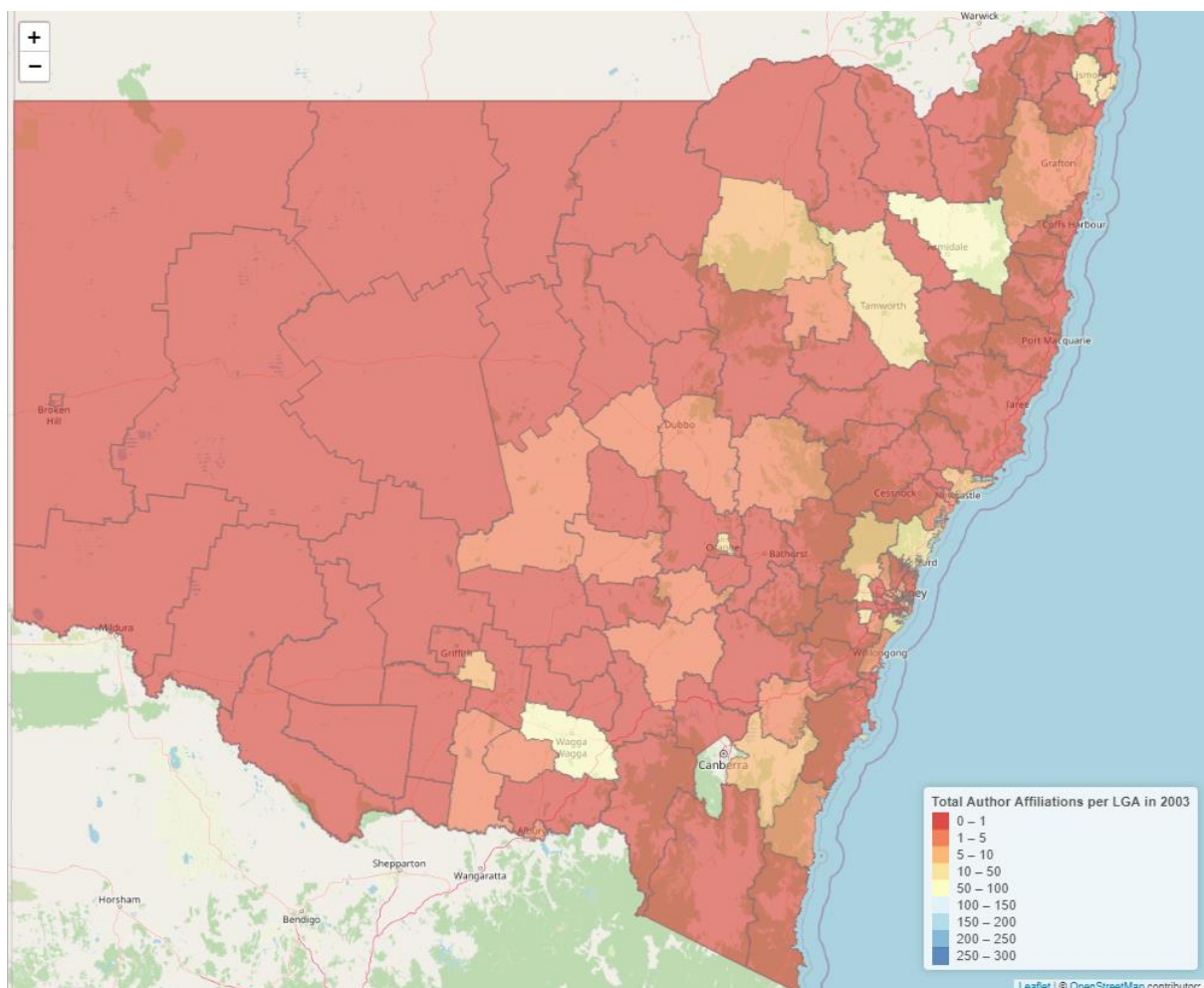
With this, the research concentration in certain areas can be clearly identified.

This has changed over time, with either increasing (or decreasing) numbers of affiliations recorded each year, or changes in the ranking. Whilst the maps that show the links detail the connections, and it is difficult to quantify them numerically, the collation of affiliations by LGA can demonstrate the intensity of research activity in each region.

10.2.1 2003

In 2003, the top three LGAs for author affiliations were Sydney (68), Armidale (64), and Wagga Wagga (56). There was a substantial drop from the third to the fourth-ranked organisation – Ryde recorded 35 affiliations – and from there, the decreases were more even, with Orange having 28 affiliations.

Figure 10-49: 2003 Author affiliations by local government area



Geospatial location of industry and other state/territory organisations, based on extracted addresses from Web of Science, geocoded in ArcGIS and visualised in R using Leaflet.

The research intensity can be observed for each year with the mapping of these affiliations (captured as the individual addresses of the authors).

The use of a scale that captures very low numbers (less than 5) allows for areas that are low in producing research output to be captured. However, the proximity of these LGAs to locations that host important research organisations (e.g., the arc of local government areas surrounding Orange and passing through Dubbo, as well as similar around Wagga Wagga) represents the ability for knowledge networks to be formed in regional areas.

Whilst there is a high concentration in Sydney, this may reflect institutional and organisation headquarters rather than the actual location of the research organisation. An exception is the appearance of Camden in this data, where the University of New South Wales has a research farm facility.

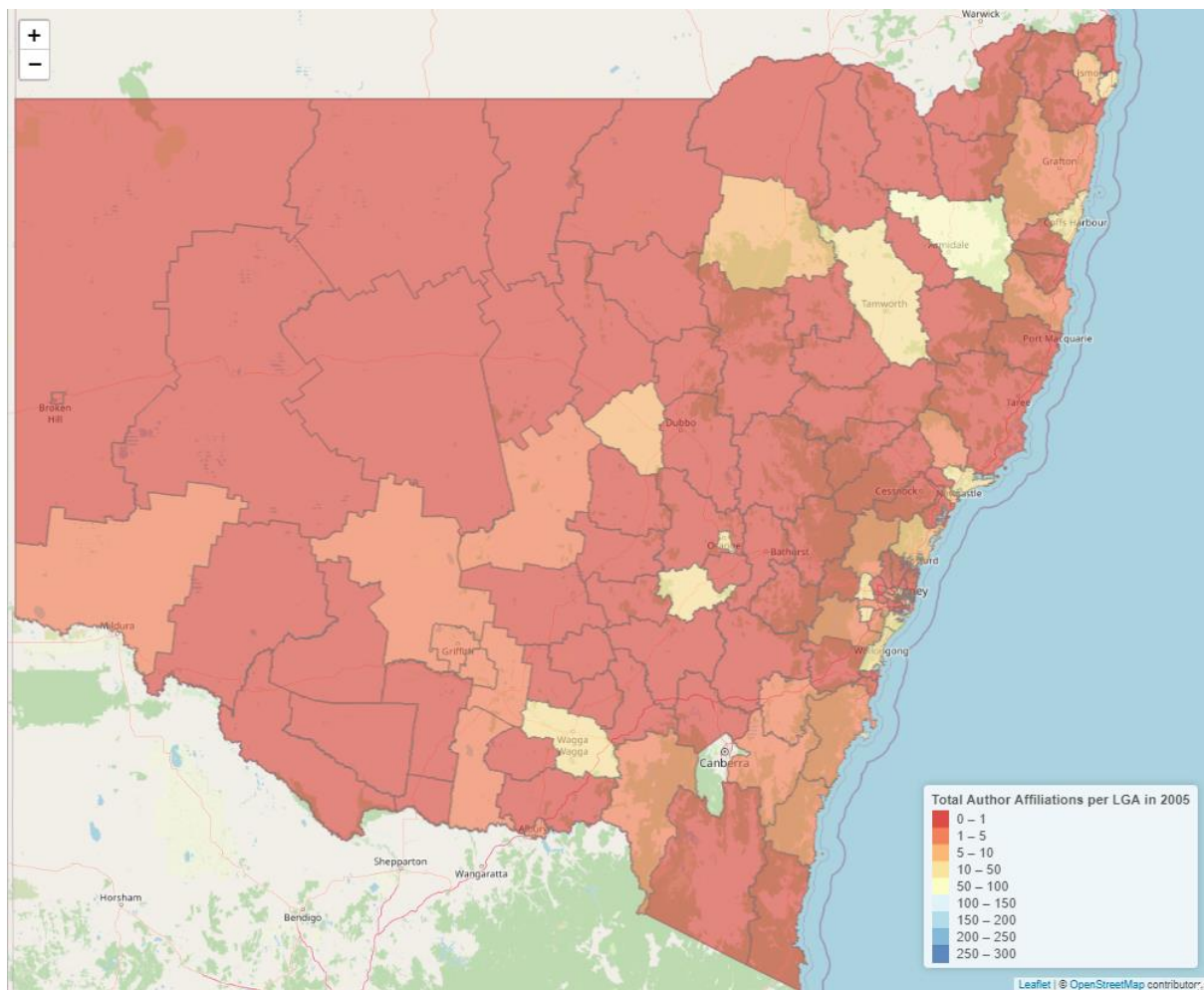
Whilst 2003 had distinguishable areas of author affiliations, later years were not as clear.

10.2.2 2005

These localised concentrations can be seen in 2005, where the band around Orange was less pronounced and shifted outwards, forming a band between Wagga Wagga, Griffith, Dubbo, and the Victorian border.

In the north of the state, an increase in the affiliations on the coast can be observed, whilst changes in the areas adjacent to Tamworth changed. Contrasting this is the performance on the South Coast – south of Wollongong – and inland towards Canberra, where there are increases in the affiliations.

Figure 10-50: 2005 Author affiliations by local government area



Geospatial location of industry and other state/territory organisations, based on extracted addresses from Web of Science, geocoded in ArcGIS and visualised in R using Leaflet.

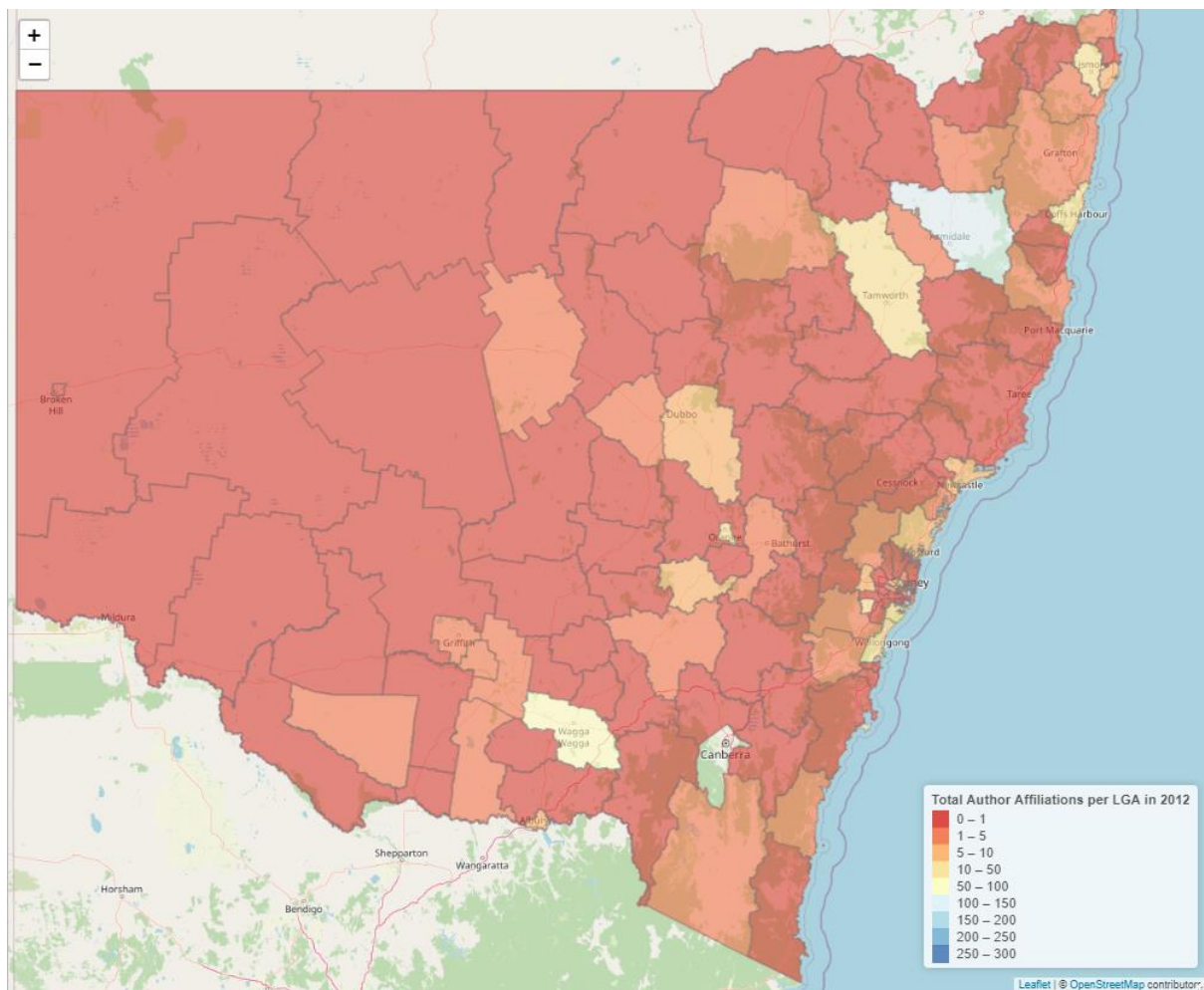
Whilst 2005 had a clear change, by 2012, the pattern of distribution was quite different.

10.2.3 2012

In 2012, the activity in the state's north increased, with a clear band of research starting at the Queensland border, with affiliations continuing through the Northern Rivers area and into the New England and the Northwest. In contrast, where previously there were clear adjacent affiliations in 2003 and 2005 in the Southwest and the Riverina area, these are less obvious with lower numbers of affiliations in these regions.

In addition, in the south of the state, the coastal LGAs had a change in concentration.

Figure 10-51: 2012 Author affiliations by local government area



Geospatial location of industry and other state/territory organisations, based on extracted addresses from Web of Science, geocoded in ArcGIS and visualised in R using Leaflet.

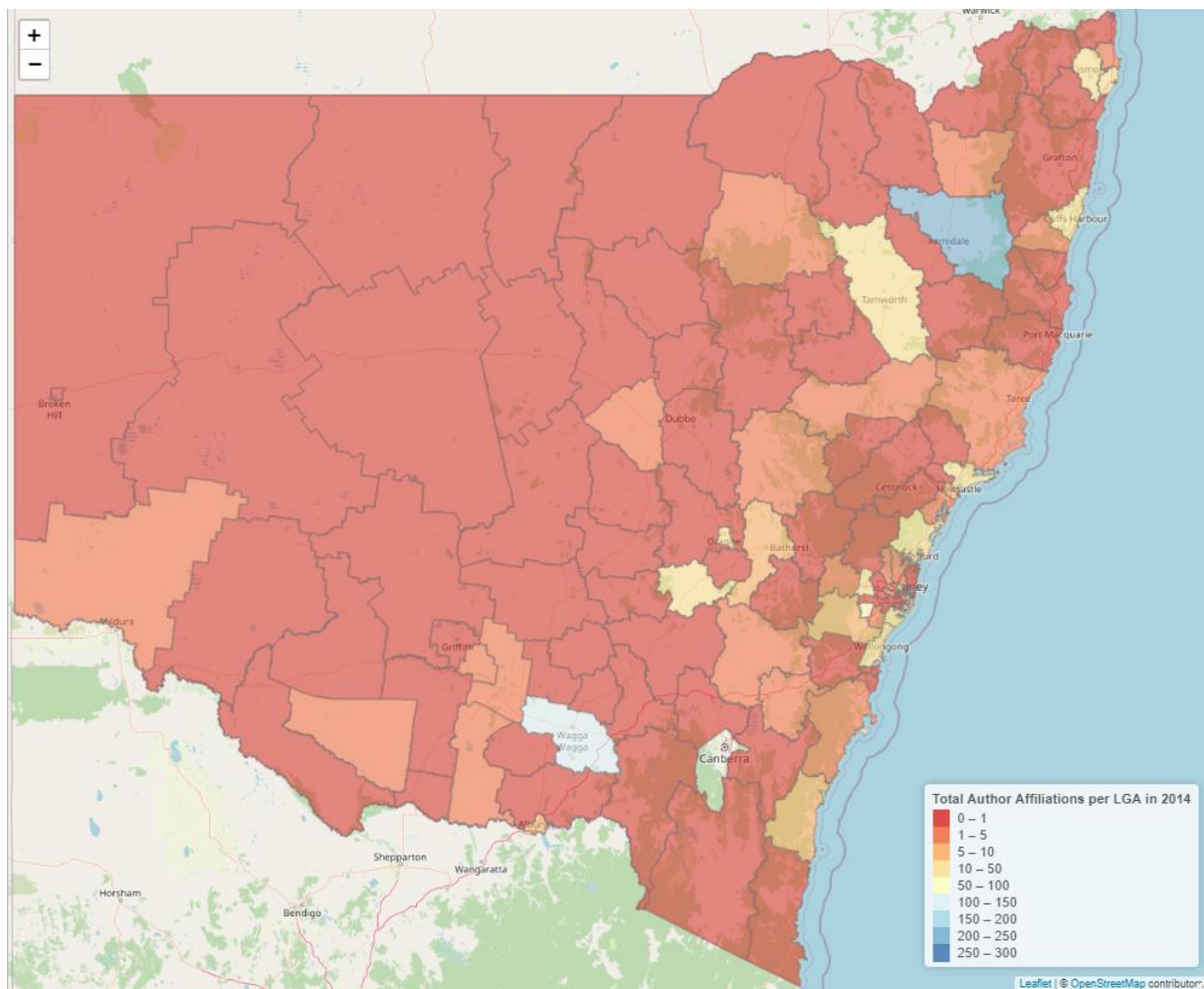
As the number of publications also increased over this time, so did the number of affiliations.

This is apparent when 2014 is examined.

10.2.4 2014

A substantial increase in publications can be seen in the Armidale area, as well as an increase by one band for Wagga Wagga. The area surrounding Mildura and the South Coast cluster of affiliations also returned, heading further inland towards Orange. In addition, a new band of affiliations formed on the Mid-North Coast from Taree through to the edge of the Hunter and then to Bathurst.

Figure 10-52: 2014 Author affiliations by local government area



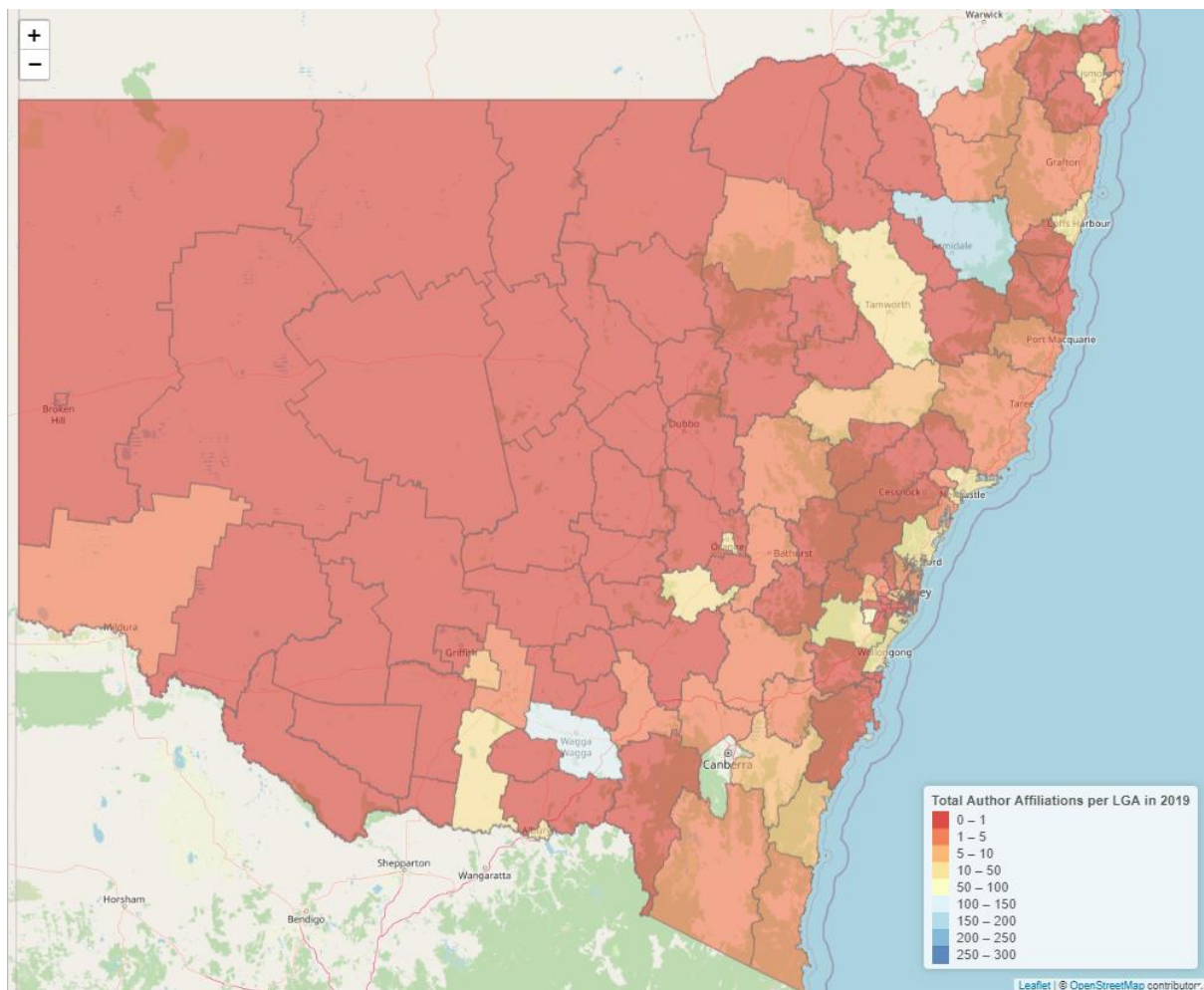
Geospatial location of industry and other state/territory organisations, based on extracted addresses from Web of Science, geocoded in ArcGIS and visualised in R using Leaflet.

The overall pattern remained unchanged, with the dominant areas remaining as Armidale, Wagga Wagga, and Sydney. This is the case through to 2019, the final year.

10.2.5 2019

For the final year of the sample, there is a near-continuous band of authors from the north of New South Wales through to the southern border with Queensland. Representing the increased volume of publications, this change can be clearly seen through the increased number of affiliations recorded across the state.

Figure 10-53: 2019 Author affiliations by local government area



Geospatial location of industry and other state/territory organisations, based on extracted addresses from Web of Science, geocoded in ArcGIS and visualised in R using Leaflet.

