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A sub-national Economic Complexity analysis of Australia's states and territories

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Abstract

This paper applies Economic Complexity analysis to the Australian sub-national economy (9 regions with 506 exported goods and services). Using a 2009 Australian multi-regional Input-Output table for base data, we determine the number of export goods or services in which each state and territory has a revealed comparative advantage, and visualise the complexity of Australia's interstate and international exports. We find that small differences in industrial capability and knowledge are crucial to relative complexity. The majority of states (especially Western Australia) export primarily resource intensive goods, yet interstate trade has many complex products that are not currently internationally exported.

Keywords: economic complexity, implied comparative advantage, Australia; input-output; sub-national; regional

JEL classifications: H70, O41, O47, O56

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1. Introduction

The long-term prosperity of Australia's states and territories depends on their success in (re)building their economic competitiveness in a post-global financial crisis, and post-Australian mining boom, globally-linked economy. The upcoming closure of the Victorian and South Australian concentrated automotive industry (Davis, Dowling, & Norrie, 2008; Taylor, 2013), and the 2015 closure of the Tasmanian heavy mining vehicle industry(Cook, Silici, & Adolph, 2015) is further weakening these states' manufacturing capabilities with the ensuing reduction in economic complexity negatively impacting on state and national prosperity. The correct identification of future industry sectors that will be beneficial to transition into, and invest in, is therefore vital for future prosperity.

An impediment to identifying beneficial sectors is the current inability to identify — at the sub-national level — competitive and comparative advantages; how best to achieve these advantages, and how to monitor progress. Hausmann and Hidalgo (Hausmann & Hidalgo, 2013; Hausmann, Hidalgo, Bustos, et al., 2014; Hidalgo & Hausmann, 2009) have developed *Economic Complexity* (EC) analysis as a method to identify current export capability as well as predict future economic growth. EC analysis has been used at a global level (Felipe, Kumar, Abdon, & Bacate, 2012; Hausmann, Hidalgo, Bustos, et al., 2014), the national level (Hausmann & Hidalgo, 2013), and at the city level (Nepelski & De Prato, 2015). However, the scarcity of detailed interstate trade data has so far proven to be a challenge in adapting EC to the sub national level.

In this paper we propose a novel source of trade data to allow a further proliferation of EC analysis: high resolution Multi-Regional Input-Output (MRIO) tables. IO tables contain matrices describing the supply, use, import, and margins of goods and services by industry sectors in economies, with data expressed in monetary terms (UN, 1999). Traditionally, IO tables have been confined to a limited number of aggregated macroeconomic sectors or commodities due to computational power limits and data availability. However, recently global and regional MRIO databases that have a high resolution of specific commodities have been produced (Lenzen, Moran, Kanemoto, & Geschke, 2013; Lenzen et al., 2014). IO tables have been previously used to examine national EC (Szyrmer, 1985a, 1985b), with Wood and Lenzen (2009) providing an analysis of Australia's internal EC from 1975 to 1999 at a 344 intermediate industry sector resolution. Wood and Lenzen revealed that Australia has transformed since 1975, with decreasing primary and manufacturing sectors and increasing tertiary and service sectors. Wood and Lenzen did not consider sub-national or international linkages and trade in their analysis, instead investigated the developments of economic structure solely at the national level.

This paper applies Hausmann and Hidalgo's EC analysis method to examine the complexity of the Australian sub-national (interstate) economy. We determine the number of export goods or services that each state and territory has a revealed comparative advantage (RCA) in, and visualise the relative complexity of Australia's interstate and international exports. The application of the EC methodology to sub-national level economies is considered a novelty in this paper. Likewise, our use of a subregional Multi-Regional Input-Output (MRIO) table for trade and export data, and the inclusion of service based sectors, are other innovations specific to this paper. Our paper differs from the work of Wood and Lenzen by focusing on using the export and import data of MRIO tables rather than the internal production and consumption data.

Section two provides a theoretical background to EC analysis. Section three lists the data sources used for the EC analysis. Section four presents the results of EC analysis. Section five discusses the results, and section six concludes. Appendixes are provided in the online accompanying data. These provide detailed results of all analysis.

2. Theoretical background

This section summarises the theory behind Hausmann and Hidalgo's (Hausmann & Hidalgo, 2013; Hausmann, Hidalgo, Bustos, et al., 2014; Hidalgo & Hausmann, 2009) EC analysis with specific attention given to its use in measuring sub-national trade.

The core concept of EC is that specific products are produced when a combination of knowledge, natural resources and monetary capital, comes together in a specific way – with each economy having its own combination of the three factors. EC theory proposes that since natural resources and monetary capital are scarce, that it is by increasing the amount of knowledge in an economy that more products can be made available for production, specifically for export. In the case of sub-national states, this export of goods could be to other sub national entities, or international export. Likewise, it is the differentiation of knowledge capital between sub national states – in addition to natural resources and monetary capital – that will help shape each state's unique EC measures.