In 2019, the concentration of research affiliation was still along clear corridors. The coastal fringe (the South, Central, Mid-North, and North coasts, and the Northern Rivers region) as well as along the Northern and Southern Tablelands, as well as the Central West. All these areas have easy access to Sydney or, in the case of the border regions, access to adjacent states (particularly the Northern Rivers).

10.3 Conclusions

The changing research landscape can be clearly seen in these examples, which provide an insight into the emerging research centres over time, as well as changes in research activity and partners. There are evident changes in the emergence of Port Augusta and the Adelaide

region of South Australia as pockets of research collaboration, unlike in New South Wales, where there are limited changes in the collaborative partner landscape. However, if there is the emergence of a new ecosystem that is growing in popularity and engagement, then this may not be apparent in the New South Wales data. Rather, like South Australia, it would appear when looking at the external connections as the novelty of these new connections would be more apparent.

The changes in the collaborations at a regional level are limited, with few new entrants. However, notably, most of these collaborations are spread across dispersed geographical areas. This dispersal (particularly when there are university and industry collaborations or variations thereof) limits the potential for spillovers in the immediate local area. Contrary to the expectations of Wise (2016), the research collaborations that may lead to the transfer of research into opportunities are limited.

Whilst a region may exhibit specialisation and subsequently a higher degree of specialisation or industry concentration in a specific field, this may not translate into research collaborations and output. Some organisations may be the dominant producers of research in a specific field and may also exhibit only limited collaborations with other research organisations.

The concentration of research output at a regional level is varied and diverse across New South Wales, and there are certainly clear continued (historical) collaborations. The emergence of new opportunities can be seen in the expansion of Port Augusta as a collaborative hub within the *university, government, and other state/territory* collaboration.

Whilst Townsville and Cairns also became connected to the New South Wales research ecosystem, there was less activity than that surrounding Port Augusta in South Australia.

Government collaborations showed a clear trend of intra-organisational collaboration within the sole author type. Clear connections between New South Wales Department of Primary

Industries research stations exist, whilst connections to Sydney may capture a CRC headquartered there. Likewise, when examining Other State/Territory collaborations, the capital cities may be host to a CRC. The role of the regional research stations is clear: they are widely distributed and can be seen as the connection between the region's needs and the research knowledge.

Returning to Wolfe (2010, p. 142), the institutional (university) endowment element can be seen to be weak at a sub-national regional level. However, at a macro level, the knowledge shared across the Southeast Asian region is very clear. Reflecting the transfer of research, the potential for this benefit to the wider global community is not inconsequential. However, this may be to the detriment of the social licence of the research organisations as they attempt to increase prestige by addressing global issues as opposed to addressing the local issues – in line with Gingras (2016, p. 55) who states that “There is a real danger that local objects that are socially important will be undervalued and thus neglected if citation indicators are used mechanically...”.

With the mapping of research addressed at a local government level, the distribution of research activity can be clearly seen; this is combined with the specialisation measurement for the three periods of the census data available (2006, 2011, and 2016) in overlapping groups of data. For example, 2011 has the data from 2008 through to 2014 laid over the specialisation value of 2011.

Chapter 11: Combining the Triple Helix and Industry

Concentration Model

In this chapter the identified output-intensive regions are matched with the regional economic activity. Without analysing the papers, any additional metadata for the paper, or the context of the paper, a direct connection cannot be made between the research output and the economic activity. However, the indicative nature of this work provides the impetus to start the next stages of analysis in the future.

The ability to identify the LGAs that have a clear connection to the research activity undertaken within the boundaries through specialisation, as well as the surrounding LGAs provides an opportunity to identify regions that may benefit from the research activity.

In the literature, innovation has been captured within the measurement of patents and specialisation. For example, Delgado (2020) applied the location quotients to measure industrial specialisation and patent grants within the U.S. Leydesdorff and Strand (2012) used business' structural data to apply the triple helix to construct an analysis of regional activity. In both these cases, the data available for Australia is very narrow and precludes these approaches.

Given this limited data, the approach of combining the specialisation (measured using Shannon's Entropy Index values) and the publication output for the agricultural research categories was used. These measurements provide an understanding of the concentration of research activity within the surrounding LGAs. The capture of diversity in the regions allows for the examination of the specialisation and the changes over time.

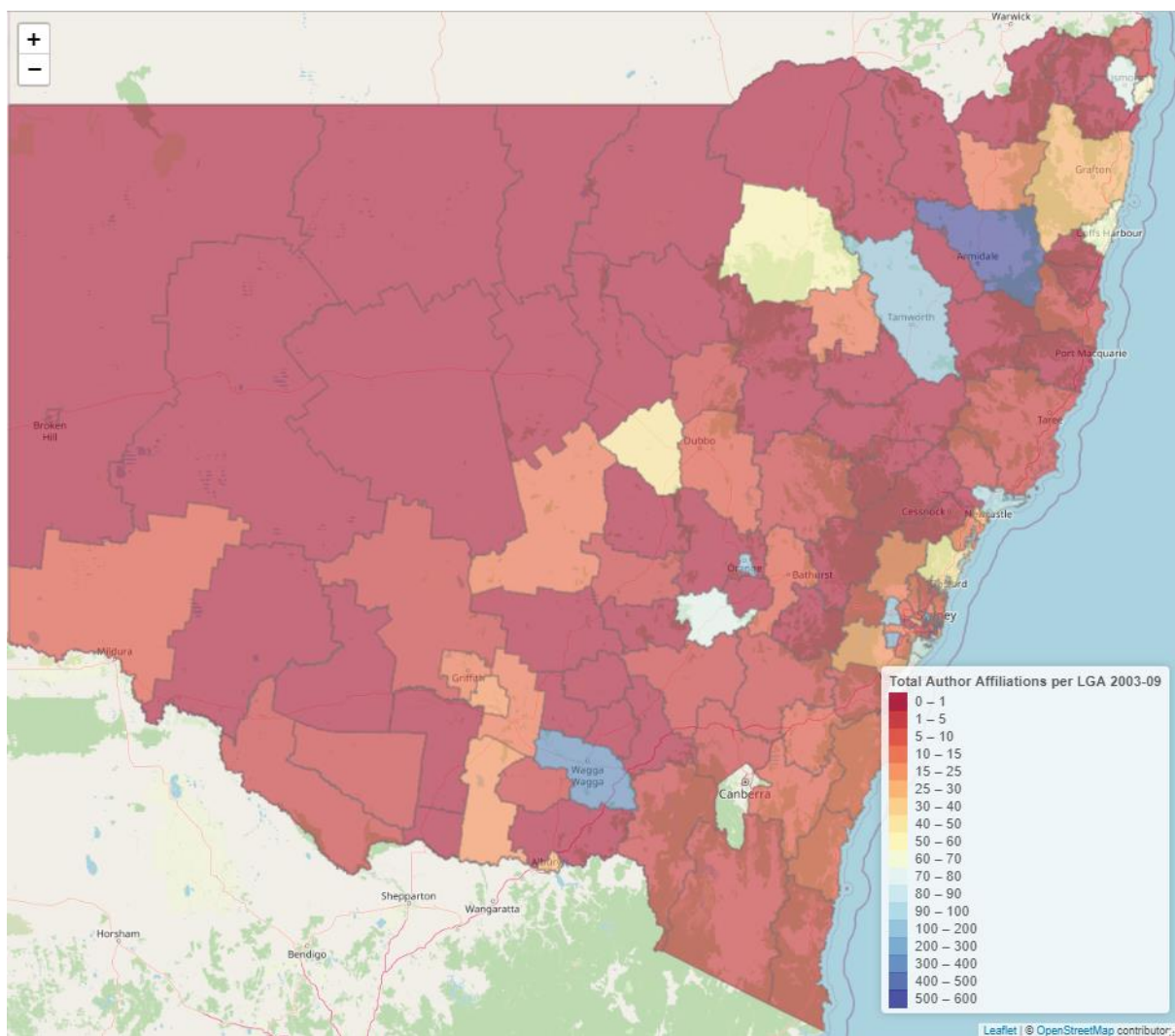
11.1 Bring the Data Together

Connections can be identified by combining visualisations and data for the census periods and the years on either side of the census. An analysis of the concentration of author affiliations by year in the LGA compared to the degree of specialisation identifies where research connects with industrial activity.

11.2 2006 Census

Examining summed affiliation data from 2003 to 2009, the concentration of publication activity can be seen clearly.

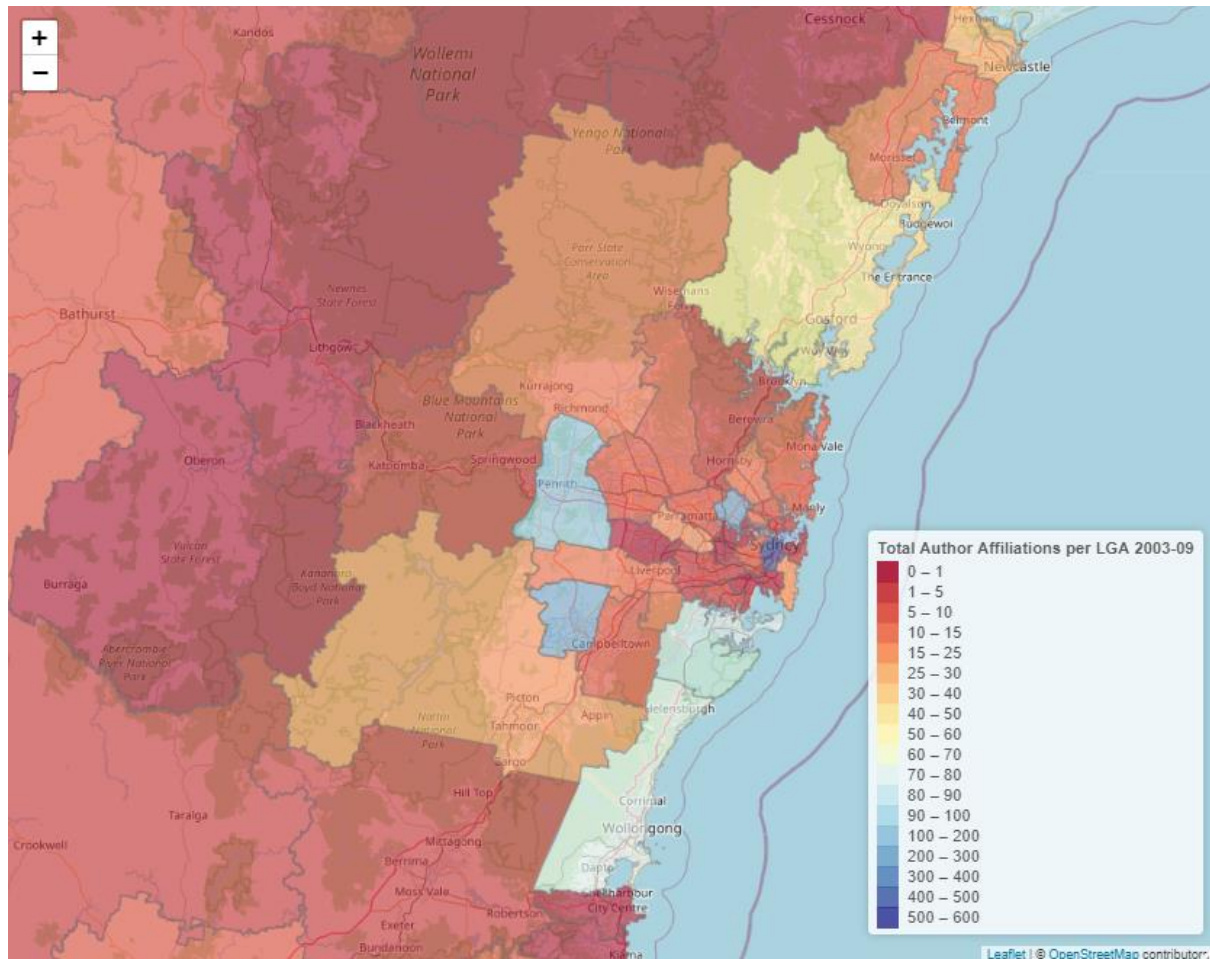
Figure 11-1: Total author affiliations, 2003–2009 by local government area



Total author affiliations for 2003–2009 by local government area from Web of Science data.

Concentrations can be seen in Armidale, Orange, Wagga Wagga, Tamworth, Narrabri, and the Clarence Valley. Furthermore, small parcels of activity surrounding Sydney become apparent with the increased number of publications.

Figure 11-2: Total author affiliations, 2003–2009 by local government area (Sydney region)

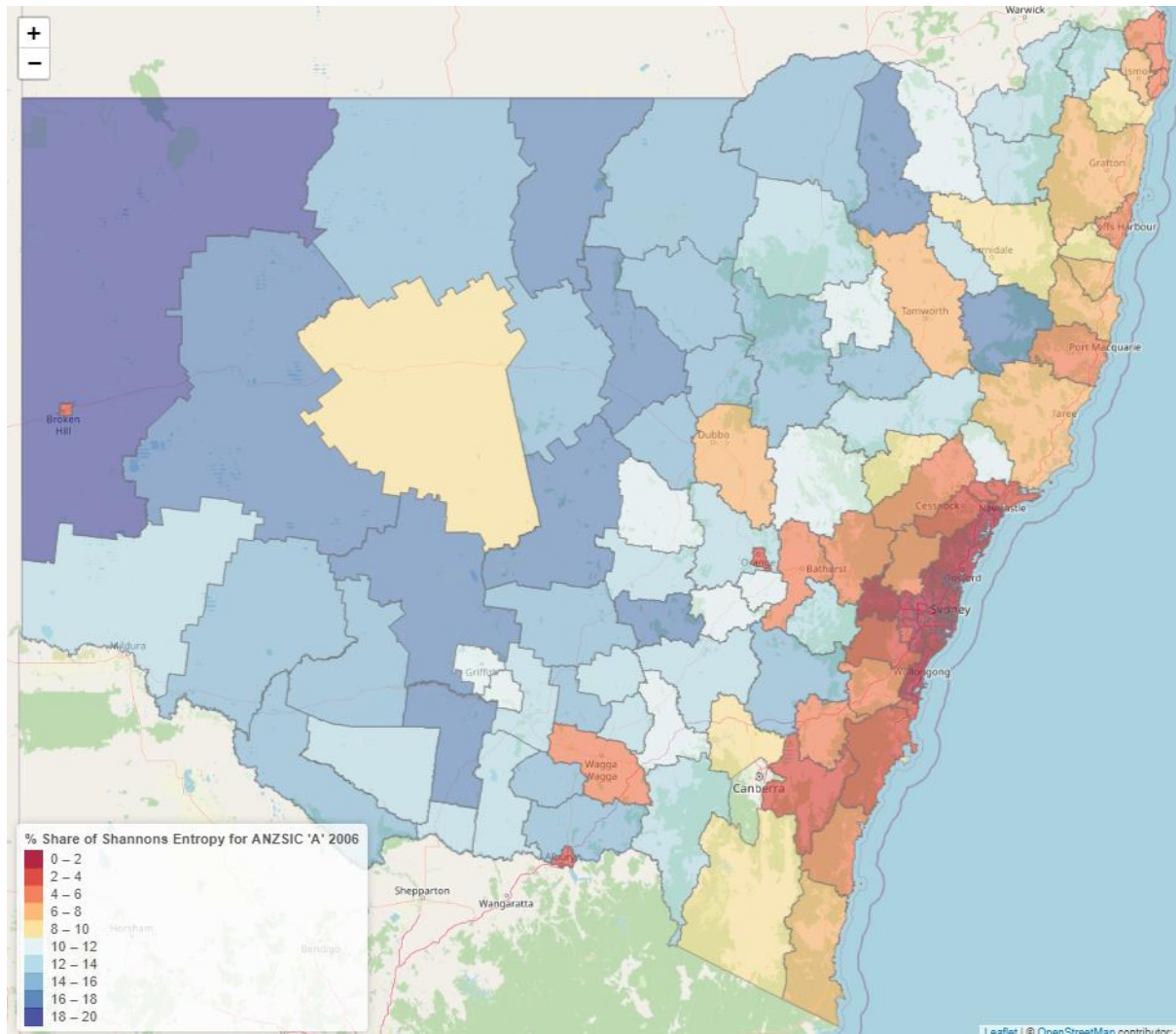


Total author affiliations for 2003–2009 by local government area from Web of Science data.

This visible share of the author affiliations in the Sydney region shows the region’s diversity. With research stations such as those found in Camden (University of Sydney), as well as other major New South Wales universities (University of Sydney and University of Western Sydney), the concentration of these author affiliations aligns with those connections. Furthermore, major industrial organisations may have Sydney head offices, reflected in the dark blue (highest bracket) located in Sydney.

When these combinations are compared to the measured industrial specialisation, the share of the Shannon's Entropy Index value accounted for by the agriculture, forestry, and fisheries industry specialisations, the connections become clearer.

Figure 11-3: 2006 Share of Shannon's Entropy



Share of Shannon's Entropy Value of agriculture, forestry, and fisheries industries by local government areas in 2006, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

With this mapped, regions with a greater share of the Shannon's Entropy Index can be identified. Regions such as Armidale and Tamworth have a high degree of specialisation and a high output through author affiliation. In contrast, both Wagga Wagga and Orange have a lower degree of specialisation but a high author affiliation connection. Whilst these local government areas have a low specialisation measurement, the areas surrounding are much

more specialised. Within the Sydney region, the share of agricultural output is very low; however, the publications from the Sydney region occupy six of the top 10 by affiliations (Sydney, Ryde, Camden, Penrith, Sutherland Shire, and Wollongong).

Table 11-1: Affiliation count and share of Shannon's Entropy compared (2003 to 2009)

Local Government Area	Affiliations between 2003 and 2009	% Share of Shannon's Entropy, 2006
Armidale Regional	564	9.505
Sydney	548	0.374
Wagga Wagga	371	5.415
Ryde	272	0.440
Camden	202	2.180
Orange	161	3.523
Penrith	128	1.326
Tamworth Regional	103	7.694
Port Stephens	91	2.925
Sutherland Shire	84	0.402

Share of Shannon's Entropy Value for agriculture, forestry, and fisheries industries compared to author affiliation by local government areas in 2006, derived from Australian Bureau of Statistics (2017a) and Web of Science, calculated with R and RStudio.

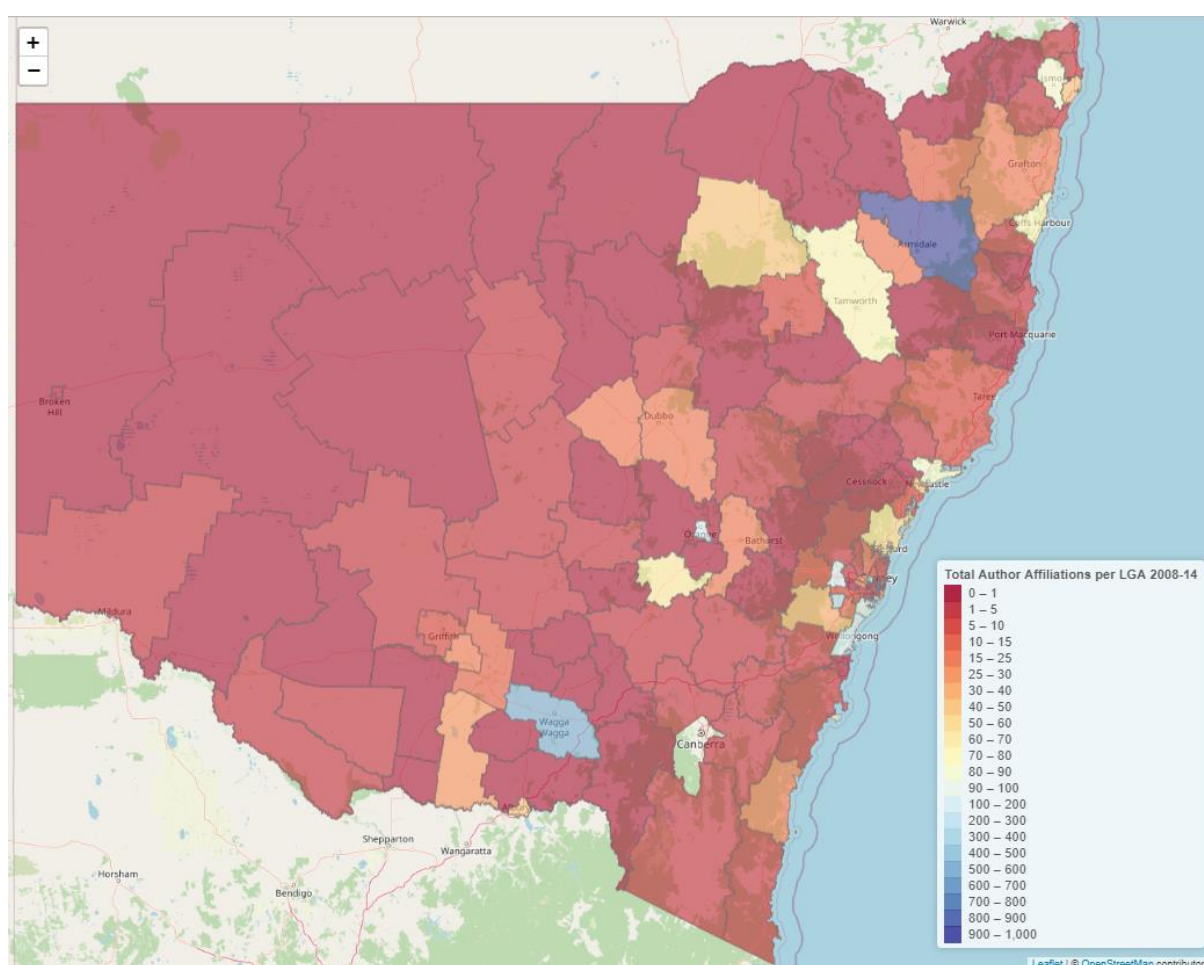
Camden, to the southwest of Sydney, has a share of the Shannon's Entropy Index Value that is approaching that of Orange and Port Stephens. With a dedicated research station for animal science, this is unsurprising.

11.3 2011 Census

According to the 2011 census data, the changes in the share of Shannon's Entropy are minimal, with many changes tending to be decreasing shares. In contrast, the author affiliations increased substantially in some areas.

Long-established regions dominated the affiliation counts, with Armidale, Wagga Wagga, and Orange clearly identifiable in the total author affiliation counts. Reflecting the concentration of the university research sectors and the government bodies (particularly Orange), these continue to be the driving forces for author affiliation in New South Wales.

Figure 11-4: Total author affiliations, 2008–2014 by local government area



Total author affiliations for 2008–2014 by local government area from Web of Science data.

Whilst the affiliation counts increased, the share of Shannon’s Entropy decreased in all local government areas, representing either a structural change in employment or an increasingly diverse economy.

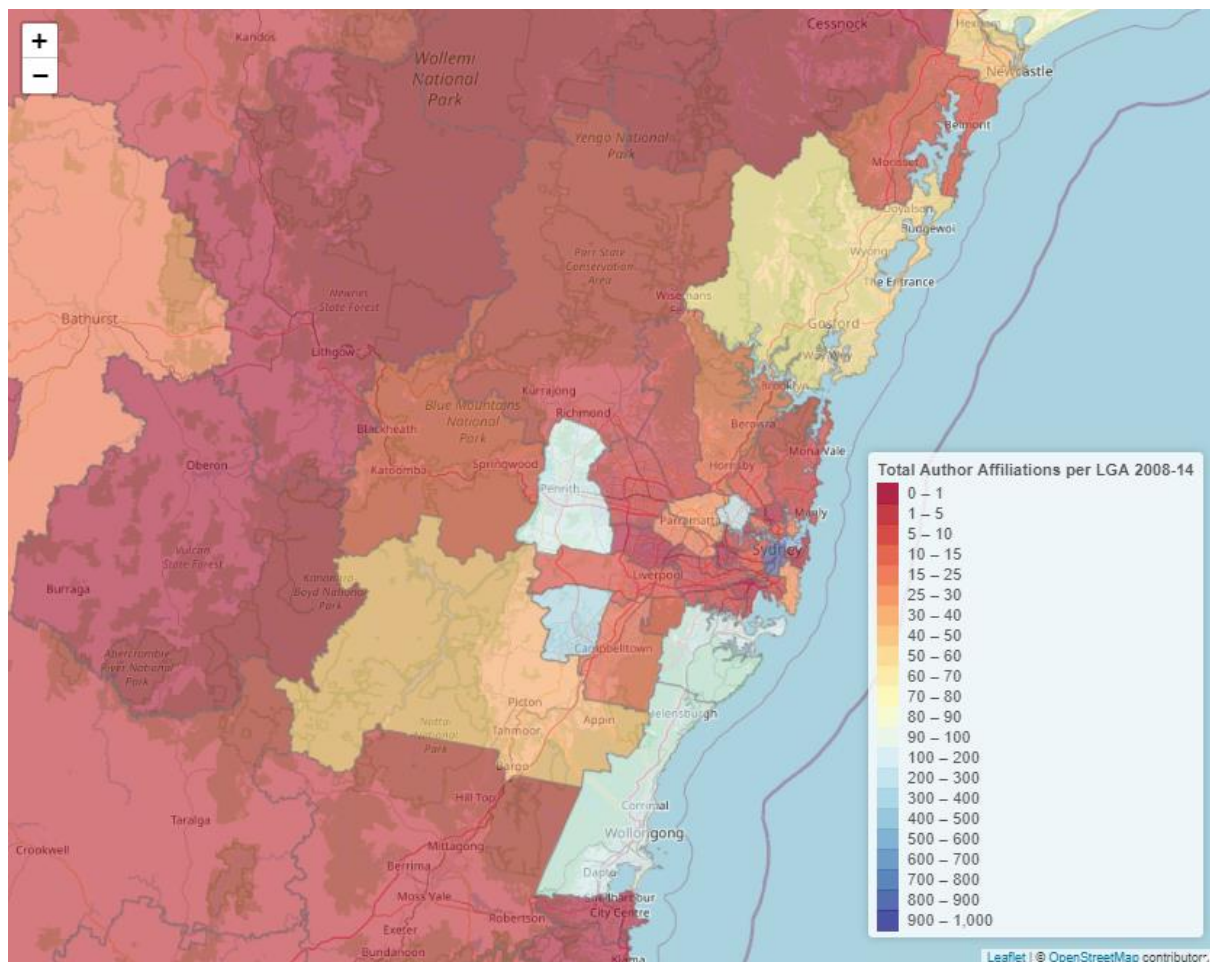
Table 11-2: Affiliation count and share of Shannon’s Entropy compared (2008–2014)

Local Government Area	Affiliations between 2008 and 2014	% Share of Shannon’s Entropy, 2011
Armidale Regional	952	9.254
Sydney	846	0.291
Wagga Wagga	523	4.866
Camden	313	1.794
Ryde	236	0.253
Wollongong	132	0.614
Orange	128	2.942
Penrith	104	1.238
Sutherland Shire	101	0.296
Port Stephens	85	2.129

Share of Shannon’s Entropy Value for agriculture, forestry, and fisheries industries compared to author affiliation by local government areas in 2011, derived from Australian Bureau of Statistics (2017a) and Web of Science, calculated with R and RStudio.

Once more, an examination of the affiliations within the Sydney region, including Wollongong, shows that the same areas from 2003 to 2009 are the dominant sources of author affiliation:

Figure 11-5: Total author affiliations, 2008–2014 by local government area (Sydney region)



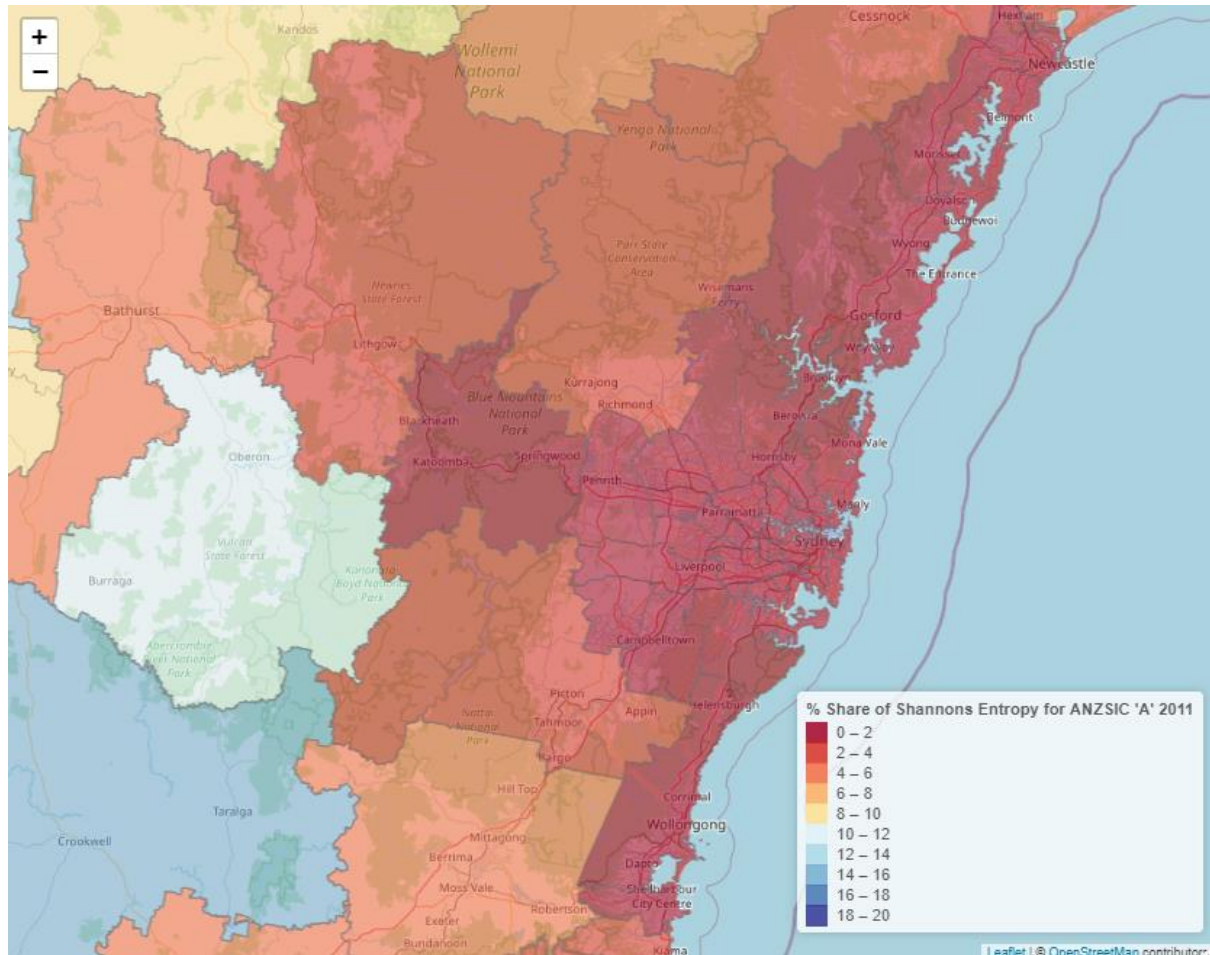
Total author affiliations for 2008–2014 by local government area from Web of Science data.

Several areas surrounding Sydney also undertake research into agriculture. When examined using the share of Shannon’s Entropy Index, these areas are focused on research with a very low share of the index accounted for by the agriculture, forestry, and fisheries industries.

As highlighted in Figure 11-6, this can be seen clearly in the Central Coast area and throughout metropolitan Sydney. When contrasted with Figure 11-5, the inverse is apparent; high numbers of affiliations can be found where there is a low level of agricultural, forestry,

and fishery employment, whereas the areas with the higher share of the Shannon's Entropy Index have a lower level of author affiliation.

Figure 11-6: 2011 Share of Shannon's Entropy by local government area (Sydney region)



Share of Shannon's Entropy Value for the agriculture, forestry, and fisheries industries by local government areas in 2011, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

Reflecting the diversity of the industrial mix in the Sydney region, the low share of the agriculture, forestry, and fisheries industries combined with the urban nature is unsurprising. However, the author affiliation counts were surprisingly high in this region, although not as high as Armidale, Wagga Wagga, or Orange, which had at least 2.9% of the Shannon's Entropy Index made up by the agricultural, forestry, and fisheries industries. The areas surrounding Sydney increase the share of the Shannon's Entropy as the distance from Sydney increases. Lithgow is one of the most diverse regions when measured using Shannon's

Entropy Index and has a share of approximately 5% for the agricultural, forestry, and fisheries industries.

11.4 2016 Census

Whilst the 2011 census period showed a substantial increase in publications in some regions, others experienced smaller changes. In 2016, the starting value for the top 10 regions was over 100; previously, this was 85.

Table 11-3: Affiliation count and share of Shannon's Entropy compared ((2013–2019))

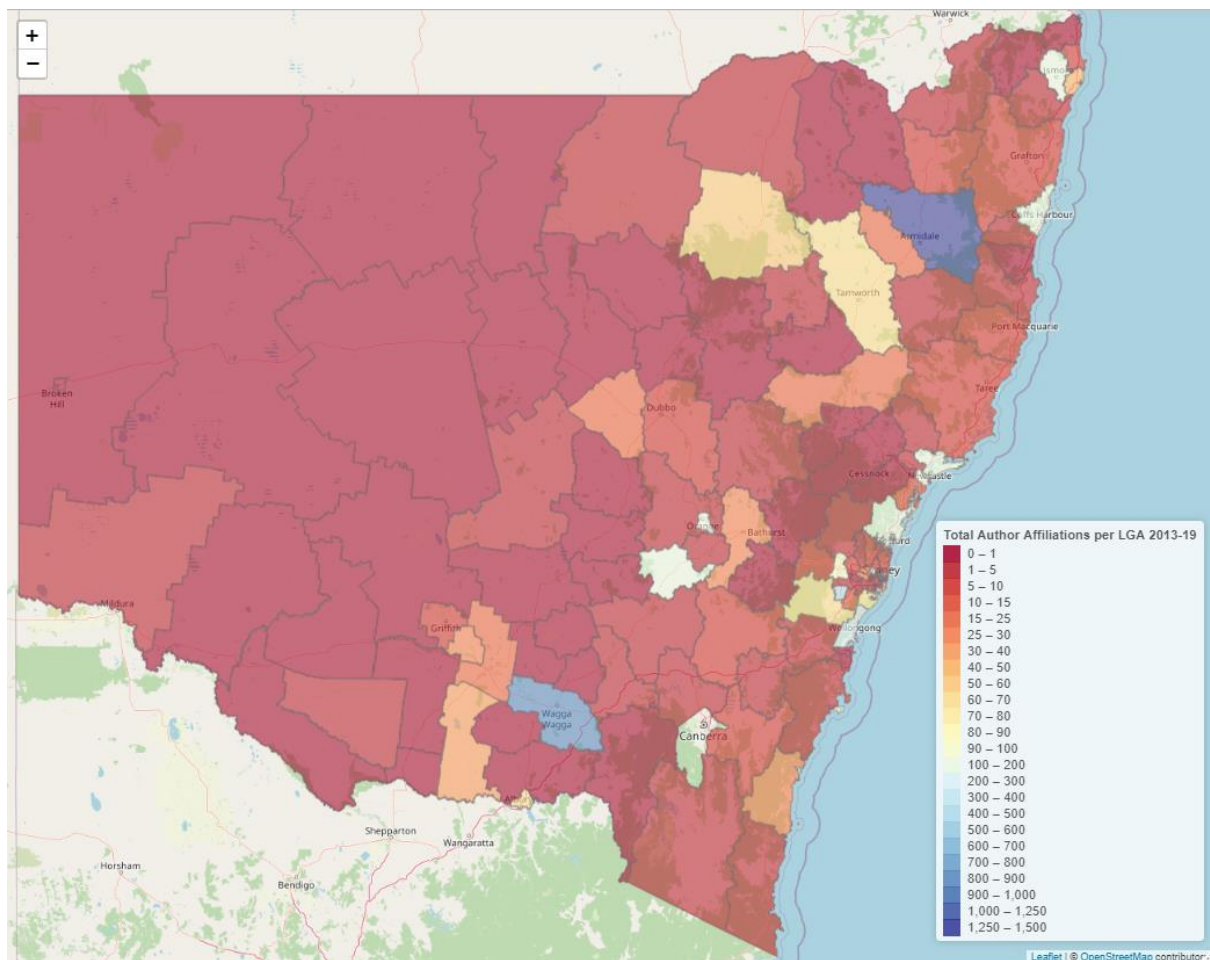
Local Government Area	Affiliations between 2013 and 2019	% Share of Shannon's Entropy, 2016
Sydney	1355	0.413
Armidale Regional	1264	9.710
Wagga Wagga	861	5.126
Camden	468	1.687
Wollongong	245	0.739
Central Coast	197	1.503
Orange	162	3.279
Ryde	141	0.440
Cowra	119	11.889
Lismore	111	6.726

Share of Shannon's Entropy Value for agriculture, forestry, and fisheries industries compared to author affiliation by local government areas in 2016, derived from Australian Bureau of Statistics (2017a) and Web of Science, calculated with R and RStudio.

Furthermore, with the inclusion of Cowra and Lismore in the top 10, more regional areas are included, as well as those with a higher share of Shannon's Entropy value captured by employment in the agriculture, forestry, and fisheries industries.

The total number of publications increased, reflecting increased output and collaborations (see Chapter 8). This increased affiliation number is not unexpected. Importantly, this period shows the increased publication (albeit less than 10% of the leading regions) that occurred within the areas that recorded a larger share of the Shannon's Entropy Index value for the agriculture, forestry, and fisheries industries. The consistent role that Tamworth, Narrabri, and Coffs Harbour LGAs play is increasing.

Figure 11-7: Total author affiliations, 2013–2019 by local government area

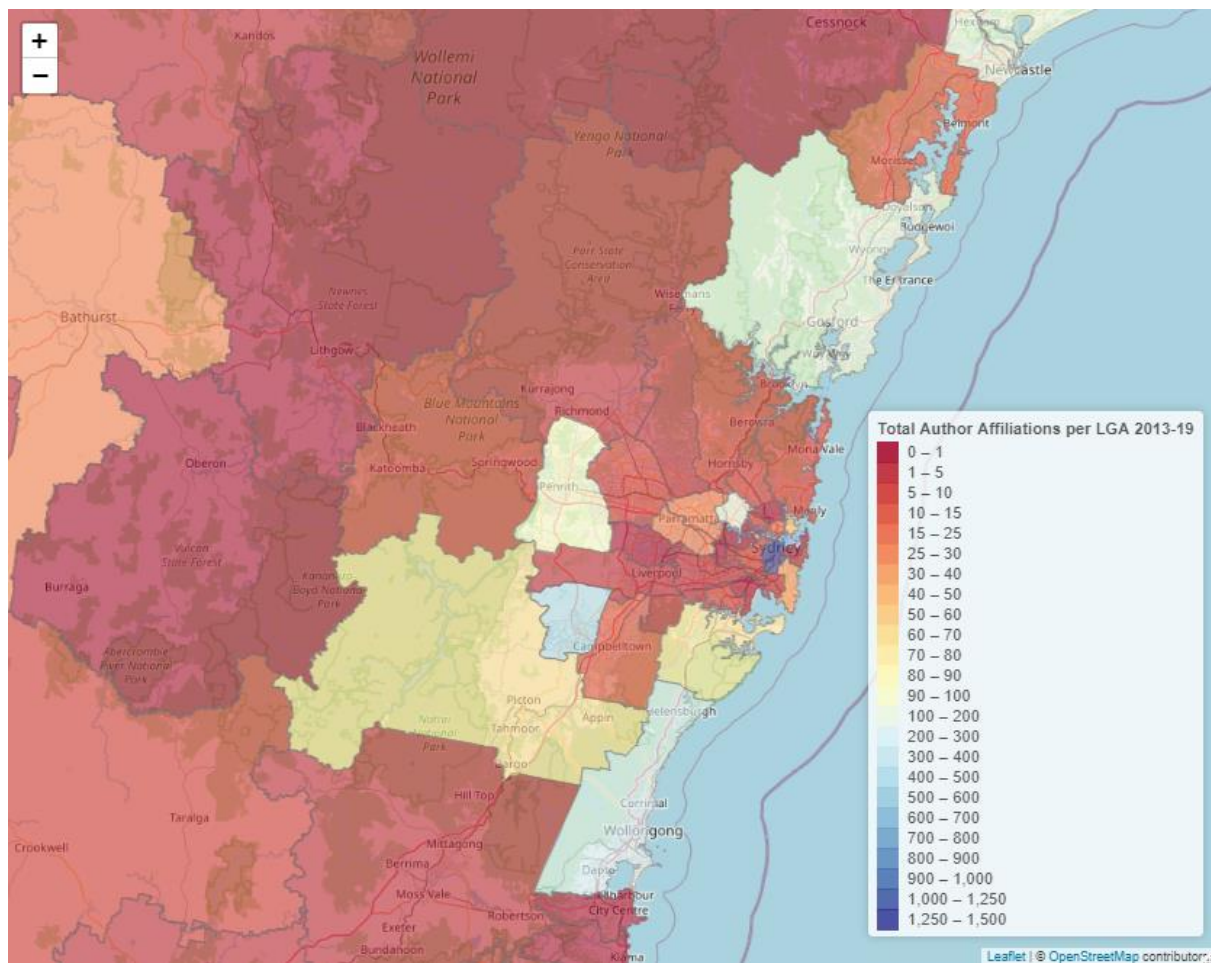


Total author affiliations for 2013–2019 by local government area from Web of Science data.

When the same analysis is applied to the Sydney region, in contrast to previous periods, the role of the Central Coast can now be seen in the data. Furthermore, Camden, Ryde, and Sydney remain the dominant regions for author affiliation within metropolitan Sydney.

With the same band of low author affiliation surrounding Sydney as in previous years, the concentration of recorded affiliations remains in the Central Coast (an increase over the previous years), Sutherland Shire, and Wollongong to the south of Sydney, as well as the Sydney City Council area.

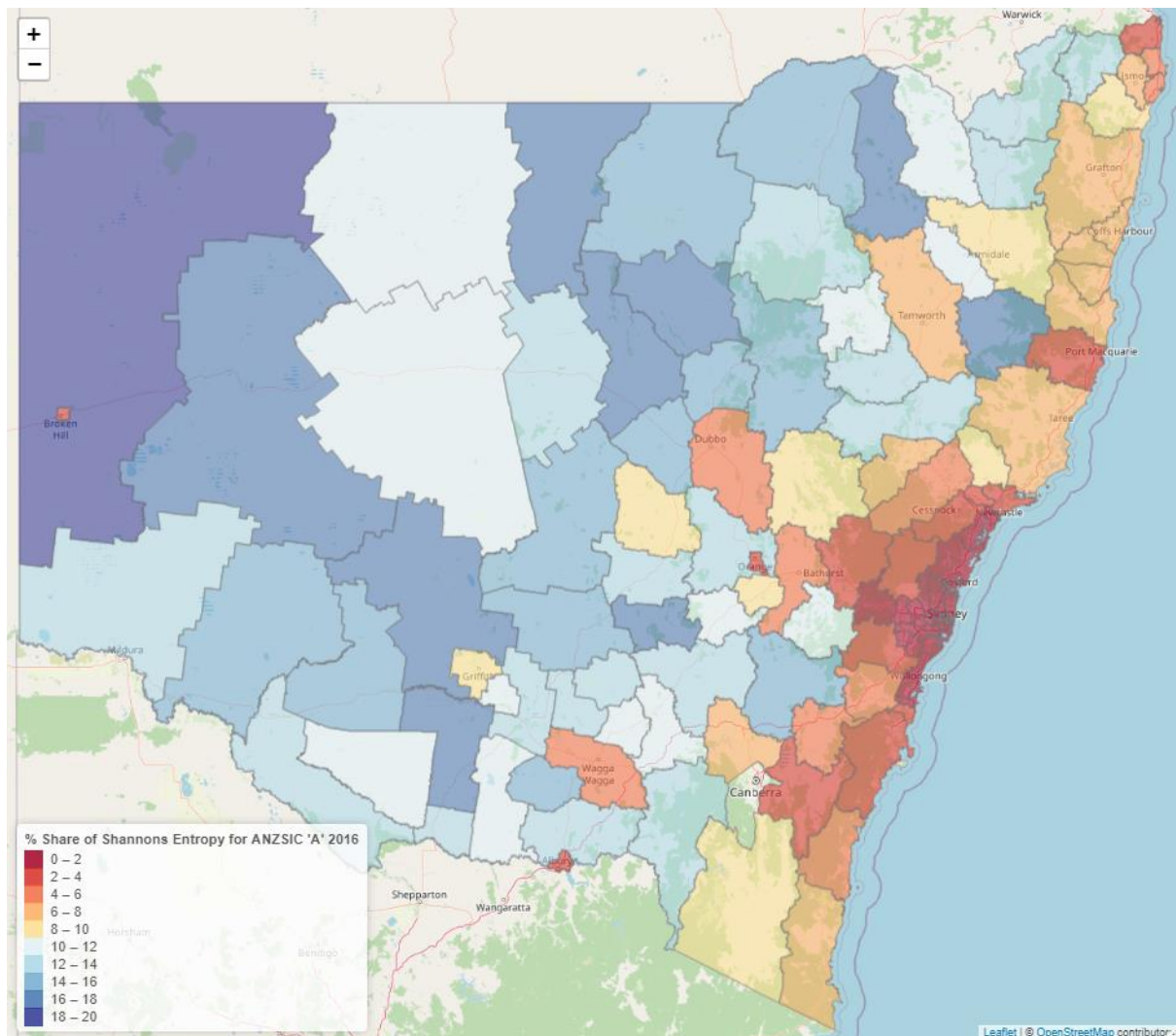
Figure 11-8: Total author affiliations, 2013–2019 by local government area (Sydney region)



Total author affiliations for 2013–2019 by local government area from Web of Science data.