Each economy's EC is also influenced by both 'relationship' capital – cultural collaboration propensity; network economic effects due to economic agent density – and 'organisational' capital – policy landscape, rules, regulations, systems, processes etc. These two additional forms of capital are difficult to quantify, and are not captured in current EC modelling. This means that EC modelling has limits to the amount of economic transformation it can explain – typically 70% of the change.

Hausmann and Hidalgo propose that the amount of knowledge capital that an economy has can be expressed in two complementary measures: Diversity, how many different products are exported by a given economy x; and Ubiquity, how many economies export product y.The ubiquity of a product reveals information about the volume of knowledge that is required for its production, with products that demand large volumes of knowledge only becoming feasible in places where all the requisite knowledge is available. Likewise, the diversity of products can indicate the relative level of knowledge in an economy when compared to other economies.

In EC modelling, diversity is used to correct the information carried by ubiquity, and ubiquity corrects the information carried by diversity, this operation is processed a finite number of times until a convergence is achieved, this is also known as Method of Reflection (Hidalgo & Hausmann, 2009). Hausmann and Hidalgo note this relationship as a mathematical formula, which provides as output the Economic Complexity Index (ECI), a ranking of economies by their complexity; and Product Complexity Index (PCI), a ranking of products by their complexity. The greater the amount of data in the model (number of products, and number of economies) the greater the intricacy, and the truer the representation of the system. This means that models with smaller numbers of aggregated products, or fewer economies, may not present reliable depictions of ECI or PCI and associated other measures.

Using the PCI, EC analysis creates a holistic measure: *opportunity value*[1] — the value to be gained by an economy from shifting production to unexploited prospects (more complex products). This value is relative to the level of technology already present in that economy. Each product also has a relative *opportunity gain*[2] — the 'spillover' benefit to an economy from producing new products in terms of providing capacity for producing even more complex products. The opportunity value score is higher for economies that are already closer[3] to more products and products that are more complex. This implies that economies with a low level of knowledge have fewer opportunities for expansion available and that the expansion is harder to achieve. Economies with high levels of complexity typically have few remaining products left to manufacture in their chosen manufacturing field[4] Economies with intermediate complexity can differ in their opportunity value scores depending on the complexity of the products (i.e. the PCI value) that they currently produce.

EC modeling suggests two ways in which economies can grow. First, if the economy is currently underperforming given the level of complexity it has. Second, Hausmann et al derive a measure of the 'proximity' of each product category to other product categories. In

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[1] In later publications, Hausmann & Hidalgo use the term *complexity outlook* instead of *opportunity value.*
[2] In later publications, Hausmann & Hidalgo use the term *complexity outlook gain* instead of *opportunity gain.*
[3] That is, closer in *Product Space*, in which products are organised such that Product a is close to Product b if a high number of countries co-export both products. The implication of high co-export numbers is that the two products are very likely to require similar types of expertise.
[4]Unless new knowledge is made available through research, as this can form the basis for new innovations. Note that this also implies that research has a higher importance for economies the higher their economic complexity – which seems to be supported by plotting Business Expenditure on R&D (BERD) as a share of GDP vs Economic complexity for all countries..

‘product space’, those close to one another are co-exported by a large number of countries, leading to the conclusion that they require similar capabilities for their production. If a country exports a product with a high Revealed Comparative Advantage (RCA), it is inferred that the country has an Implied Comparative Advantage (ICA) in those products that are ‘close’ (in Product Space) to this exported high RCA product and could, therefore, develop production capacity in those products. It should also expect to be able to develop the capability to export them with respectable RCA.

It should be noted that the ECI is not a measure of trade openness, or a report on the level of export diversification. Nor is the ECI related to an economy’s size, population size or the population’s education level. There is, however, some relation between ECI, on the one hand, and population density (linked to the agglomeration economic benefits of having mutually beneficial economic agent interaction within relatively close geographical proximity) on the other. Hausmann and Hidalgo articulates this as denser populations having closer networks and greater knowledge exchange (Hausmann & Hidalgo, 2013; Hausmann, Hidalgo, Bustos, et al., 2014; Hidalgo & Hausmann, 2009). We would, as a consequence, expect propensity to collaborate to affect ECI positively in economies that have similar size and population density. The ECI is a more generalised measure of potential growth related to how knowledge is translated into the capability to produce products in each specific economy.