Further analysis is limited without breaking the affiliations in this case into the organisation types. However, with the location of university campuses (Camden, Central Coast, and Wollongong) and government agencies (Cronulla for the New South Wales Department of Fisheries) in proximity to Sydney, the composition of the affiliations is complex and diverse. Finally, the share of Shannon’s Entropy Index accounted for by agriculture, forestry, and fisheries employment was relatively unchanged in 2016 compared to 2006 or 2011. The regions with a higher share of agriculture, forestry, and fisheries employment are inland from the coast and often with lower values of diversification, reflecting the increased industrial specialisation. With this, agriculture, forestry, and fisheries activity can be seen to be concentrated in the inland regions, along and to the west of the Great Dividing Range.

Figure 11-9: Share of Shannon's Entropy Value for the agriculture, forestry, and fisheries industries by local government areas in 2016



Share of Shannon's Entropy Value for the agriculture, forestry, and fisheries industries by local government areas in 2016, derived from Australian Bureau of Statistics (2017a), calculated with R and RStudio, and displayed using Leaflet.

With the areas of specialisation identified, as well as the location of authors (through their affiliation details), the ability to identify opportunities for research engagement and networks is possible.

11.5 Conclusions

Whilst there are clearly specialised regions for the agriculture, forestry, and fisheries industries, there may not be the clear connection to the research activities; rather, research is undertaken at an organisational level that dictates where it is undertaken. Assets and

knowledge may not be transferable in the short term, but government research priorities also have a role. This role can be seen in the changes in the Tamworth Regional Council area, reflecting the work of the New South Wales Department of Primary Industries located in the LGA. Furthermore, the infrequency of industry co-authorship limits the ability to measure the industry dispersal to the different LGAs.

The comparison of the share of Shannon's Entropy Index to the author affiliation reveals those areas with a clear connection between the two, as well as those with a diverse industry and, subsequently, a lower share of the index value. In the case of the regions within the metropolitan Sydney area, the share of Shannon's Entropy Index is much lower, reflecting the increased diversity and other specialisations in those regions.

If the theory of knowledge spillovers in a region (local government area) can be said to hold true in the regional areas, because there is a knowledge spillover (that local government area or adjacent/nearby) that can be utilised, then the challenge is the meaning of the metropolitan regions that have a high author affiliation rating. What is known is that these organisations will undertake collaborative work (as measured by the triple helix) and that this work is likely to be with areas that can be seen to have the higher agricultural, forestry and fishery industry employment share within Shannon's Entropy Index.

The spillover in the case of the Sydney metropolitan area may not be quantified in these metrics; rather, it is a spillover at an organisational level. When an organisation achieves a critical mass in terms of publications, it is necessary to work with those organisations, partly due to the way that funds are allocated, and this work is across the state. Alternatively, the spillover effect could be flipped to the spill-in effect. Research is driven by community problems, addressing the opposite of Gingras (2016, p. 55). If the collaboration is needed to address the local objects (problems), and that local is state-wide, or the knowledge is only

held in a few places, then the opposite is true. The collaboration network drives potential collaborators (and the knowledge capital) together more than the citation metrics allow for and addresses socially important issues.

With the identification of the highest areas of publication, the share of agriculture, forestry, and fisheries industrial employment in Shannon's Entropy Index, and consideration of the triple helix's role within these measurements, policy recommendations can be made to support the required research.

Chapter 12: Conclusions

The main aim of this research was to test the application of the triple helix model to Australia and evaluate the relationships that could be discovered. The second aim was to investigate the geospatial dispersal of research collaborations and evaluate any connections to economic specialisations.

Clear trends and patterns appeared from the triple helix to author affiliations and regional specialisations. The quantification of these is novel and beneficial for the wider research and economic community. Using an alternative to the traditional academic performance at an individual level metric to one usable across research sectors and organisational levels is beneficial for decision-makers.

Including geospatial data at the address level enables the connection between regions to show the concentration of activity and the networks of the connections, and the regional ramifications of research policy are visible. Furthermore, the addition of industry activity at a local government level allows for the specialisation and the contribution of industrial activity to be captured. With this knowledge, policy directions can be structured to build on existing relationships, develop new opportunities, or structure research strategies to meet the requirements of local economic activity.

12.1 Findings

This research aimed to assess whether the triple helix could be used to measure the collaboration within New South Wales research activity and if university, industry, and government collaborations are related to regional economic specialisation and activity. Each of these is broken down and examined in the next section.

12.1.1 Can the Triple Helix be Used to Measure Collaboration?

In addition to showing the changes in the patterns and behaviours of collaboration, applying the triple helix to measure collaboration is instrumental in underpinning the process. The classification of organisations was a substantial task, but the resulting R scripts are now expandable for future years at a lower cost (time).

This research identified the nature of the collaboration within New South Wales and at a wider scale across Australia and globally. Furthermore, this was more detailed than the pure share of research (expressed as a percentage) and highlighted trends and patterns that were otherwise excluded.

Within the results of the collaborations, the changes in the international collaboration trends and the surge in publications around the Excellence in Research for Australia reporting periods were of particular interest. Visible in both the complete dataset and the agriculture-related research, these policies can be seen to impact the behaviour of researchers.

This research showed significant differences between the different actors involved in the research. Trends exist in both collaboration activity and the magnitude of the transmission values derived from the triple helix calculation. These changes highlight the different impacts that the collaborations have on the overall knowledge and, therefore, the potential for the impact of the research. Collaboration trends change over time, but overarching observations can be made on the role of the different organisational types.

12.1.1.1 All publications

Within the entire dataset, when research was co-authored by government, there was a decrease in collaboration over time when New South Wales universities were involved or when there was a foreign collaboration in pairwise and triple combinations. Influences such

as government policy changes and the Excellence in Research for Australia reporting periods are clearly visible within the university collaborations.

Industry tended to increase working with other state/territory; however, when working with universities in a triple combination, the trend was moving towards less collaboration, and that collaboration was undertaken at a lower level. This highlights a more independent nature than collaborations with a higher magnitude.

When government was examined in all fields, in the triple combination, the trend with university co-authors was a decrease in collaboration. Again, reflecting institutional and government policy changes, these collaborations decreased in magnitude.

Finally, the quadruple and quintuple helices provide insight into the most complex relationships between collaborations. This complexity contains the most diverse and broadest collaborations; they all continued the same trend of decreasing collaboration over time.

From these results, the trends in the collaborative landscape show decreasing collaborations over time. Whilst university researchers are pushed to collaborate, these collaborations may be limited. Collaborations within the same organisational type are more common, although they had to be measured in the approach undertaken. To measure this type of collaboration, it is necessary to adjust the model to capture the fractional share of authorship. This could be a development to be included in any future modelling.

Overall, the trends observed in the all-sector collaborations reflect an overall decrease in collaboration. However, as can be seen, when an individual sector of the research environment is analysed, the trends are very different. This was evident when the seven areas of agriculture-related research were analysed.

12.1.1.2 Agriculture

Whilst the analysis across all research areas demonstrated a clear decreasing trend of collaboration or increasing independence, the field of agriculture research showed a decrease before an increase in collaboration. Reflecting the changes in the research ecosystem and policies, these increases can be seen in the triple helix analysis.

Taking the combinations in turn, the pairs presented a mixture of increasing and decreasing combinations, and the partners involved in the trends were identifiable. There were increasingly independent trends before a return to collaboration. Including universities in the pairs was common in the move towards independence. A return to collaboration can only be seen within domestic research after 2015. However, research involving overseas partners was not as affected by the move towards independence. Crucially, industry engagement with universities was much lower than the other combinations but still demonstrated a return to collaboration after 2015.

With industry collaboration with universities demonstrating a decreasing trend, the combinations that involved industry show that university connections were substituted with other research collaborators. When examining industry pairs, all exhibited a neutral to increasing collaboration trend from 2010, whilst university and industry demonstrated a clear decrease.

Similar to industry, government showed that other actors could be substitutes for university collaboration. Increasing collaborations with other state or territory partners and industry countered the significant decrease in collaboration that universities and government demonstrated.

Reflecting external demand for knowledge, the collaborations with other states or territories and foreign actors were more varied; again, universities were dominant in leading the

decreasing collaborations, highlighted by the university and other state/territory pair.

Government collaborations remained dominant in magnitude, whilst industry was substantially lower. However, government collaborations appear to have substituted for universities, with an increase occurring as universities exited these collaborations.

When considering the triple helix models with agriculture, the increased complexity in the connections between actors again leads to universities having a low point of collaboration around 2015 before increasing. However, the smallest change in this was when universities collaborated with foreign actors and either other states or territories and governments. The role of government as an intermediary in other collaborations would benefit from future analysis to understand their role in enabling these collaborations.

Reviewing the industry collaborations in the triple combinations, university collaboration was again substituted for collaborative partners; government, other state/territory or foreign all took the place of universities and led to increasing collaborations, whilst university and industry collaborations all became increasingly independent.

Finally, moving to the quadruple and quintuple helix combinations, the least common but also the most complex, universities are again most likely to lead to a decrease in collaboration, whilst (in the quadruple) the industry, government, other state/territory, and foreign combination exhibits a clear increase in collaboration.

Whilst the triple helix (or n-tuple helix) can provide a valuable tool to follow, there are limitations. What has not been captured, and perhaps is crucial for the agriculture sectors, is adopting changed practices through research projects. The measurement of the author affiliation relies on all contributors being included in the affiliation. However, if the research was undertaken to examine the diffusion of new ideas or practices, this was not captured and

therefore minimised the potential relevance to the surrounding areas. This provides additional future opportunities for research.

12.1.2 Specialisation

The application of the Shannon's Entropy Index for the measurement of specialisation and diversity in the local government areas, as well as the component parts of the specialisation value (expressed as a percentage of the total Shannon's Entropy Index), is novel and provides a valuable alternative to the location quotient. Whilst the location quotient offers some benefits, the size of the labour markets and the share of employment in those relative to the state (or national) proportion is sufficient that it leads to extreme values substantially larger than the normal range. In contrast, Shannon's Entropy Index accounts for this specialisation and results in an index value that is still meaningful for comparisons between regions.

This research confirmed the distribution of industry diversity in the local government areas. Identifying this diversity and the associated concentration of the role of agriculture in calculating this diversity value allows for the measurement of specialisation. Hence the opportunity for identifying regions where there may be an increased opportunity for research connection is now possible.

Identifying where there are strong research bases and industry specialisation will allow for learning to be shared between different agents; conversely, identifying weaknesses will allow for structured action (potentially government-led – the third pillar of the triple helix) to be undertaken to build resilient communities. The occurrence of mismatched triple helix and industry specialisation may reflect workforce skills shortages or under-skilling, and thus the need to implement extension to build these areas. Using an industry specialisation metric to reflect theoretical demand, the future engagement of industry will enable improved research outcomes as it matches the needs of the differing regions.

The contribution of this research to understanding the economic landscape within Australia compliments and subsequently extends the work of the Australian Bureau of Statistics (2014). The ABS approached the measurement of the specialisation at Statistical Area 4 and for a single period, examining three years of data at a more focused level (local government area) allows for increased knowledge of the economic composition and diversity. Examining the local government area provides the opportunity for decision-makers involved in planning and marketing a region for economic development and activity within the boundaries they manage. In contrast, the use of Statistical Area 4 is not representative of a management level; rather, it is an arbitrary statistical unit of measurement that captures economic activity.

Adopting a time series or panel approach to analysing the economic diversity and the subsequent changes enables measuring the changes. However, identifying the drivers of these changes is still required, as well as additional drivers that may apply.

One source of weakness in this research that could have affected the measurements of specialisation (particularly relevant to the research output) is concentrating solely on agriculture, forestry, and fisheries employment. An improvement would be to assess the role of the research sector, with the potential to measure this at another level of ANZSIC divisions or by measuring occupation.

Ultimately, the research contributes to understanding the economic composition of the New South Wales economy and, subsequently, the opportunity for researchers to engage with areas of specialisation. With the adaptability of the methodology used, other industries can be assessed for their contribution to Shannon's Entropy Index value. Furthermore, if a single-year approach is taken, adopting the between and within entropy measurements would be possible through the component industries within the ANZSIC divisions.

12.1.3 Author or Organisation Location

With the author affiliation data extracted, identifying the strong research bases is possible. Clearly visible in the agricultural research data, these bases are often synonymous with the areas with higher agriculture, forestry, and fisheries industry employment contribution to Shannon's Entropy Index.

The widespread distribution of research connections, as well as the distribution of the organisations, was much greater than expected. Conversely, the lack of localised connection was unexpected. Reflecting the increased diversity of research collaboration and cooperation, this widespread dispersal of research organisations showcases the lack of regionalisation of agricultural research. However, whilst the research was widely dispersed, the areas that did contain the research organisations also coincided with the LGAs with a high share of contribution from agriculture, forestry, and fisheries employment to the Shannon's Entropy Index.

Co-location in the event of single organisation types was more commonplace, and engagement between government and university was often inter-regional rather than localised. Furthermore, these connections were often across a considerable distance as opposed to adjacent LGAs.

This research was undertaken to establish if regional innovation systems exist in New South Wales and evaluate the subsequent regional economic development. This connection was not observable. However, the knowledge and data capturing of the networks of the research collaborations substantially benefited the knowledge of the research innovation systems as being greater than that observable in an LGA. Whilst observations surrounding clustering and endowments could not be made, and limited conclusions can be drawn, identifying the

networks comprising the triple (or n-tuple) helix is a significant gain to the knowledge surrounding the research ecosystem.

Measurement of the concentration over six-year periods to compare to the census data highlights the intensity of research output from three dominant regions: Armidale, Wagga Wagga, and Sydney. With these three local government areas dominating the research output, there is the potential for a small degree of clustering. However, these areas were all likely to have connections within New South Wales, Australia, and internationally.

One of the more significant findings to emerge from this research is that the distributed university and government research campuses result in research output that is observable in the total numbers. University examples include Camden and Narrabri (both University of Sydney) campuses, as well as the University of Newcastle's Ourimbah campus. For government, the changing priorities within the New South Wales Department of Primary Industries can be seen in the prominence of Tamworth, Grafton, and Mildura and the rise of Cronulla and Port Stephens for fishery research.

Further research in this field would be beneficial in establishing additional connections between the local government areas, organisation types, and quantification through the measurement of the n-tuple helix.

12.2 Policy Implications

The process, findings, and observations from this research have several practical implications for all the organisational types involved. Reflecting on the triple helix and the role of government in enabling it or the n-tuple, as well as university research management, the policy implications of the knowledge from the n-tuple helix analysis will allow a retrospective examination of policy changes.

The policy implications will focus on the n-tuple helix related to the agriculture-related research rather than the entire research landscape.

12.2.1 Research Management

The ability for managers of research activities to have a repeatable measurement system that can be added to and expanded, as well as scaled up (or down), allows for greater transparency. Applied to existing databases, an open system of analysis allows for institutional-level examination of relevant research fields with an extensive list of rules already developed. With this improved analysis tool, the ability to analyse the mathematically defined relationships rather than the relative share of the publications is possible.

The rules in existence are bounded geographically and by time. To develop a repeatable and accurate measurement system in the future, the owners of the databases may consider increasing their metadata to include the organisation type at the research and funding levels. This would enable a simplified research analysis with a truly standard organisation type. Furthermore, maintaining the disaggregation of the research organisations at an address level allows for a more accurate analysis of the knowledge transfer at a localised level, particularly with state or federal organisations.

12.2.2 Government

In the original triple helix model (Etzkowitz & Leydesdorff, 1995), which builds on the observations of Etzkowitz (1994), the role of government was described as the creation of policies to enable university–industry collaboration. Moreover, the objective of governments in developing economic prosperity and innovation necessitated enabling and encouraging interaction. In contrast, the role of government in New South Wales is a catalyst for

collaboration; without government involvement, limited research is undertaken by some organisations.

Government intervention and engagement take two forms: the enabler through legislation and direction of research outcomes (intervention) and collaboration with other research organisations (engagement).

Addressing the intervention role of government, political changes can be seen to impact research collaboration, particularly when foreign policy is changed to enable (or disable) international collaboration. At both levels of analysis, this change could be observed, particularly within the university and foreign collaborations, where government policy can be seen in shocks to the increasing collaboration.

Due to the funding originating from government for foundational and some applied research activity, there is also an expectation and requirement for reporting. This reporting was carried out in the Excellence in Research for Australia reporting periods. As these reporting periods approach, clear spikes in the outputs are visible in the triple helix analysis. The Excellence in Research for Australia as a key performance metric for university research ensures that research will be produced and maximum outputs are recorded.

Further government interventions may include the introduction of new opportunities for enterprise (e.g., the increased activity observed in Port Augusta, South Australia). A benefit of the measurement from outside South Australia is that the opportunities presented in South Australia are visible. In contrast, the measurement from within New South Wales minimises the discovery of these new areas of engagement, as any change locally would be smaller and more incremental.

Whilst the interventions are often directed from a federal level in Australia, the engagement role is often more localised. This can be seen in the involvement of the New South Wales Department of Primary Industries in the agriculture-related research sector, with a limited engagement with CSIRO research stations. Quantifying these organisations at an address level is advantageous for this decision-making. Basing the measurements on the head office (Orange and Canberra for New South Wales Department of Primary Industries and CSIRO, respectively) limits the opportunity to understand the relationship between both local and distant organisations.

The research outcomes contribute to understanding the role of the many research stations at the engagement level. With the indication of the collaboration network of these research stations not only within New South Wales but wider, the ability to understand where and with whom research is being undertaken is key. This analysis allows the knowledge to be developed and analysed.

Further research into the funding sources captured within the article metadata would enhance this analysis and provide the opportunity to change government research management practices and funding allocation. This information could be used to develop an improved model that captures the direct financial involvement of government (or industry) in the research landscape.

12.2.3 University

The university sector underpins the entire generation of new knowledge in many scenarios. In many economies and societies, the sector represents the top level of new knowledge generation, making it pivotal to generating new knowledge. The social licence attached to that is related to the connection to the local economy. With the rise of international

collaborations, the change in that social licence can be seen, and now includes a connection to the international community in many cases.

Increasing internationalisation of research reflects the need for universities to broaden their impact and reach and attract international funding. Further analysis of this international funding is possible using the funding information contained within the metadata, again providing a future opportunity for research.

Whilst the measurement of only university authorship reflects the internal cooperation within an institution, there are opportunities for inter-institution collaboration on the challenges faced across the Australian agricultural research sector. This may be captured in the measurement of university and other state/territory co-authorship (and variations thereof), reflecting the collaboration on shared problems.

This work contributes to existing knowledge of research output by providing a measurement of the university–industry–government collaboration for the agricultural research sector and the location of this research. The measurement of collaborations within New South Wales and Australia, and subsequently out to the international landscape, provides the knowledge to understand the diversity of research and the opportunities presented.

This research provides insights for university research managers, project coordinators, and other interested parties. With this increased knowledge surrounding the relationships and locations of the research, future collaborations can be developed that have an increased meaning, minimising the risk of neglecting local issues.

The internationalisation of university research collaborations and the associated bi-directional flows of knowledge has increased since 2003 – and continues to grow. The challenge facing policymakers is managing the expectations of the research parties and focusing on the

relevant issues. A risk here is the focus on publications in quality journals that may require a less specific focus (a more acceptable article for an international market) than a domestic or local journal and a subsequent decrease in the impact at a local level.

Adoption of the measurement of the triple helix using the approaches set out here becomes a powerful tool to measure university output and showcases the collaborative nature of research. Furthermore, as a method to measure across time and space, the metric provides insight into changes in institutional policies. Clear communication of a standardised address format, agreed upon within all institutions, would simplify the analysis process by removing inconsistent address details.

Therefore, bringing this together, the policy recommendations for the university sector are to adopt the measurement of the triple helix and apply the analysis of both collaborations and locations. Furthermore, this new information should be utilised to develop interventions to ensure that the local needs are met, as well as the international role of the university in social and economic development in the agricultural research landscape.

12.2.4 Industry

Incentives for industry to become involved in research are varied; the validation of a new commercial idea through a scientifically rigorous and defensible process may be beneficial, or implementation of a new research-driven outcome may be required to achieve commercial adoption and validation.

Creating a knowledge-based economy requires the adoption of research by industry through the creation of new enterprises (commercialisation of research) or the adoption of new technologies (knowledge spillovers). Reflecting an increase in the knowledge capital in a region, these changes can drive new economic opportunities. The collaboration measured

within the n-tuple helix demonstrates a demand for knowledge that may result from either the commercialisation of research or knowledge spillovers.

With agriculture requiring a longer time frame for the results to be generated from experimental research (a growing season or the length of time for livestock to reach maturity), there will be a lag between the start of the experiment and observable results. Government incentives for the engagement of research services from government or university by industry exist, and these may be captured in the funding records within the metadata.

The measurement of industry engagement in the n-tuple helix can be a tool for industry to identify growth opportunities. Identifying localised collaboration networks will allow the establishment of clusters, whilst the engagement with local research organisations may enable the transfer of new technologies to a commercialisation phase. This multi-directional process requires the engagement of all actors, including universities and government, as well as international connections. Industry will require assistance in developing these connections, or researchers will need to understand the commercial opportunities for their research.

Enabling the development of industry connections will require focusing on the interests of both industry and universities. The differing goals for these may be the cause of the decline of the university and industry relationships. In contrast, industry found willing partners in the New South Wales government, other states or territories, or overseas. This change reflects that industry wants to work collaboratively, but there is an engagement issue.

From this, there is a need for continued efforts to make the university research ecosystem more accessible to industry – or vice versa. To address this, industry must know the access points of university research, and these must be open. However, the development of applied research, rather than theoretical or fundamental research, may increase this connectivity.

Finally, collaborations between industry and research organisations can be identified by measuring specialisations. Identifying areas with a higher share of Shannon's Entropy Index provides insight into where agricultural activity may be the greatest. Subsequent demand in these areas may be more significant for research outcomes if presented with the opportunity to improve productivity.

12.3 Openness of Research

An explicit goal of this work was to create an open and transparent approach to measuring Web of Science data. This was met through the presentation of the data collection phase (adopting the PRISMA framework), the use of R and RStudio (widely used free statistical and data visualisation tools), and the availability of the scripts required for the analysis through their storage in a GitHub repository¹⁰. The exception was the geocoding and mapping of the triple helix relationships, both of which required using ArcGIS services. Whilst there are routes to access the Google and Bing geocoding databases, these services are limited in terms of volumes of queries and the required API access rights. The decision was made to use ArcGIS for ease of use. Likewise, mapping the triple helix relationships was simpler within ArcGIS than within R – but not impossible in R.

The intention was to move from the hidden algorithm approach used by other researchers to a more open and accessible tool that can be expanded and refined over time. The ability to scale and develop the tool is advantageous for research evaluation with Australia, as this provides the foundations for a new measurement method of collaboration and relevancy.

¹⁰ https://github.com/Ed-Lefley/PhD_Ntuple-helix.git

12.4 Future Work

A natural progression of the triple helix analysis is to expand to the remaining states and territories at individual levels or to a complete model of Australia. With a distinct state and federal governance system, the ability to separate the government activity into state and federal levels is present. This provides opportunities for examining different policies that can be implemented in the differing election cycles.

In the era of open-access publication, the Web of Science data contains the access status of publications (as well as citations 180 days before download). This data would allow for further analysis of the potential and actual impact that research may have. The role of open access, and therefore a more accessible research ecosystem, is an area that would benefit from increased investigation.

Continued identification of where there are strong research bases and industry specialisations will allow for learning to be shared between different agents. Conversely, the identification of weaknesses will allow for structured action (potentially government-led – the third pillar of the triple helix) to be undertaken to build the required resilient communities. The occurrence of mismatched triple helix and industry specialisation may reflect workforce skills shortages or under-skilling, and therefore the need for extension to be undertaken to build these areas. Using an industry specialisation metric to reflect theoretical demand, the future engagement of industry will enable improved research outcomes as it matches the needs of the different regions.

These opportunities for future work, as well as interrogation of the Web of Science data regarding funding and keywords, will provide increased knowledge of the Australian research landscape in terms of origins, engagement, and connections at both a domestic and an international scale.

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Appendix i: The Original (pre-2021) N-Tuple Helix Calculation

The original Shannon's Entropy calculation is a composite of the probability of an event (or state) or combination of event (states).

The calculation of the *H-Value* in a Shannon's Entropy calculation requires either the assumption of an equal likelihood distribution (50:50 chance, such as heads or tails), or the calculation of the probability of the event and the probability of not the event. To do this for the required actors, the calculations require the establishment of sets. With these sets, the distribution can be calculated.

Drawing upon the examples provided by Leydesdorff and Sun (2009), an example of the traditional triple helix calculation can be demonstrated. For a single actor such as the university sector, represented as (1,*,*), this can be calculated using the probability for each set – the occurrence of the set and the non-occurrence of the set (0,*,*).

$$H(U) = - \log_2 \left(\sum \frac{\Sigma(1,*,*)}{N} \right) - \log_2 \left(\sum \frac{\Sigma(0,*,*)}{N} \right)$$

Equation i-1

Applied to a pair, such as university and industry collaboration (UI), represented as (1,1,*) in sets, the calculation of the mutual information (*T*) can be performed.

Requiring an additional two H-Values, H(I) and H(UI), the final calculation is:

$$\begin{aligned}
T(UI) = & \left(-\log_2 \left(\sum \frac{\Sigma(1,*,*)}{N} \right) - \log_2 \left(\sum \frac{\Sigma(0,*,*)}{N} \right) \right) \\
& + \left(-\log_2 \left(\sum \frac{\Sigma(*,1,*)}{N} \right) - \log_2 \left(\sum \frac{\Sigma(*,0,*)}{N} \right) \right) \\
& - \left(-\log_2 \left(\sum \frac{\Sigma(1,1,*)}{N} \right) - \log_2 \left(\sum \frac{\Sigma(0,0,*)}{N} \right) \right)
\end{aligned}$$

Equation i-2

The subsequent transmission value calculation for the complete triple helix (UIG) becomes:

$$T(UIG) = H(U) + H(I) + H(G) - H(UI) - H(IG) - (HUG) + H(UIG)$$

Equation i-3

Expanding this calculation from the triple helix (three actors) to the quadruple helix (four actors) requires the calculation of the additional combinations. Expanded to four actors there are now fifteen combinations comprising single actors, paired actors, triple combinations, and a single quadruple.

Drawing on the sets from the triple helix, the same approach of the probability of the event and the probability of the non-event are calculated.

For example, consider the set in the form of (U,I,G,S) can be represented as a binary value (1 or 0) set. In the case of a university author affiliation, the binary set would be (1,*,*,*) where * denotes 1 or 0. Extended to a pair, of University and Industry, the set would be (1,1,*,*).

With these combinations there is the inverse – the set that is not University (0,*,*,*) or University and Industry (0,0,*,*), and so forth. Note however, there is no inverse of University, Industry, Government and Other State/Overseas as a complete quadruple helix.

Extended to the quintuple, there are 31 combination that can be defined as combinations of University, Industry, Government, Other State and Foreign – represented as sets of (U, I, G, S, F).

Having matched each individual address to an organisation type, it is possible to therefore convert the individual address records to sets of actors; for example, ‘university, industry, university’.

With this matched organisational data, it was chosen to categorise data as a true (1) or false (0), using a series of rules in R that would create additional columns for each actor.

Subsequently combined into a single value, separated by a comma, this binary classification allows for the creation of sets as each value is applied to the address data. Applied to the example above, the quadruple set would be (1,1,0,0) and as a quintuple as (1,1,0,0,0)

With up to 31 sets now calculated (depending on quadruple or quintuple helix being calculated) the calculation could now be performed using the wildcard (*) within the sets.

Appendix ii: Comparison of Clipper Code

Notes/Process explainer	New	Original
	<p>** revised 16 Feb. 2021;MAJOR REVISIONS</p> <p>** th4 for Hungarian data</p> <p>SET(_SET_EOL, CHR(10))</p>	<p>** th4 for Hungarian data</p> <p>SET(_SET_EOL, CHR(10))</p>
Top of program – introductory text	<p>** input data</p> <p>clear screen</p> <p>* vn1 = 0</p> <p>* vn2 = 0</p> <p>* vn3 = 0</p> <p>* vn4 = 0</p> <p>vtemp = "Y"</p> <p>TEXT</p> <p>v.2 of TH4.exe; 16 Feb. 2021</p> <p>This routine computes three- and four-dimensional transmissions between and among NOMINAL variables. Input file is data.txt with five fields as follows:</p> <p>"id001","12","text1","var3","var4"</p> <p>The first variable is an identifier, the four next ones are nominal values. Note that numbers will be handled as character strings. Each case on one line, string variables, the comma is used as delimiter.</p> <p>Output file is th4.dbf; new runs are appended to an existing file; if absent, th4.dbf is generated by the program. The program assumes that all observations are valid; typos lead to the introduction of a new class!</p> <p>(c) Loet Leydesdorff, 2012, 2021</p>	<p>** input data</p> <p>clear screen</p> <p>* vn1 = 0</p> <p>* vn2 = 0</p> <p>* vn3 = 0</p> <p>* vn4 = 0</p> <p>vtemp = "Y"</p> <p>TEXT</p> <p>This routine computes three- and four-dimensional transmissions between and among NOMINAL variables. Input file is data.txt with five fields as follows:</p> <p>"id001","12","text1","var3","var4"</p> <p>The first variable is an identifier, the four next ones are nominal values. Note that numbers will be handled as character strings. Each case on one line, string variables, the comma is used as delimiter.</p> <p>Output file is th4.dbf; new runs are appended to an existing file; if absent, th4.dbf is generated by the program. The program assumes that all observations are valid; typos lead to the introduction of a new class!</p> <p>(c) Loet Leydesdorff, 2012</p>
<p>Setting the number of Organisation types Variable:</p> <p>Leydesdorff R</p> <p>Vn1 U</p> <p>Vn2 I</p> <p>Vn3 G</p> <p>Vn4 O</p> <p>If no vn4 (only triple helix) ignore vn4</p>	<p>ENDTEXT</p> <p>wait</p> <p>clear screen</p> <p>vname = space(30)</p> <p>@ 5,1 say "name of the run ?" get vname</p> <p>read</p> <p>clear screen</p> <p>@ 5,1 say "wait >> "</p> <p>* @ 8,1 Say "N of categories of the first variable" Get vn1</p> <p>* @ 9,1 Say "N of categories of the second variable " Get vn2</p> <p>* @10,1 Say "N of categories of the third variable" get vn3</p> <p>* read</p>	<p>ENDTEXT</p> <p>wait</p> <p>clear screen</p> <p>vname = space(30)</p> <p>@ 5,1 say "name of the run ?" get vname</p> <p>read</p> <p>clear screen</p> <p>@ 5,1 say "wait >> "</p> <p>* @ 8,1 Say "N of categories of the first variable" Get vn1</p> <p>* @ 9,1 Say "N of categories of the second variable " Get vn2</p> <p>* @10,1 Say "N of categories of the third variable" get vn3</p> <p>* read</p>

Notes/Process explainer	New	Original
	<pre> * @11,1 say "Is there a fourth variable ?" get vtemp * read * clear screen * if upper(vtemp) = "Y" * @11,1 Say "N of categories of the fourth variable " get vn4 * read * else * vn4 = 0 * endif </pre>	<pre> * @11,1 say "Is there a fourth variable ?" get vtemp * read * clear screen * if upper(vtemp) = "Y" * @11,1 Say "N of categories of the fourth variable " get vn4 * read * else * vn4 = 0 * endif </pre>
<p>Create data file using the id number (row number) and the data from vn1, vn2, vn3, vn4.</p> <p>Count all records using recount() to get denominator</p> <p>Eof = End of File</p>	<pre> select 1&& generate file input.dbf and read input data delete file temp.dbf create temp append blank replace field_name with "id" replace field_type with "c" replace field_len with 30 append blank replace field_name with "v1" replace field_type with "c" replace field_len with 30 append blank replace field_name with "v2" replace field_type with "c" replace field_len with 30 append blank replace field_name with "v3" replace field_type with "c" replace field_len with 30 * if vn4 > 0 append blank replace field_name with "v4" replace field_type with "c" replace field_len with 30 * endif create input from temp append from data.txt delimited go top do while .not. eof() if len(trim(id)) = 0 delete endif skip enddo pack go top vN = recount() </pre>	<pre> select 1&& generate file input.dbf and read input data delete file temp.dbf create temp append blank replace field_name with "id" replace field_type with "c" replace field_len with 30 append blank replace field_name with "v1" replace field_type with "c" replace field_len with 30 append blank replace field_name with "v2" replace field_type with "c" replace field_len with 30 append blank replace field_name with "v3" replace field_type with "c" replace field_len with 30 * if vn4 > 0 append blank replace field_name with "v4" replace field_type with "c" replace field_len with 30 * endif create input from temp append from data.txt delimited go top do while .not. eof() if len(trim(id)) = 0 delete endif skip enddo pack go top vN = recount() </pre>
Write output file (th4.dbf eventually) with the Shannon's Entropy for singles, pairs, trios, and	<pre> ** make output file select 2 use temp delete all pack </pre>	<pre> ** make output file select 2 use temp delete all pack </pre>

Notes/Process explainer	New	Original
	replace field_dec with 9 append blank replace field_name with "Hwxz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Hwyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Hxyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Hwxyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9	replace field_dec with 9 append blank replace field_name with "Hwxz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Hwyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Hxyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Hwxyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9
<p>Write output file (th4.dbf eventually) with the Transmission value for pairs, trios, and quadruple combinations.</p> <p>Create 15 columns in total for Transmission</p>	append blank replace field_name with "Twx" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twy" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Txy" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Txz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Tyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twxy" replace field_type with "n" replace field_len with 16 replace field_dec with 9	append blank replace field_name with "Twx" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twy" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Txy" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Txz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Tyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twxy" replace field_type with "n" replace field_len with 16 replace field_dec with 9

Notes/Process explainer	New	Original
	<pre> append blank replace field_name with "Twxz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Txyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twxyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Rwxyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "name" replace field_type with "c" replace field_len with 30 append blank replace field_name with "N_" replace field_len with 9 replace field_type with "n" if .not. file("th4.dbf") create th4 from temp else use th4 endif </pre>	<pre> append blank replace field_name with "Twxz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Txyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Twxyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "Rwxyz" replace field_type with "n" replace field_len with 16 replace field_dec with 9 append blank replace field_name with "name" replace field_type with "c" replace field_len with 30 append blank replace field_name with "N_" replace field_len with 9 replace field_type with "n" if .not. file("th4.dbf") create th4 from temp else use th4 endif </pre>
Set the Shannon's Entropy values as zero (simplifies calculation in Clipper87)	<pre> *** vHw = 0 vHx = 0 vHy = 0 vHz = 0 vHwx = 0 vHwy = 0 vHwz = 0 vHxy = 0 vHxz = 0 vHyz = 0 vHwxy = 0 vHwxz = 0 vHwyz = 0 vHxyz = 0 vHwxyz = 0 </pre>	<pre> *** vHw = 0 vHx = 0 vHy = 0 vHz = 0 vHwx = 0 vHwy = 0 vHwz = 0 vHxy = 0 vHxz = 0 vHyz = 0 vHwxy = 0 vHwxz = 0 vHwyz = 0 vHxyz = 0 vHwxyz = 0 </pre>

Notes/Process explainer	New	Original
<p>Map the calculation for singles (W,X,Y,Z or U,I,G,O)</p> <p>Denominator is number of rows as imported</p>	<pre> select 1 index on v1 to v1 do while .not. eof() store v1 to vv1 n = 0 do while v1 == vv1 .and. .not. eof() n = n + 1 skip enddo vHw = vHw - (n/vN) * log(n/vN) / log(2) enddo index on v2 to v2 do while .not. eof() store v2 to vv2 n = 0 do while v2 == vv2 .and. .not. eof() n = n + 1 skip enddo vHx = vHx - (n/vN) * log(n/vN) / log(2) enddo index on v3 to v3 do while .not. eof() store v3 to vv3 n = 0 do while v3 == vv3 .and. .not. eof() n = n + 1 skip enddo vHy = vHy - (n/vN) * log(n/vN) / log(2) enddo * if vn4 > 0 index on v4 to v4 do while .not. eof() store v4 to vv4 n = 0 do while v4 == vv4 .and. .not. eof() n = n + 1 skip enddo vHz = vHz - (n/vN) * log(n/vN) / log(2) enddo * else *Hz = 0 * endif select 2 append blank replace Hw with vHw, Hx with vHx, Hy with vHy, Hz with vHz </pre>	<pre> select 1 index on v1 to v1 do while .not. eof() store v1 to vv1 n = 0 do while v1 == vv1 .and. .not. eof() n = n + 1 skip enddo vHw = vHw - (n/vN) * log(n/vN) / log(2) enddo index on v2 to v2 do while .not. eof() store v2 to vv2 n = 0 do while v2 == vv2 .and. .not. eof() n = n + 1 skip enddo vHx = vHx - (n/vN) * log(n/vN) / log(2) enddo index on v3 to v3 do while .not. eof() store v3 to vv3 n = 0 do while v3 == vv3 .and. .not. eof() n = n + 1 skip enddo vHy = vHy - (n/vN) * log(n/vN) / log(2) enddo * if vn4 > 0 index on v4 to v4 do while .not. eof() store v4 to vv4 n = 0 do while v4 == vv4 .and. .not. eof() n = n + 1 skip enddo vHz = vHz - (n/vN) * log(n/vN) / log(2) enddo * else *Hz = 0 * endif select 2 append blank replace Hw with vHw, Hx with vHx, Hy with vHy, Hz with vHz </pre>
Double the denominator to represent the increase	vn1 = vn	

Notes/Process explainer	New	Original
<p>in dimensionality moving towards pairs.</p> <p>Create temp file (temp2.dbf)</p>	<p>$vn = 2 * vn1$ && 16 Feb 2021: with increasing dimensionality the number of options increases</p> <pre> select 9 delete file temp.dbf create temp append blank replace field_type with "c", field_len with 30, field_name with "count" delete file temp2.dbf create temp2 from temp </pre>	
<p>Original: Create a new variable (v12) that represents pairs</p> <p>HWX parallel to HUI</p> <p>New:</p> <p>Write v1 (W/U) to vv1</p> <p>Write v2 (X/I) to vv2</p> <p>Sum vv1 and vv2</p> <p>Subtract sum from $n*2$</p>	<p>* wx, wy, wz, xy, xz, yz</p> <pre> select 1 set index to go top do while .not. eof() store v1 to vv1 store v2 to vv2 select 9 append blank replace count with vv1 append blank replace count with vv2 select 1 skip enddo select 9 use temp2 index on val(trim(count)) to icount go top vHwx = 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 do while val(trim(count)) == vv1 .and. .not. eof() n = n + 1 skip enddo vHwx = vHwx - (n/vN) * log(n/vN) / log(2) enddo </pre>	<pre> select 1 index on v1 + v2 to v12 do while .not. eof() store v1 to vv1 store v2 to vv2 n = 0 do while v1 == vv1 .and. v2 == vv2 .and. .not. eof() n = n + 1 skip enddo vHwx = vHwx - (n/vn) * log(n/vn) / log(2) enddo </pre>
<p>Original: Create a new variable (v16) that represents pairs</p> <p>HWY parallel to HUG</p>	<p>* wz, wy, xy, xz, yz** wx</p> <pre> select 9 use temp2 delete all pack select 1 set index to go top do while .not. eof() store v1 to vv1 store v3 to vv2 </pre>	<pre> index on v1 + v3 to v16 do while .not. eof() store v1 to vv1 store v3 to vv3 n = 0 do while v1 == vv1 .and. v3 == vv3 .and. .not. eof() n = n + 1 skip enddo vHwy = vHwy - (n/vn) * log(n/vn) / log(2) enddo </pre>

Notes/Process explainer	New	Original
	<pre> select 9 append blank replace count with vv1 append blank replace count with vv2 select 1 skip enddo select 9 use temp2 index on val(trim(count)) to icount go top vHwy = 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 do while val(trim(count)) == vv1 .and. .not. eof() n = n + 1 skip enddo vHwy = vHwy - (n/vN) * log(n/vN) / log(2) enddo </pre>	
Original: Create a new variable (v23) that represents pairs HXY parallel to HIG	<pre> * wz, xy, xz, yz** wx, wy select 9 use temp2 delete all pack ** xy select 1 set index to go top do while .not. eof() store v2 to vv1 store v3 to vv2 select 9 append blank replace count with vv1 append blank replace count with vv2 select 1 skip enddo select 9 use temp2 index on val(trim(count)) to icount go top vHxy = 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 </pre>	<pre> index on v2 + v3 to v23 do while .not. eof() store v2 to vv2 store v3 to vv3 n = 0 do while v2 == vv2 .and. v3 == vv3 .and. .not. eof() n = n + 1 skip enddo vHxy = vHxy - (n/vn) * log(n/vn) / log(2) enddo </pre>

Notes/Process explainer	New	Original
	<pre> do while val(trim(count)) = vv1 .and. .not. eof() n = n + 1 skip enddo vHxy = vHxy - (n/vN) * log(n/vN) / log(2) enddo </pre>	
<p>Original: Create a new variable (v24) that represents pairs HXZ parallel to HUO</p>	<pre> * wx, xz, yz** wz, wy, xy, select 9 use temp2 delete all pack ** xz select 1 set index to go top do while .not. eof() store v2 to vv1 store v4 to vv2 select 9 append blank replace count with vv1 append blank replace count with vv2 select 1 skip enddo select 9 index on val(trim(count)) to icount go top vHxz = 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 do while val(trim(count)) = vv1 .and. .not. eof() n = n + 1 skip enddo vHxz = vHxz - (n/vN) * log(n/vN) / log(2) enddo </pre>	<pre> index on v2 + v4 to v24 do while .not. eof() store v2 to vv2 store v4 to vv4 n = 0 do while v2 == vv2 .and. v4 == vv4 .and. .not. eof() n = n + 1 skip enddo vHxz = vHxz - (n/vn) * log(n/vn) / log(2) enddo </pre>
<p>Original: Create a new variable (v34) that represents pairs</p> <p>New:</p> <p>HYZ Parallel to HGO</p>	<pre> * yz** wz, wy, xy, wx, xz, select 9 use temp2 delete all pack select 1 set index to go top do while .not. eof() store v3 to vv1 </pre>	<pre> index on v3 + v4 to v34 do while .not. eof() store v3 to vv3 store v4 to vv4 n = 0 </pre>

Notes/Process explainer	New	Original
	<pre> store v4 to vv2 select 9 append blank replace count with vv1 append blank replace count with vv2 select 1 skip enddo select 9 index on val(trim(count)) to icount go top vHyz= 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 do while val(trim(count)) = vv1 .and. .not. eof() n = n + 1 skip enddo vHyz = vHyz - (n/vN) * log(n/vN) / log(2) enddo select 9 use temp2 delete all pack </pre>	<pre> do while v3 == vv3 .and. v4 == vv4 .and. .not. eof() n = n + 1 skip enddo vHyz = vHyz - (n/vn) * log(n/vn) / log(2) enddo </pre>
<p>Original: Create a new variable (v14) that represents pairs</p> <p>New:</p> <p>HWZ Parallel to HGO</p>	<pre> select 1 set index to go top do while .not. eof() store v1 to vv1 store v4 to vv2 select 9 append blank replace count with vv1 append blank replace count with vv2 select 1 skip enddo select 9 index on val(trim(count)) to i9 go top vHwz= 0 do while .not. eof() store val(trim(count)) to vv1 nhelp = 0 do while val(trim(count)) = vv1 .and. .not. eof() nhelp = nhelp + 1 skip enddo </pre>	<pre> index on v1 + v4 to v14 do while .not. eof() store v1 to vv1 store v4 to vv4 n = 0 do while v1 == vv1 .and. v4 == vv4 .and. .not. eof() n = n + 1 skip enddo vHwz = vHwz - (n/vn) * log(n/vn) / log(2) enddo </pre>

Notes/Process explainer	New	Original
	<pre> vHwz = vHwz - (nhelp/vN) * log(nhelp/vN) / log(2) vhelp = - (nhelp/vN) * log(nhelp/vN) / log(2) *? str(nhelp) + str(vhelp) + str(vHwz) enddo * ? str(vHwz) </pre>	
	<pre> *** wz, wy, xy, wx, xz, yz select 2 replace Hwx with vHwx, Hwy with vHwy, Hwz with vHwz replace Hxy with vHxy, Hxz with vHxz, Hyz with vHyz </pre>	<pre> select 2 replace Hwx with vHwx, Hwy with vHwy, Hwz with vHwz replace Hxy with vHxy, Hxz with vHxz, Hyz with vHyz </pre>
	<pre> vn = 3 * vn1 && Feb 21 select 9 use temp2 delete all pack select 1 set index to go top do while .not. eof() store v1 to vv1 store v2 to vv2 store v3 to vv3 select 9 append blank replace count with vv1 append blank replace count with vv2 append blank replace count with vv3 select 1 skip enddo select 9 index on val(trim(count)) to icount go top vHwxy = 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 do while val(trim(count)) = vv1 .and. .not. eof() n = n + 1 skip enddo vHwxy = vHwxy - (n/vN) * log(n/vN) / log(2) enddo select 9 use temp2 </pre>	<pre> select 1 index on v1 + v2 + v3 to v123 do while .not. eof() store v1 to vv1 store v2 to vv2 store v3 to vv3 n = 0 do while v1 == vv1 .and. v2 == vv2 .and. v3 == vv3 .and. .not. eof() n = n + 1 skip enddo vHwxy = vHwxy - (n/vn) * log(n/vn) / log(2) enddo index on v1 + v2 + v4 to v124 do while .not. eof() store v1 to vv1 store v2 to vv2 store v4 to vv4 n = 0 do while v1 == vv1 .and. v2 == vv2 .and. v4 == vv4 .and. .not. eof() n = n + 1 skip enddo vHwxz = vHwxz - (n/vn) * log(n/vn) / log(2) enddo index on v1 + v3 + v4 to v134 do while .not. eof() store v1 to vv1 store v3 to vv3 store v4 to vv4 n = 0 do while v1 == vv1 .and. v3 == vv3 .and. v4 == vv4 .and. .not. eof() n = n + 1 skip enddo vHwyz = vHwyz - (n/vn) * log(n/vn) / log(2) enddo index on v2 + v3 + v4 to v234 do while .not. eof() </pre>

Notes/Process explainer	New	Original
	<pre> delete all pack select 1 set index to go top do while .not. eof() store v1 to vv1 store v2 to vv2 store v4 to vv3 select 9 append blank replace count with vv1 append blank replace count with vv2 append blank replace count with vv3 select 1 skip enddo select 9 index on val(trim(count)) to icount go top vHwxz = 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 do while val(trim(count)) = vv1 .and. .not. eof() n = n + 1 skip enddo vHwxz = vHwxz - (n/vN) * log(n/vN) / log(2) enddo select 9 use temp2 delete all pack select 1 set index to go top do while .not. eof() store v1 to vv1 store v3 to vv2 store v4 to vv3 select 9 append blank replace count with vv1 append blank replace count with vv2 append blank replace count with vv3 select 1 skip </pre>	<pre> store v2 to vv2 store v3 to vv3 store v4 to vv4 n = 0 do while v2 == vv2 .and. v3 == vv3 .and. v4 = vv4 .and. .not. eof() n = n + 1 skip enddo vHxyz = vHxyz - (n/vn) * log(n/vn) / log(2) enddo select 2 replace Hwxy with vHwxy, Hwxz with vHwxz, Hwyz with vHwyz, Hxyz with vHxyz </pre>

Notes/Process explainer	New	Original
	<pre> enddo select 9 index on val(trim(count)) to i9a go top vHwyz = 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 do while val(trim(count)) = vv1 .and. .not. eof() n = n + 1 skip enddo vHwyz = vHwyz - (n/vN) * log(n/vN) / log(2) enddo select 9 use temp2 delete all pack select 1 set index to go top do while .not. eof() store v2 to vv1 store v3 to vv2 store v4 to vv3 select 9 append blank replace count with vv1 append blank replace count with vv2 append blank replace count with vv3 select 1 skip enddo select 9 index on val(trim(count)) to icount go top vHxyz = 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 do while val(trim(count)) = vv1 .and. .not. eof() n = n + 1 skip enddo vHxyz = vHxyz - (n/vN) * log(n/vN) / log(2) enddo </pre>	
	<pre> vn = 4 * vn1 select 9 </pre>	<pre> select 1 index on v1 + v2 + v3 + v4 to v1234 </pre>

Notes/Process explainer	New	Original
	<pre> use temp2 delete all pack select 1 set index to go top do while .not. eof() store v1 to vv1 store v2 to vv2 store v3 to vv3 store v4 to vv4 select 9 append blank replace count with vv1 append blank replace count with vv2 append blank replace count with vv3 append blank replace count with vv4 select 1 skip enddo vn = 4 * vn1 select 9 index on val(trim(count)) to icount go top vHwxyz = 0 do while .not. eof() store val(trim(count)) to vv1 n = 0 do while val(trim(count)) = vv1 .and. .not. eof() n = n + 1 skip enddo vHwxyz = vHwxyz - (n/vN) * log(n/vN) / log(2) enddo select 9 delete all pack </pre>	<pre> do while .not. eof() store v1 to vv1 store v2 to vv2 store v3 to vv3 store v4 to vv4 n = 0 do while v1==vv1 .and. v2 == vv2 .and. v3 == vv3 .and. v4 = vv4 .and. .not. eof() n = n + 1 skip enddo vHwxyz = vHwxyz - (n/vn) * log(n/vn) / log(2) enddo </pre>
	<pre> select 2 replace Hwxy with vHwxy, Hwxz with vHwxz, Hwyz with vHwyz, Hxyz with vHxyz replace Hwxyz with vHwxyz </pre>	<pre> select 2 replace Hwxyz with vHwxyz </pre>
	<pre> ** transmissions replace Twx with (Hw + Hx) - Hwx replace Twy with (Hw + Hy) - Hwy replace Twz with (Hw + Hz) - Hwz replace Txy with (Hx + Hy) - Hxy replace Txz with (Hx + Hz) - Hxz </pre>	<pre> ** transmissions replace Twx with (Hw + Hx) - Hwx replace Twy with (Hw + Hy) - Hwy replace Twz with (Hw + Hz) - Hwz replace Txy with (Hx + Hy) - Hxy replace Txz with (Hx + Hz) - Hxz </pre>

Notes/Process explainer	New	Original
	replace Tyz with $(Hy + Hz) - Hyz$ replace Twxy with $(Hw + Hx + Hy - Hwx - Hwy - Hxy + Hwxy)$ replace Twxz with $(Hw + Hx + Hz - Hwx - Hwz - Hxz + Hwxz)$ replace Twyz with $(Hw + Hy + Hz - Hwy - Hwz - Hyz + Hwyz)$ replace Txyz with $(Hx + Hy + Hz - Hxy - Hxz - Hyz + Hxyz)$ replace Twxyz with $(Hw + Hx + Hy + Hz - Hwx - Hwy - Hwz - Hxy - Hxz - Hyz + Hwxy + Hwxz + Hwyz + Hxyz - Hwxyz)$ replace Rwxxyz with $-(Hw + Hx + Hy + Hz - Hwx - Hwy - Hwz - Hxy - Hxz - Hyz + Hwxy + Hwxz + Hwyz + Hxyz - Hwxyz)$ replace name with trim(vname) replace N_ with vN clear all return	replace Tyz with $(Hy + Hz) - Hyz$ replace Twxy with $(Hw + Hx + Hy - Hwx - Hwy - Hxy + Hwxy)$ replace Twxz with $(Hw + Hx + Hz - Hwx - Hwz - Hxz + Hwxz)$ replace Twyz with $(Hw + Hy + Hz - Hwy - Hwz - Hyz + Hwyz)$ replace Txyz with $(Hx + Hy + Hz - Hxy - Hxz - Hyz + Hxyz)$ replace Twxyz with $(Hw + Hx + Hy + Hz - Hwx - Hwy - Hwz - Hxy - Hxz - Hyz + Hwxy + Hwxz + Hwyz + Hxyz - Hwxyz)$ replace Rwxxyz with $-(Hw + Hx + Hy + Hz - Hwx - Hwy - Hwz - Hxy - Hxz - Hyz + Hwxy + Hwxz + Hwyz + Hxyz - Hwxyz)$ replace name with trim(vname) replace N_ with vN clear all return

Appendix iii: Details of R Code and Processes

Underpinning the process of not only the ingestion of the data from Web of Science exports, but also the ethos of transparency and replication, the following are excerpts of the code structure and routines that were written to import the Web of Science data into R for analysis.

R (R Core Team, 2022) and RStudio (RStudio Team, 2022), as well as the following packages were used within the RStudio environment:

- ‘readxl’ version 1.4.1, (Wickham & Bryan, 2022)
- ‘dplyr’ version 1.0.10 (Wickham et al., 2022)
- ‘plyr’ version 1.8.7 (Wickham, 2011)
- ‘stringr’ version 1.4.1 (Wickham, 2022)
- ‘DataCombine’ version 0.2.21 (Gandrud, 2016)
- ‘data.table’ version 1.14.4 (Dowle & Srinivasan, 2022)
- ‘tibble’ version 3.1.8 (Müller & Wickham, 2022)
- ‘stringi’ version 1.7.8 (Gagolewski, 2022)
- ‘ggplot2’ version 3.3.6 (Wickham, 2016)
- ‘ggthemes’ version 4.2.4 (Arno, 2021)

Broken into segments, each script allowed for a standardised process of data handling that was the same for both the ‘All Web of Science’ and ‘Ag7’ – denoted as WoS_All (or a derivative of) and Ag7 within the scripts.

With the Web of Science data downloaded as Microsoft Excel (xls) files in batches of five hundred records per file, these were all saved in annual folders. Each record contains 68 columns of data, of which the key columns used in this research are those of the addresses and the year of publication.

iii.i Runsheet

An overall run script simplifies the process of running a repeatable script, an overall run script was generated that called the scripts in turn. Data was treated in a single block, rather than year by year data.

iii.ii Import

A simple script was written to import the CSV files in a single process, with variations for each year. Within this code, the import of the individual files from a stored file, for the subsequent analysis

```
#1 Load Read XLS Tool
library(readxl)

###For each year, change WoS_YYYY
##2003
setwd("~/TH_2022_02/Data/2020_12_29_DL_Yr2003")
xlsfiles <- list.files(pattern = "\\*.xls")
WoS_2003 <- read_xls(xlsfiles[1])
for (f in xlsfiles[-1]) WoS_2003 <- rbind(WoS_2003, read_xls(f))
```

Segment of R Script for the import of Excel files into R for analysis.

A simple script was written to import the CSV files in a single process, with an accelerated process for importing files in bulk. With the download of files from the Web of Science database, the limitation is that the files are limited to 500 records per file, with over 270,000 records, there were over 540 files to import.

From this file, the address data is extracted from the column titled “Addresses”.

```
#2022 01 27
#Ed Lefley
#Regex Corrections
#Running the TH calculations later has thrown up inconsistencies in the
Address column for a number of records
#These records require fix of a record that threw an invalid regular
expression because of a missing ) - record 96462 - fix using
https://stackoverflow.com/questions/27721008/how-do-i-deal-with-special-
characters-like-in-my-regex Only one occurrence so use sub instead of gsub
```



```

#Required packages
library(stringr)
library(dplyr)
library(DataCombine)

#Error was "(UFJF, Juiz De Fora, Brazil;", which required editing the CSV
file to correct (2013, Savedrecs(18), line 498) by adding the required )
in the original record.
#Error in gsub(pattern = replaceData[i, from], replacement =
replaceData[i, : invalid regular expression 'CREAF, Cerdanyola Del Valles
(18193, Catalonia, Spain', reason 'Missing ')'' Corrected in Reorder and
clean
#https://stackoverflow.com/questions/31585111/regular-expression-error-
when-using-stringr-r-package-to-search-for-curly-brac
WoS_All_D <- data.frame(WoS_All_Record$Addresses)
WoS_All_D <- rename(WoS_All_D, Addresses_D = WoS_All_Record.Addresses)

WoS_All_D <- str_replace_all(WoS_All_D$Addresses_D, "\\(18193", "018193")
#Fix address 207182
#Error in gsub(pattern = replaceData[i, from], replacement =
replaceData[i, : invalid regular expression 'Oslo Metropolitan Univ, Fac
Hlth Sci, ****15, Oslo, Norway', reason 'Invalid use of repetition
operators'In addition: Warning message:tIn gsub(pattern = replaceData[i,
from], replacement = replaceData[i, : TRE pattern compilation error
'Invalid use of repetition operators. Manually corrected in original
record, (2018, savedrecs(02), line 32)
#Fix: https://stackoverflow.com/questions/31585111/regular-expression-
error-when-using-stringr-r-package-to-search-for-curly-brac
****15 affected record number 197353
#Led to discovery of *,*, errors elsewhere
#WoS_All_D <- gsub('\\****15', '15', WoS_All_D) #Fix Norwegian Address
WoS_All_D <- str_replace_all(WoS_All_D, "\\*", "")
#WoS_All_D <- gsub("\\*", "", WoS_All_D) #Fix 4 other records that had *.
WoS_All_D <- str_replace_all(WoS_All_D, ", , ,|, ,", "")

WoS_All_D <- gsub("\\[.*?\\]", "", WoS_All_D)
WoS_All_D <- data.frame(WoS_All_D)

WoS_All <- cbind(WoS_All_Record, WoS_All_D)
colnames(WoS_All, do.NULL = FALSE)
WoS_All <- data.frame(WoS_All)

```

Excerpt of R Script for the cleaning and management of data.

With cleaned data, and errors removed, the process of separating and reordering the many addresses from the single column can commence.

iii.iii Separating and Reordering Addresses

To reorder the addresses, it was necessary to split them into a vector for subsequent handling.

iii.iii.i Convert Data Frame to Vector

The next stage of the process was to organise the data into a manageable form; the data was processed following the structure laid out in Figure 5-1. This code required the rearrangement of the address field in the Web of Science data; without modifying the original dataset, this was undertaken with a duplicated column of address data.

```
#Cleaning Duplicates
#2021 02 14
#Ed Lefley

##Convert Convert Addresses to matrix then vector, based on
https://www.tutorialspoint.com/how-to-convert-columns-of-an-r-data-frame-
into-a-single-vector

##Packages needed
library(stringr)
library(data.table)

WoS_AA <- (as.vector(as.matrix(WoS_All_Addresses)))
WoS_AA <- unlist(strsplit(WoS_AA,";"))
WoS_AA <- as.matrix(WoS_AA)
WoS_AA <- trimws(WoS_AA,"both")

WoS_AAU <- as.data.frame(unique(WoS_AA))
WoS_U_D <- str_split(WoS_AAU$V1, ",",n=Inf, simplify = TRUE)

WoS_AA <- as.data.frame(WoS_AA)
WoS_A_D <- str_split(WoS_AA$V1, ",",n=Inf, simplify = TRUE)
```

Segment of R Script for the to split data frame to vector

iii.iii.ii Rearranging Addresses

With the newly arranged data, a script was developed to bring the data into a new format for ease of geo-coding in the long term.

```
###2021 01 12
#Revised 2021 02 05
#Revised 2021 02 08
#Revised 2021 02 24 (Finalised)
#Revised 2021 10 25 (Including all)
#Ed Lefley
#Rearranging address details so that Google Maps is correct, based on
Garvan issue found 2021 01 11

library(stringr)
```

```

library(data.table)

#Take a sample and add an extra unique character - in this case ~
#test_split <- gsub("[,]", "~", WoS_2017Addresses[1:150])
#Split at the ~

#DF names: WoS_U_Addresses and WoS_A_D

#convert matrix to data.frame
WoS_U_D <- data.frame(WoS_U_D)
WoS_A_D <- data.frame(WoS_A_D)
#New Columns: V1:V13
#Reverse the order
WoS_U_D_REV <-
(paste(WoS_U_D$X13, WoS_U_D$X12, WoS_U_D$X11, WoS_U_D$X10, WoS_U_D$X9, WoS_U_D$
X8, WoS_U_D$X7, WoS_U_D$X6, WoS_U_D$X5, WoS_U_D$X4, WoS_U_D$X3, WoS_U_D$X2, WoS_U
_D$X1, sep = "~"))

WoS_U_D_REV <- as.data.frame(WoS_U_D_REV)
WoS_U_D_REV <- gsub("~~~", "", WoS_U_D_REV$WoS_U_D_REV)
WoS_U_D_REV <- gsub("~~", "", WoS_U_D_REV)
WoS_U_D_REV <- gsub("~", "~", WoS_U_D_REV)
WoS_U_D_REV <- as.data.frame(WoS_U_D_REV)
WoS_U_D_REV <- trimws(WoS_U_D_REV$WoS_U_D_REV)
WoS_U_REV_DD <- as.data.frame(WoS_U_D_REV)

#New Columns: V1:V13 for _All
#Reverse the order
WoS_A_D_REV <-
(paste(WoS_A_D$X13, WoS_A_D$X12, WoS_A_D$X11, WoS_A_D$X10, WoS_A_D$X9, WoS_A_D$
X8, WoS_A_D$X7, WoS_A_D$X6, WoS_A_D$X5, WoS_A_D$X4, WoS_A_D$X3, WoS_A_D$X2, WoS_A
_D$X1, sep = "~"))

WoS_A_D_REV <- as.data.frame(WoS_A_D_REV)
WoS_A_D_REV <- gsub("~~~", "", WoS_A_D_REV$WoS_A_D_REV)
WoS_A_D_REV <- gsub("~~", "", WoS_A_D_REV)
WoS_A_D_REV <- gsub("~", "~", WoS_A_D_REV)
WoS_A_D_REV <- as.data.frame(WoS_A_D_REV)
WoS_A_D_REV <- trimws(WoS_A_D_REV$WoS_A_D_REV)
WoS_A_REV_DD <- as.data.frame(WoS_A_D_REV)

```

Segment of R Script for rearranging addresses

iii.iii.iii Cleaning Of Errors in Addresses

Once the data was rearranged into a new structure, preliminary cleaning was undertaken to remove obvious errors. The following code is a snippet from the complete code but shows examples of the errors found in the data.

```

#All Addresses Clean
#Ed Lefley

```

```

#2021 03 25
#Revised 2021 03 29
#Further revised 2021 08 25
#Further revised 2021 08 30

##Purpose: Take the standardisation discovered from the Reorder.r script
and apply to all address details.
#Load packages:
library(stringr)
library(data.table)
#Starting data = 474633

#Remove the leading character
https://stackoverflow.com/questions/46671796/conditionally-remove-leading-or-trailing-character-in-r)
#
WoS_A_REV_DD_S<- gsub('^,~', '', WoS_A_REV_DD_S$WoS_A_D_REV)
WoS_A_REV_DD_S <- as.vector(as.matrix(WoS_A_REV_DD_S))
WoS_A_REV_DD_S <- str_split(WoS_A_REV_DD_S,"~", n=Inf, simplify = TRUE)
WoS_A_REV_DD_S <- as.matrix(WoS_A_REV_DD_S)
WoS_A_REV_DD_S <- trimws(WoS_A_REV_DD_S,"both")
WoS_A_REV_DD_S <- as.data.frame(WoS_A_REV_DD_S)

#Rejoin
WoS_A_REV_RJ <-
as.vector(paste(WoS_A_REV_DD_S$V1,WoS_A_REV_DD_S$V2,WoS_A_REV_DD_S$V3,WoS_
A_REV_DD_S$V4,WoS_A_D$X1, sep = " "))
WoS_A_REV_RJ<- as.data.frame(WoS_A_REV_RJ)
remove(WoS_A_REV_DD_S)

#WoS_FA_U_RJ_OU_All <- unique(WoS_FA_RJ_O_All) #279935

#WoS_FA_U_AA_DF_U<-unique(WoS_FA_U_AA_DF)
####High Level patterns
#*,
WoS_A_REV_RJ <- gsub("[*]", "", WoS_A_REV_RJ$WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub(",,,", "", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub(" ", " ", WoS_A_REV_RJ)
#Australia Typos
WoS_A_REV_RJ <- gsub("Austraian", "Australian ", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Australia", "Australia ", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("AustraIia", "Australia ", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Australia", "Australia ", WoS_A_REV_RJ)
#Other
WoS_A_REV_RJ <- gsub("Hosp Australia|Hosp Australasia", "Hosp",
WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Hospital|Hopsital", "Hosp", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Univ Australia", "Univ", WoS_A_REV_RJ)
#WoS_A_REV_RJ <- gsub(", dc,|, DC,|, Dc,", ",", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Ply Ltd", "Pty Ltd", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Cooperat,", "Cooperat Ltd,", WoS_A_REV_RJ)
#Austria
WoS_A_REV_RJ <- gsub("Australia, Graz", "Austria, Graz", WoS_A_REV_RJ)

```

```

WoS_A_REV_RJ <- gsub("Australia, Feldkirch", "Austria, Feldkirch",
WoS_A_REV_RJ)

#Canada
WoS_A_REV_RJ <- gsub("Australia, ON, Nepean", "Australia, NSW, Nepean",
WoS_A_REV_RJ)

#Peoples R China
WoS_A_REV_RJ <- gsub("Australia, Kunming|Australia, Kunming
650201|Australia, NSW, Kunming|Australia, NSW, Kunming", "Peoples R China,
Kunming", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Australia, Jiangsu", "Peoples R China, Jiangsu",
WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Australia, Xuzhou, Sch Mechatron Engn, China Univ
Min & Technol China Univ Min & Technol", "Peoples R China, Xuzhou, Sch
Mechatron Engn, China Univ Min & Technol", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Australia, NSW, Sydney, Ctr Excellence Tibetan
Plateau Earth Sci, CAS", "Peoples R China, Ctr Excellence Tibetan Plateau
Earth Sci, CAS", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Australia, Vic, Melbourne, CAS Ctr Excellence
Tibetan Plateau Earth Sci CAS Ctr Excellence Tibetan Plateau Earth Sci",
"Peoples R China, Ctr Excellence Tibetan Plateau Earth Sci, CAS",
WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Australia, NSW, Sydney, Xian Univ Architecture &
Technol Xian Univ Architecture & Technol|Australia, NSW, Sydney, Xian Univ
Architecture & Technol Xian Univ Architecture & Technol", "Peoples R
China, Xian Univ Architecture & Technol", WoS_A_REV_RJ)

#Fixes from TH_Calc_V4
#Cape Breton Canada
WoS_A_REV_RJ <- gsub("Australia, NSW B1P 6L2, Sydney,", "Canada, Nova
Scotia B1P 6L2, Sydney,", WoS_A_REV_RJ)
WoS_A_REV_RJ <- gsub("Australia, NSW B1Y 6L2, Sydney", "Canada, Nova
Scotia B1Y 6L2", WoS_A_REV_RJ)

```

Segment of R Script for cleaning of addresses (including removing mis-coded addresses).

Following this manipulation, this subsequent data is then categorised by organisational type.

Without this categorisation, the data would not be in a classified model that would enable the generation of the Triple Helix.

iii.iv Categorisation

With this categorisation model, the development of the algorithm that Abramo et al. (2014, p. 185) reference is possible. Examples of this code can be seen in the following code snippet for universities:

With over 700 lines of code, a small snippet is reproduced to show the record keeping and decision-making process for the categorisation of organisation type:

iii.iv.i University

```
#Splitting TH Function up
#2021 12 20
#Ed Lefley

###2021 04 07
#Ed Lefley
#Filter for Triple Helix
#Tested concept in Excel
#Converted to R Script
#Over 110 types of organisation that need to be categorised as
Uni/Gov/Industry for Triple Helix
#2021 10 27: Converted to cover all

library(stringr)
library("stringi")

#Use String Detect to match the characteristics in the affiliation to then
match it to the different classifications:
#University
university<- stri_detect_regex(Combined_Addresses$Short_Address,
"Univ|TAFE|Tafe|UNSW|UNE|AGBU|UTS|UWA,|UWA| USC
|SCU|USQ|UON|UniSA|HawkesburyInst|Hawkesbury Inst Environm|Western Sydney
univ|ANU|RMIT|CQU|CollHi|Agribio|Acad Sport|Inst Sport|Avondale Ctr|
|Phen Facil|NCHECR|ADFA|Australian Def Acad|Inst Supercond|
|Dept Civil Surveying & Environm Engn|Hunter Creat Ind & Technol| #Part of
Uni of Newcastle
|Fac Pharm|Monash Inst Pharmaceut Sci|Fac |
|Ctr Appl Climate Sci| #USQ
|Blue Mt World| #Already listed as part of UNSW

#Google 2021 05 10
|Macquarie Res Ctr Astron|Joanna Briggs Inst|
#JBI part of Univ Adelaide

#2021 05 27 Part of USyd
|Baird Inst|Discipline Accounting|

#2021 05 12
|William Angliss Ins|Wesley Inst|POWMRI| #POWMRI now Neuroscience
Australia, has edu.au URL
|Murdoch Children| #Murdoch Childrens Res has edu.au url
|Gilbert Tobin Ctr|Transport & Rd Safety TARS Res| #part of UNSW
|Broken Bay Inst|BBi| #part of the Catholic Univ
|Sydney Asia Pacific Migrat Ctr|US Studies Ctr| #part of USYD
|Southern Cross Geosci|Cross GeoSci| #part of SCU
```

```
|Western Australian Geothermal Ctr Excellence| #part of Curtin & WA
universities
|ANZAC Res Inst|Anzac Res Inst|Res Inst, ANZAC|Anzac Inst|ANZAC Inst|
#ANZAC Res Inst has edu.au URL

#Google 2021 06 01
|CAMA| #Part of Crawford/ANU
|CANR| #Part of WSU

#Google 2021 06 08
|Moreton Bay Res Stn| #Part of UQ
|Ctr Complex Dynam Syst & Control| #UoN
|Ctr Number Theory Res| #MQ/USYD
|Ctr Excellence Electromat Sci| .edu.au url
```

Excerpt of R Script for the categorisation of university, including research notes in decision making..

iii.iv.ii Industry

For industry, over 2,800 lines were constructed to act as the lookup for the categorisation process. An example can be seen below:

```
#Splitting TH Function up
#2021 12 20
#Ed Lefley

###2021 04 07

#Ed Lefley
#Filter for Triple Helix
#Tested concept in Excel
#Converted to R Script
#Over 110 types of organisation that need to be categorised as
Uni/Gov/Industry for Triple Helix
#2021 10 27: Converted to cover all

library(stringr)
library("stringi")

#Industry
industry <-
stri_detect_regex(Combined_Addresses$Short_Address,"NATA|Australian Acad
Sci|AARNet|Australias Acad & Res Network|
|Angus|Trust|Assoc|NRMA|Herefords Australia|Dairy Australia|Club|Rotary
Club|
|Grains & Legumes Nutr Counc|
|Black Dog|Movember Fdn|
|AUSMEAT|Equine Ctr|Equine Res|Bovine Res|Equine Serv|Bovine Serv|Dressage
Club|Feedlot Serv|Horse SA|Equestrian Australia|Australian
Paralymp|Dressage NSW|Disabil Sports Australia|
|Swimming Queensland|
|Racing|Wine|
```

```
|Basketball|Cricket|Football|Rugby|Netball|Rabitoths|St George Illawarra
Dragon|Perth Wildcats|Western Bulldogs FC|Sydney Swans|Sydney Roosters|GWS
Giants|Gold Coast Suns|ACT Brumbies|FC|AFL|Sydney Thunder|
|Tennis Australia|Cycling Australia|Water Polo|Surfing|NRL|Rowing
Australia|Kayak|Canoeing|Climbing Anchors Australia|Queensland Outdoor
Recreat Federat|Paddle Australia|Australian Sailing Team|
|Australian Ski Federat|Australian Jockey Club|Archery Australia|
|Surf Life Saving|RSL|Surf Lifesav|RLSSA|YHA|
|Amateur Astron|
```

```
#Checked with Google 2021 05 02:
```

```
|Marine Estuarine & Freshwater Ecol|
|Macadamia|Plantat|Peanut Co Australia|
|Meat & Livestock Australia|
|Pty|Ltd|Inc|Corp|PL|Farms|PTY LTD|PTY|LTD|P L,|P L |
|Aquarium|Sydney Inst Marine Sci|SeaWorld|Sea World|Sea World|Wildlife
World|Seaworld|Dreamworld|Flight Ctr|
|Opera|Conservatorium|Theatre|Orchestra|Symphony|
|Barnardos|BackTrack|Save Children|Smith Family|Royal Far West|
```

```
#Google 2021 05 06:
```

```
|Orygen|ORYGEN|
|Catholic|Anglicare|AngliCare|Baptist|Anglican|Archdiocese|Diocese|Uniting
Church|Presbyterian|Community Church|Diocesan|
```

Excerpt of R Script for the categorisation of industry, including research notes in decision making.

With these categorisations, a rule-based process was applied to the triple helix combination; the generation of the sets then facilitated the calculation of the triple helix relationship.

This code required development for each combination of the triple helix; to confirm the categorisation when there was uncertainty, each organisation was searched for using Google, and when Google was unable to provide information the Australian Business Register (ABR) Lookup was used. This requirement for the additional processes enabled additional data to be collected on the organisational type, including charitable, government and de-registered (closed down) for future analysis. This can be seen in the following code snippet:

```
#2022 01 02
#Commercial Matches
|Abbott Prod| #Matches Pty Ltd
|Schroder Investment Management|
|Scholefield Robinson Hort Serv| #63 008 199 737 (Cancelled)
|Henry Schein Halas| #83 132 312 515
|Intervet Schering Plough Anim Hlth| #99 134 212 749

#NFP
|Perth.*Prostate Canc Fdn Australia| #42 073 253 924
```


|Hepatitis WA| #42 743 157 642
 |Thorne Harbour Hlth| #52 907 644 835
 |Schizophrenia Fellowship NSW| #58 903 786 913
 |Schizophrenia Res Lab Schizophrenia Res Lab| #Belongs to either NISAD or
 Neurosci Res Australia
 |Perth Blood Inst| #24 164 941 815
 |Perron Inst Neurol & Translat Sci|Perron Res Inst| #99 070 870 398
 |WAPHA|WA Primary Hlth Alliance|Western Australian Primary Hlth Alliance|
 #11 602 416 697 WA Primary Health Alliance
 |WA.*Mercy Hlth| #31 098 197 490
 |Lung Inst Western Australia| #78 098 197 636
 |WA.*Hlth Consumers Council| #87 841 350 116
 |WA.*Belgravia Med Ctr| #50 406 716 169
 |Orthopaed Western Australia| #87 120 165 675
 |Australian Neuromuscular Res Inst| #99 070 870 398
 |Autism West| #54 354 917 843
 |Gateway Hlth| #76 640 576 694
 |Nunkuwarrin Yunti| #59 643 754 108
 |Mater Hosp Pimlico|Townsville.*Mater Hosp| #98 094 529 263
 |Qld.*Mater Res| #28 109 834 719
 |Qld.*Wesley Res Inst|Qld.*Wesley Med Res| #85 066 149 666

 #NFP Health ATSI
 |Gurriny Yealamucka Hlth Serv| #31 210 982 991
 |Carbal Hlth Serv| #50 275 271 535

 #Commercial Health
 |Jeffery & Ree Clin Psychologists| #27 415 311 716
 |Specialist Orthopaed Grp| #<http://www.orthospecialist.com.au/> specialist
 orthopaedic group
 |WA.*Illawarra Med Ctr| #11 009 587 428
 |Mends St Med Ctr| #45 117 854 163 Cancelled
 |Trojan Hlth| #64 109 580 967
 |Trigg Hlth Care Ctr| #83 971 096 594
 |Skin Spectrum Med Serv| #47 631 234 429
 |Perth Voices Clin| #62 611 998 433
 |Perth Orthopaed Inst| #17 621 504 634
 |Perth Orthopaed & Sports Med Ctr| #82 171 737 969
 |Hollywood Orthopaed Grp| #26 103 038 713
 |Hollywood Med Ctr| #98 738 850 459
 |Hearing Voices Network Western Australia| #16 006 875 727
 |Genet & Rare Dis Network| #63 614 315 270
 |Fremantle Mental Hlth Serv| #12 605 867 022
 |Fremantle Dermatol| #40 846 266 059
 |Fremantle Hepatitis Serv| #18 125 199 500
 |WA.*Apsley Med Ctr| #34 143 296 208 Cancelled
 |Allergy West| #32 717 685 905
 |Sarich Neurosci Res Inst| #17 009 171 402
 |Malabar Orthopaed Clin| #35 054 501 950
 |Torquay Walk Clin| #43 164 230 693
 |Fertility SA| #31 141 685 579
 |FBW Gynaecol Plus| #34 159 091 219
 |Chandlers Hill Surg| #92 237 654 567
 |Adelaide Pathol Partners| #14 083 414 822 Cancelled

```
|Prahran Market Clin| #94 843 932 843
|Trop Hlth Solut| #78 152 580 679
|Outlook Eye Specialists| #74 151 980 899
|Eye & Laser Ctr Gold Coast| #32 607 556 258
|Qld.*Porter Eye Care| #19 115 576 326

#Vet
|Anim Eye Serv| #25 010 629 928

#Commercial Health Training
|Trop Med Training| #30 099 056 890 Cancelled

#Commercial Education
|Blue Mt Int Hotel Management Sch| #65 077 681 568
|Kaplan Business Sch| #97 117 669 397
|Kilmore Int Sch| #33 006 300 876
|Australian Sch Business| #53 141 903 077 (only BNE postcode)
|MIT Sydney| #20 072 324 755

#NFP Education
|John Berne Sch| #68 159 428 251
|MLC Sch| #84 645 102 325
|Mt Eliza Business Sch| #80 007 268 233
|Sch Field Studies| #33 168 822 490
```

Excerpt of R Script for the categorisation of industry, including research notes in decision making.

iii.iv.iii Government

A similar code was written for government agencies, and can be seen in the following:

```
#Splitting TH Function up
#2021 12 20
#Ed Lefley

###2021 04 07
#Ed Lefley
#Filter for Triple Helix
#Tested concept in Excel
#Converted to R Script
#Over 110 types of organisation that need to be categorised as
Uni/Gov/Industry for Triple Helix
#2021 10 27: Converted to cover all

library(stringr)
library("stringi")

#Government
government <- stri_detect_regex(Combined_Addresses$Short_Address,
"Parliament|Australian Taxat Off|Reserve Bank Aus|Reserv Bank
Aurstralia|Productiv Commiss|Prod Commission|Australian Competit &
Consumer Commiss|Dept Foreign|Bureau Stat|
###Google 2021 06 09
```

```
|Yarralumla| #Governor General's residence
|Supreme court|Supreme Court|Senator|Legal Aid|Off Legal Serv|Environm
Defenders Off|Publ Prosecut|Legislat Council NSW|Land & Environm Court
NSW|Circuit Court|High Court Aus|Queensland Court|Fed Court|Magistrate|NSW
Supreme Cour|Appeals Tribunal|Court NSW|Coroners Court|Australian Human
Rights Commiss|Australian Secur & Investments Commiss|APRA|NSW
Juvenile|Juvenile Justice|Community Justice|NSW Land & Environm Court|NSW
Legislat |NSW Court Appeal|Audit Off NSW|
|NSW Commis|
|Dust Dis Board|Workcover|WorkCover|Dept Human
Serv|SafeWork|Centrelink|Safe Work NSW|Safe Work Aus|
|Dept Community Serv|Dept Hou|Dept Family & Community Ser|Dept
Families|Child Protect Serv|NSW Family|Off NSW Advocate Children & Young
People|
|Dept Immigr|Villawood Immigrat Detent Ctr|
|ACT Dept|
###Google 2021 06 08
|ACT Child Dev Serv|
|Adelaide & Mt Lofty Ranges Nat Resources Manageme|
|Katherine Res Stn|
##
|Correct Serv|Correct Facil|Correct Ctr|
|AFP|
|Educ|Sport & Recreat|NSW Off Sport|Dept English, Redlands|Dept English
Dept English|
|Aboriginal Affairs NSW|
|Patents|IP Australia|
|FireBrigade|Fire Brigade|Fire & Emergency|Fire & Rescue|Emergency
Management Victoria|Bushfires NT|Bushfires Council|NSW Rural Fire
Serv|Tasmania Fire Serv|Fire Rescue NSW|Ambulance|State Emergency
Serv|SES|Poison|
|State Coroner|
|NSWDept|NSWDPI|DPI|NSW Agr|Grafton Aquaculture Ctr|NSW Dep Environ &
Climate Change|Dept Prima|Dept prim|Dept Pria|PIRSA|DEC|DECC|
|Dept Land|Dept Nat R|Pig & Poultry Prod Inst|
|Infrastruct Victoria|Infrastruct NSW|
```

Excerpt of R Script for the categorisation of government, including research notes in decision making.

As can be seen, once patterns are identified, those patterns are followed to discover similar phrases.

With these now identified, an algorithm was developed to move these categorisations into a list that could be referenced to create the sets required for the triple helix calculation.

```
TH_List <- do.call("cbind",
                  list(Combined_Addresses,
                      university_th,
                      government_th,
                      industry_th))
colnames(TH_List, do.NULL = FALSE)
```

```

#Extra columns take on name from previous script
#university
#government
#industry

# Create replacements data frame
TH_Match <- data.frame(from = Combined_Addresses$Full_Address, to =
TH_List$TH)

#Duplicate WoS_All_Record and Convert to data frame for FindReplace
instead of a Dplyr tibble
(https://github.com/lyons7/emojidictionary/issues/1)
WoS_TH <- as.data.frame(WoS_All)

#Find Other Australian State Data
TH_List$States <- str_detect(Combined_Addresses$Short_Address, "Australia,
Vic|Australia, Qld|Australia, SA|Australia, Tas|Australia, WA|Australia,
ACT|Australia, NT", negate = FALSE)

#Moved TH LList to after Address Cleanup
TH_List$TH <- ifelse(TH_List$Australian == 0, "Overseas",
                    ifelse(TH_List$States == 1, "Other_State",
                          ifelse(TH_List$university == 1, "University",
                                ifelse(TH_List$government == 1,
"Government",
                                     ifelse(TH_List$industry == 1,
"Industry",
                                             "Unknown"))))))

```

Excerpt of R Script for the creation of sets for the triple helix index.

A cross reference table that enables a find and replace function to be run is created

```

WoS_TH_M <- stri_replace_all_fixed(WoS_TH_V, pattern = TH_Match_From,
replacement = TH_Match_To, vectorise_all = FALSE)
stringi_et <- Sys.time()

stringi_elapsed <- (stringi_et-stringi_st)
View(stringi_elapsed)
WoS_TH_M <- as.data.frame(WoS_TH_M)
colnames(WoS_TH_M) <- c("Addresses")

#Bring across to full list WoS_All_Record
#https://stackoverflow.com/questions/25372082/create-column-based-on-presence-of-string-pattern-and-ifelse

WoS_TH_M$TH_U <-
ifelse(grepl("University|Univ",WoS_TH_M$Addresses), '1', '0')
WoS_TH_M$TH_I <- ifelse(grepl("Industry",WoS_TH_M$Addresses), '1', '0')
WoS_TH_M$TH_G <- ifelse(grepl("Government",WoS_TH_M$Addresses), '1', '0')
WoS_TH_M$TH_F <- ifelse(grepl("Overseas",WoS_TH_M$Addresses), '1', '0')
WoS_TH_M$TH_S <- ifelse(grepl("Other_State",WoS_TH_M$Addresses), '1', '0')
WoS_TH_M$TH_UK <- ifelse(grepl("Unknown",WoS_TH_M$Addresses), '1', '0')

```

```
#Join to original dataset, and remove Unknowns
WoS_TH_2 <- WoS_TH

WoS_TH_2 <- WoS_TH_2[!is.na(WoS_TH_2$WoS_All_D), ]
WoS_TH_2 <- as.data.frame(WoS_TH_2)

WoS_M <- cbind(WoS_TH_2, WoS_TH_M)
WoS_TH_M_TH_SS <- subset(WoS_M, TH_UK == 0)
Excerpt of R Script for the creation of triple helix index sets
```

From these, the sets for the triple helix index calculation can be derived.

iii.v Triple Helix Calculation

With the classifications now able to be put into sets, the calculations can be performed year by year from the overall data set. Once again, duplications of the original data are used rather than the original data.

iii.v.i Sets

```
##Triple Helix Calculation for 4 Variables
#Ed Lefley
#Shawn Leu
#2021 12 02
#2021 12 08
#2021 12 10
#2022 01 19 Added Overseas and changed to using full dataset

#Based on Leydesdorff's original calculations
#Expanded using Hu et al (2021)
library(stringr)
library(data.table)

#Don't run everytime - only run on initial set up
#WoS_TH_M_TH_SS$TH_NN <- (ifelse(WoS_TH_M_TH_SS$TH_F == 1, 1,
#                                ifelse(WoS_TH_M_TH_SS$TH_S ==1, 1,
#                                0)))

Entropy_WoS_5 <- as.data.frame(paste(WoS_TH_M_TH_SS$TH_U,
                                     WoS_TH_M_TH_SS$TH_I,
                                     WoS_TH_M_TH_SS$TH_G,
                                     WoS_TH_M_TH_SS$TH_S,
                                     WoS_TH_M_TH_SS$TH_F,
                                     sep = ","))

colnames(Entropy_WoS_5) <- c("Set")
WoS_TH_M_TH_SS_5 <- cbind(WoS_TH_M_TH_SS, Entropy_WoS_5)
#248,645
```

```

WoS_TH_M_TH_SS_5 <- subset(WoS_TH_M_TH_SS_5, Set != "0,0,0,0,0") #removes
338
WoS_TH_M_TH_SS_5 <- subset(WoS_TH_M_TH_SS_5, Set != "0,0,0,1,1") #removes
1,003
WoS_TH_M_TH_SS_5 <- subset(WoS_TH_M_TH_SS_5, Set != "0,0,0,1,0") #removes
554
WoS_TH_M_TH_SS_5 <- subset(WoS_TH_M_TH_SS_5, Set != "0,0,0,0,1") #removes
1,397

```

Excerpt of R Script for the subset of university, industry, government, other state/territory, and foreign

iii.v.ii Triple Helix

With the sets now established, the calculation of the Triple Helix values can commence.

```

#Triple Helix Calculation for 4 Variables
#Ed Lefley
#Shawn Leu
#2021 12 02
#2021 12 08
#2021 12 10
#2022 01 19 Added Overseas and changed to using full dataset
#2022 03 24 Changed to match Leydesdorff 2021 revision
#2022 08 31 Removed (0,0,0,1,0), (0,0,0,0,1) and (0,0,0,1,1) sets using
WoS_TH_M_TH_SS_5 dataframe

#Based on Leydesdorff's original calculations
#Expanded using Hu et al (2021)
library(stringr)
library(data.table)

WoS_5H_2006 <- subset(WoS_TH_M_TH_SS_5, Publication_Year == 2006)

#With the newly created set, now create a key based on the set patterns:
#Entropy_2006_5 <- cbind.data.frame(WoS_5H_2006$TH_U, WoS_5H_2006$TH_I,
WoS_5H_2006$TH_G, WoS_5H_2006$TH_S, WoS_5H_2006$TH_F)
#write.csv(Entropy_2006, "data.txt", col.names =FALSE)
#Set the total number of rows:
denom_2006 <- nrow(WoS_5H_2006)

#Entropy calculation for UI covers
#(U,I,G,0)

#Using the WoS_5H_2006$TH_U, WoS_5H_2006$TH_I, WoS_5H_2006$TH_G,
WoS_5H_2006$TH_S and WoS_5H_2006$TH_F columns, to replicate the 2021
revision of the TH4.exe model the following is performed:

#Convert character to numeric
WoS_5H_2006$TH_U <- as.numeric(WoS_5H_2006$TH_U)
WoS_5H_2006$TH_I <- as.numeric(WoS_5H_2006$TH_I)
WoS_5H_2006$TH_G <- as.numeric(WoS_5H_2006$TH_G)
WoS_5H_2006$TH_S <- as.numeric(WoS_5H_2006$TH_S)

```

```

WoS_5H_2006$TH_F <- as.numeric(WoS_5H_2006$TH_F)

WoS_5H_2006$Set <- (paste(WoS_5H_2006$TH_U,
                          WoS_5H_2006$TH_G,
                          WoS_5H_2006$TH_I,
                          WoS_5H_2006$TH_S,
                          WoS_5H_2006$TH_F, sep = ","))

#subset without (0,0,0,1,0), (0,0,0,0,1) and (0,0,0,1,1) sets

#U Single
PU_2006_5LL <- sum((WoS_5H_2006$TH_U/denom_2006))
PNU_2006_5LL <- sum((denom_2006-sum(WoS_5H_2006$TH_U))/denom_2006)

```

Excerpt of R Script for the triple helix index (Code skipped for brevity)

```

#Pairs (10)
#Multiply denom_2006 by 2 for the pairs
denom_2006_2 <- denom_2006*2
#UI
PUI1_2006_5LL <- sum((WoS_5H_2006$TH_U+WoS_5H_2006$TH_I)/denom_2006_2)
PUI2_2006_5LL <- sum((denom_2006_2-
sum(WoS_5H_2006$TH_U+WoS_5H_2006$TH_I))/denom_2006_2)

#UG Pairs
PUG1_2006_5LL <- sum((WoS_5H_2006$TH_U+WoS_5H_2006$TH_G)/denom_2006_2)
PUG2_2006_5LL <- sum((denom_2006_2-
sum(WoS_5H_2006$TH_U+WoS_5H_2006$TH_G))/denom_2006_2)

```

Excerpt of R Script for the triple helix index (Code skipped for brevity)

```

#Multiply denom_2006 by 3 for the Triples (10)
denom_2006_3 <- denom_2006*3

#UIG Triples
PUIG1_2006_5LL<-
sum((WoS_5H_2006$TH_U+WoS_5H_2006$TH_I+WoS_5H_2006$TH_G)/denom_2006_3)
PUIG2_2006_5LL<- sum((denom_2006_3-
sum(WoS_5H_2006$TH_U+WoS_5H_2006$TH_I+WoS_5H_2006$TH_G))/denom_2006_3)

```

Excerpt of R Script for the triple helix index (Code skipped for brevity)

```

#Multiply denom_2006 by 4 for the quads (5)
denom_2006_4 <- denom_2006*4

#UIGS
PUIGS1_2006_5LL <-
sum((WoS_5H_2006$TH_U+WoS_5H_2006$TH_I+WoS_5H_2006$TH_G+WoS_5H_2006$TH_S)/
denom_2006_4)
PUIGS2_2006_5LL <- sum((denom_2006_4-
sum(WoS_5H_2006$TH_U+WoS_5H_2006$TH_I+WoS_5H_2006$TH_G+WoS_5H_2006$TH_S))/
denom_2006_4)

```

Excerpt of R Script for the triple helix index (Code skipped for brevity)

```

#Shannon's Entropy calculations:
HU_2006_5LL <- (-PU_2006_5LL*(log2(PU_2006_5LL))) -
(PNU_2006_5LL*(log2(PNU_2006_5LL)))

```

```
HI_2006_5LL <- (-PI_2006_5LL*(log2(PI_2006_5LL))) -
(PNI_2006_5LL*(log2(PNI_2006_5LL)))
```

Excerpt of R Script for the calculation of Shannon's Entropy (Code skipped for brevity)

#Pairs

```
HUI_2006_5LL <- -(PUI1_2006_5LL*(log2(PUI1_2006_5LL))-
(PUI2_2006_5LL*(log2(PUI2_2006_5LL)))
HUG_2006_5LL <- -(PUG1_2006_5LL*(log2(PUG1_2006_5LL))-
(PUG2_2006_5LL*(log2(PUG2_2006_5LL)))
```

Excerpt of R Script for the calculation of Shannon's Entropy (Code skipped for brevity)

#Triples

```
HUIG_2006_5LL <- -(PUIG1_2006_5LL*(log2(PUIG1_2006_5LL))) -
((PUIG2_2006_5LL*(log2(PUIG2_2006_5LL)))
HUIS_2006_5LL <- -(PUIS1_2006_5LL*(log2(PUIS1_2006_5LL))) -
((PUIS2_2006_5LL*(log2(PUIS2_2006_5LL)))
```

Excerpt of R Script for the calculation of Shannon's Entropy (Code skipped for brevity)

#Quads

```
HUIGS_2006_5LL <- -(PUIGS1_2006_5LL*(log2(PUIGS1_2006_5LL))) -
((PUIGS2_2006_5LL*(log2(PUIGS2_2006_5LL)))
HUIGF_2006_5LL <- -(PUIGF1_2006_5LL*(log2(PUIGF1_2006_5LL))) -
((PUIGF2_2006_5LL*(log2(PUIGF2_2006_5LL)))
```

Excerpt of R Script for the calculation of Shannon's Entropy (Code skipped for brevity)

#Quintuple

```
HUIGSF_2006_5LL <- -(PUIGSF1_2006_5LL*(log2(PUIGSF1_2006_5LL))) -
((PUIGSF2_2006_5LL*(log2(PUIGSF2_2006_5LL)))
```

Excerpt of R Script for the calculation of Shannon's Entropy (Code skipped for brevity)

PAIRS

```
TUI_2006_5LL <- (HU_2006_5LL + HI_2006_5LL - HUI_2006_5LL)*#1000
TUG_2006_5LL <- (HU_2006_5LL + HG_2006_5LL - HUG_2006_5LL)*#1000
T
```

Excerpt of R Script for the calculation of the Triple Index T-Value (Code skipped for brevity)

#TRIPLE

```
TUIG_2006_5LL <- (HU_2006_5LL + HI_2006_5LL + HG_2006_5LL - HUI_2006_5LL
- HUG_2006_5LL - HIG_2006_5LL + HUIG_2006_5LL)*#1000
TUIS_2006_5LL <- (HU_2006_5LL + HI_2006_5LL + HS_2006_5LL - HUI_2006_5LL
- HUS_2006_5LL - HIS_2006_5LL + HUIS_2006_5LL)*#1000
```

Excerpt of R Script for the calculation of the Triple Index T-Value (Code skipped for brevity)

#QUAD

```
TUIGS_2006_5LL <- (HU_2006_5LL + HI_2006_5LL + HG_2006_5LL + HS_2006_5LL
- HUI_2006_5LL - HUG_2006_5LL - HUS_2006_5LL - HIG_2006_5LL - HIS_2006_5LL
- HGS_2006_5LL + HUIG_2006_5LL + HUIS_2006_5LL + HUGS_2006_5LL +
HIGS_2006_5LL - HUIGS_2006_5LL)*#1000
```

```
TUIGF_2006_5LL <- (HU_2006_5LL + HI_2006_5LL + HG_2006_5LL + HF_2006_5LL
- HUI_2006_5LL - HUG_2006_5LL - HUF_2006_5LL - HIG_2006_5LL - HIF_2006_5LL
- HGF_2006_5LL + HUIG_2006_5LL + HUIF_2006_5LL + HUGF_2006_5LL +
HIGF_2006_5LL - HUIGF_2006_5LL)*#100
```

Excerpt of R Script for the calculation of the Triple Index T-Value (Code skipped for brevity)

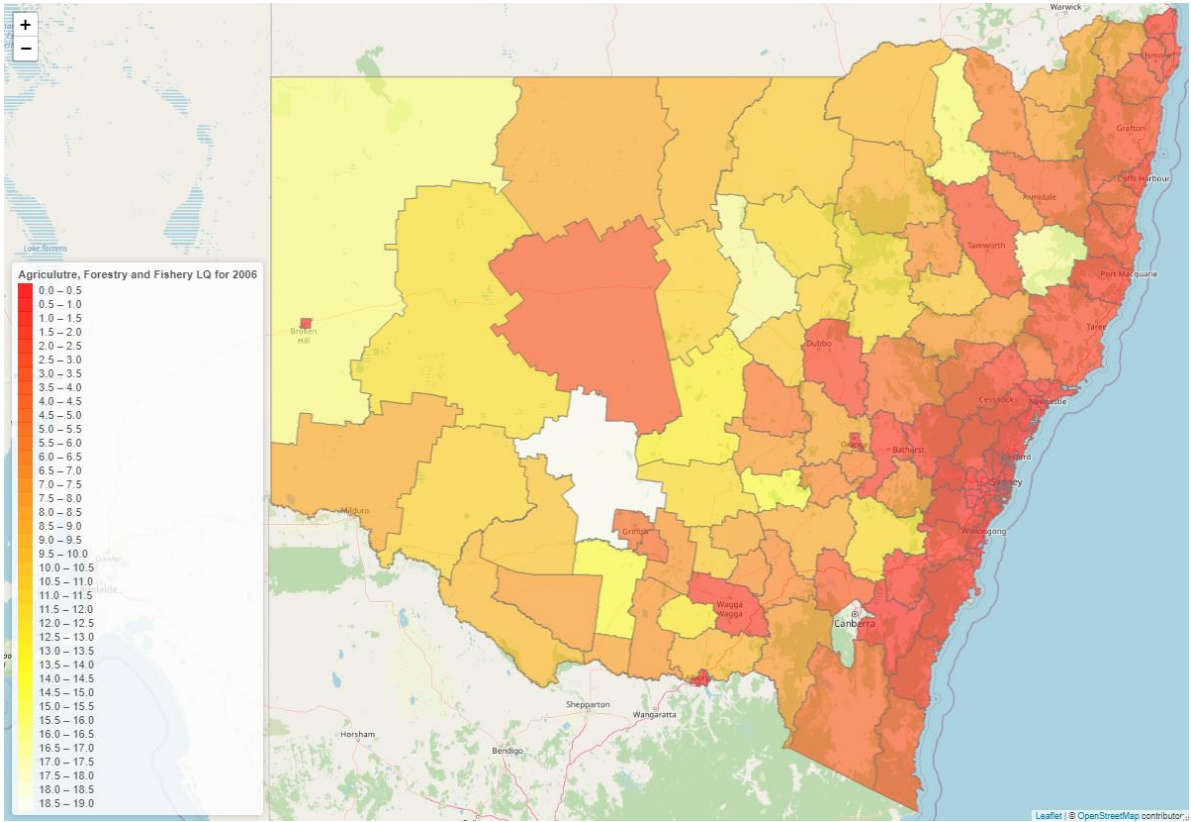

```
#QUINTUPLE
TUIGSF_2006_5LL <- (HU_2006_5LL + HI_2006_5LL + HG_2006_5LL + HS_2006_5LL
+ HF_2006_5LL -
                    HUI_2006_5LL - HUG_2006_5LL - HUS_2006_5LL -
HUF_2006_5LL - HIG_2006_5LL - HIS_2006_5LL - HIF_2006_5LL - HGS_2006_5LL -
HGF_2006_5LL - HSF_2006_5LL +
                    HUIG_2006_5LL + HUIS_2006_5LL + HUIF_2006_5LL +
HUGS_2006_5LL + HUGF_2006_5LL + HUSF_2006_5LL + HIGS_2006_5LL +
HIGF_2006_5LL + HISF_2006_5LL + HGSF_2006_5LL -
                    HUIGS_2006_5LL - HUIGF_2006_5LL - HUISF_2006_5LL -
HUGSF_2006_5LL - HIGSF_2006_5LL +
                    HUIGSF_2006_5LL)*1000
```

Excerpt of R Script for the calculation of the Triple Index T-Value (Code skipped for brevity)

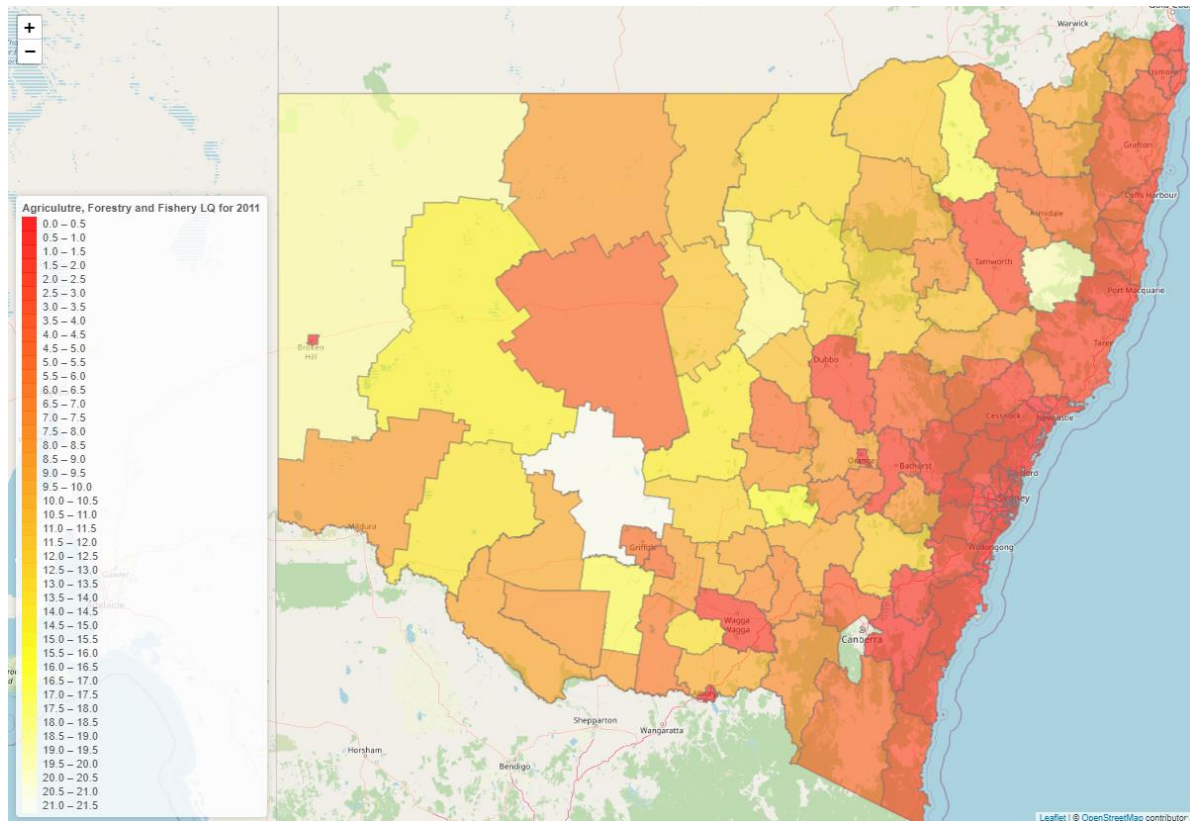
From these calculations, repeated in full for all years, the graphs showing the changes over time of the different collaborations can be constructed.

Appendix iv: Location Quotient Maps

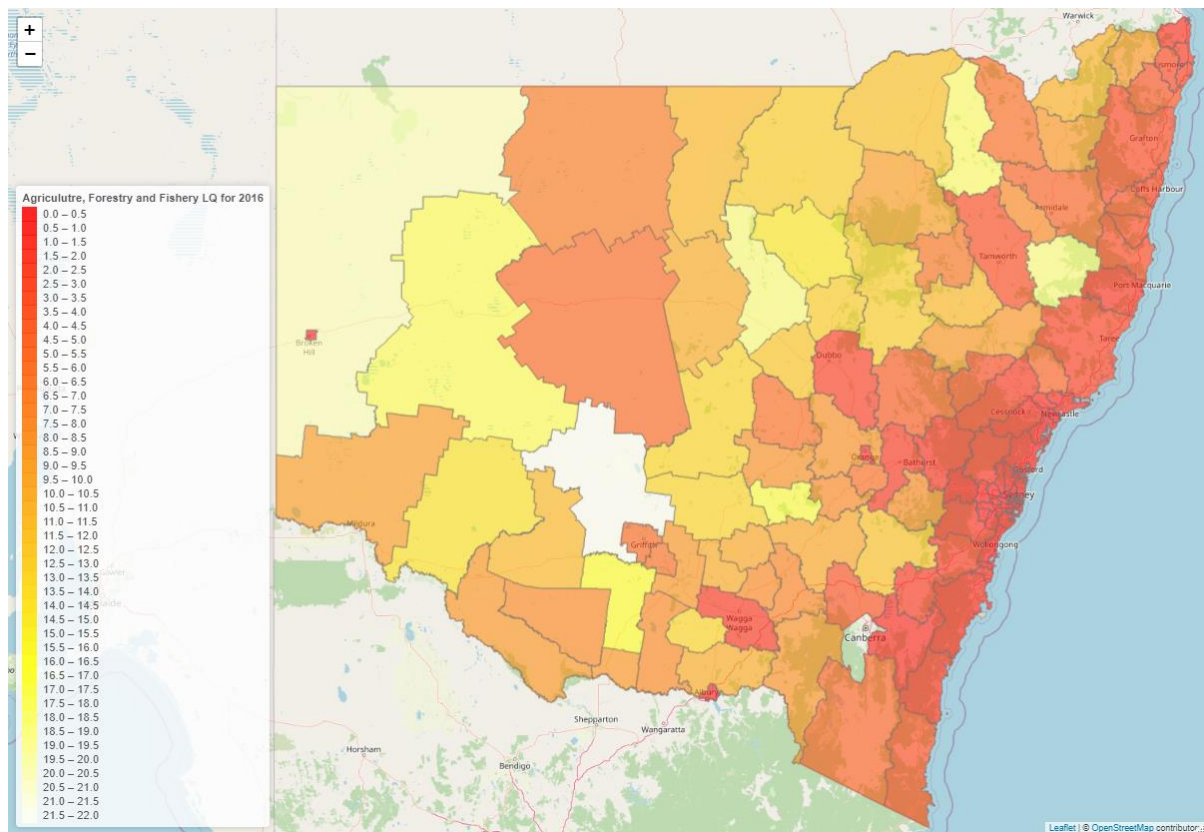
iv.i 2006



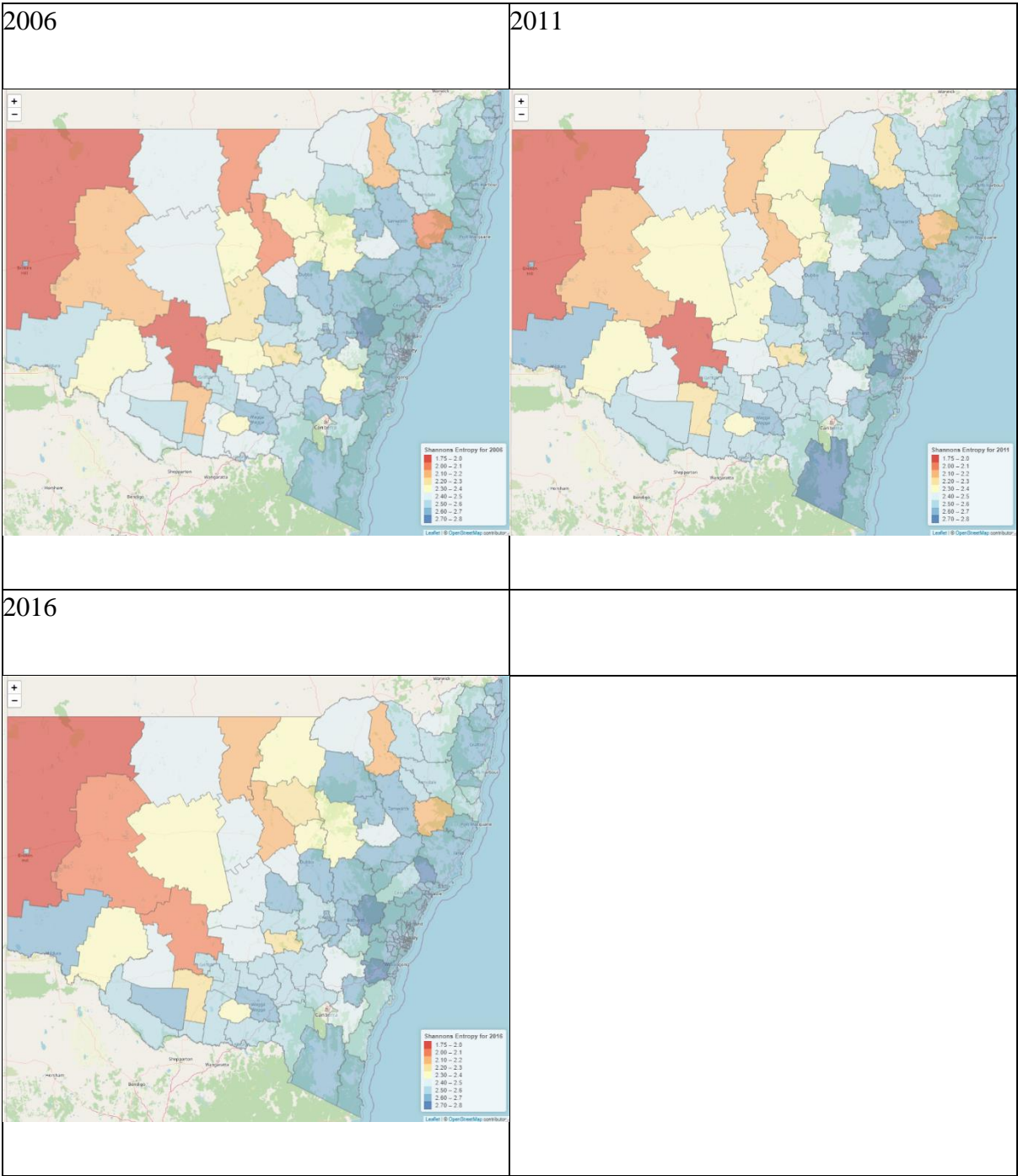
iv.ii 2011



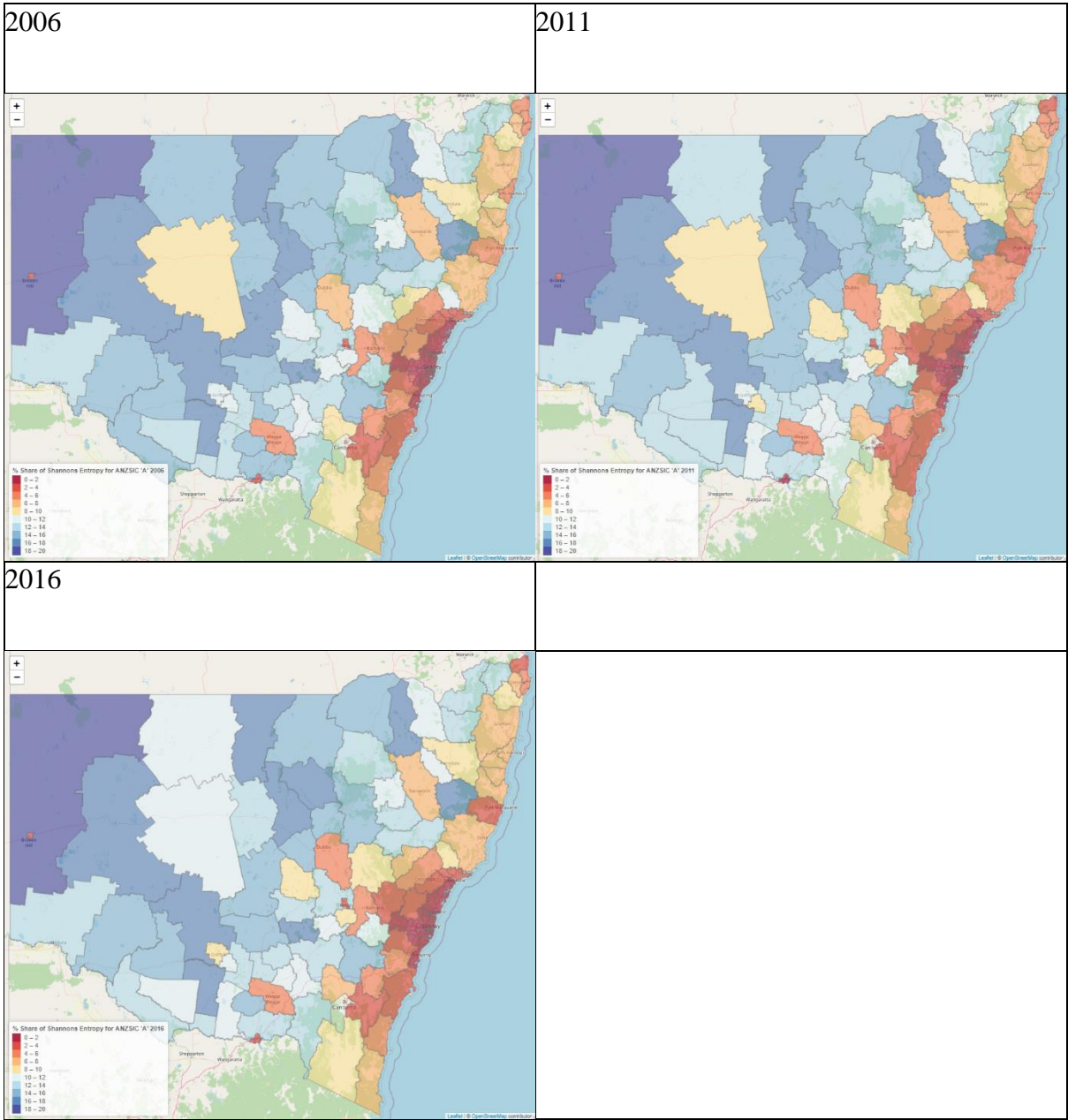
iv.iii 2016



Appendix v: Comparison of Shannon’s Entropy values



Appendix vi: Comparison of Shannon's Entropy Share



Appendix vii: Author Affiliation Maps

All maps show the location of industry and other state/territory organisations, based on extracted addresses from Web of Science, geocoded in ArcGIS and visualised in R using Leaflet.