Export data is used, rather than total production data, because trade data is more readily available, and because it is a better indicator of international competitiveness in a product, that is, it offers a ‘value proposition’ that appeals to a significant number of ‘non-captive’ buyers. In addition, for export products to be of importance in EC modelling an economy must export a significant quantity – as indicated by the economy possessing a Revealed Comparative Advantage (RCA) in that product. EC modelling uses Balassa's (Balassa, 1965) definition of RCA. Specifically, an economy has an RCA in a product if it exports 'more than its "fair" share — that is, more than the share of total world trade that the product represents'. As formal definition, if X_{cp} represents the exports of country c in product p, then the Revealed Comparative Advantage that country *c* has in product *p* can be written as

$$RCA_{cp} = \frac{X_{cp}}{\sum_c X_{cp}} \Big/ \frac{\sum_p X_{cp}}{\sum_{cp} X_{cp}}$$

Of course, in the context of sub-regional EC modelling, the subscript *c* would represent the State (or sub-region) instead of country.[5]

A state or territory has a significant export presence in a good or service within the sub-regional economy if its revealed comparative advantage (RCA) is greater than 1 – and thus produces more than its "fair share" when compared to total Australian production. Accordingly, Revealed Comparative Advantage (RCA) can then be used to construct a matrix (M_{cp} matrix) that connects each state to the products that it makes. The entries in M_{cp} matrix are 1 if state *c* exports product *p* with Revealed Comparative Advantage larger than 1, and zero otherwise.

Once the M_{cp} matrix is constructed, diversity $k_{c,0}$, and ubiquity $k_{p,0}$ can be calculated simply by summing over the columns and rows of M_{cp}, respectively. Formally, $k_{p,0} = \sum_c M_{cp}$.

[5] We have chosen to use consistent terminology so that the accustomed formulae remain the same and intact.

To generate a more accurate measure of the number of capabilities available in a state, or number of capabilities required by a product, the information that diversity and ubiquity carry is to be corrected by using each one to correct the other. For states, this requires calculation of the average ubiquity of the products that each state exports, the average diversity of the states that make those products and so forth. For products, on the other hand, this requires calculation of the average diversity of the states that make them and the average ubiquity of the other products that these states make. This can be expressed by the recursion:

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} \, . \, k_{p,N-1}$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_{c} M_{cp} \, . \, k_{c,N-1}$$

$k_{c,N}$ can be rewritten as

$$k_{c,N} = \sum_{c'} \widetilde{M_{cc'}} \, k_{c',N-2}$$

where

$$\widetilde{M_{cc'}} = \sum_{p} \frac{M_{cp} \, M_{c'p}}{k_{c,0} \, k_{p,0}}$$

We then calculate $\vec{K}$, the eigenvector that corresponds to the second largest eigenvalue of the matrix $\widetilde{M_{cc'}}$ (because this is the eigenvector that captures most of the variance in the system). The Economic Complexity Index (ECI) is defined as

$$\overrightarrow{ECI} = \frac{\vec{K} - < \vec{K} >}{stdev(\vec{K})}$$

where < > denotes the average, *stdev* stands for the standard deviation and $\vec{K}$ is the eigenvector of $\widetilde{M_{cc'}}$ associated with the second largest eigenvalue.

Product Complexity Index (PCI) can be defined analogously. Due to the symmetry of the problem this can be done simply by swapping the indices *c* and *p* in the definitions above. Hence, we define PCI as

$$\overrightarrow{PCI} = \frac{\vec{Q} - < \vec{Q} >}{stdev(\vec{Q})}$$

where $\vec{Q}$ is the eigenvector of $\widetilde{M_{pp'}}$ associated with the second largest eigenvalue.

The objective of EC modelling is to provide the ECI and PCI to establish the RCA of each economy, and allow identification of potential products that the state might have opportunities in. This is where the concept of opportunity value (OV) is useful. Before we see a formal definition of OV, it is important to understand the notion of proximity between the products, and also the notion of distance between state c and the product *p*. Formally, for a pair of products *p* and *p*' proximity is defined as:

$$\emptyset_{pp'} = \frac{\sum_c M_{cp} M_{cp'}}{\max(k_{p,0}\, , k_{p',0})}$$

where $M_{cp} = 1$ if state *c* exports product *p* with $RCA_{cp} > 1$ and 0 otherwise, and $k_{p,0}$ is the ubiquity of the product *p*. Measure of proximity is based on the conditional probability that a state that exports product *p* will also export product *p'*.

The concept of distance gives us an idea of how ‘far away’ each product is given a state’s current mix of exports. The distance between state c and the product *p* is defined as the weighted proportion of products connected to product p that state c is not exporting. The weights are given by proximities. Formally,

$$d_{cp} = \frac{\sum_{p'}\left(1 - M_{cp'}\right) \emptyset_{pp'}}{\sum_{p'} \emptyset_{pp'}}$$

Opportunity Value of a state *c* can then be defined as

$$OV_c \quad = \sum_{p'}\left(1 - d_{cp'}\right)(1 - M_{cp'})\, PCI_{p'}$$

where PCI_p stands for PCI of a product *p* while d_{cp} denotes distance between state c and the product *p*. The term $1 - M_{cp'}$ makes sure that we count only the products that the state *c* is not currently exporting (with RCA >1). Higher OV indicates that a state (and the products it produces) are in the vicinity of more products and/or of products that are more complex.

OV can be used to calculate the potential benefit to a state if it were to move to a particular new product. This is called the "opportunity gain" (OG) that state c would obtain from making (and exporting) product *p*. This is calculated as the change in opportunity value that would come as a consequence of developing product *p*. OG quantifies the contribution of a new product in terms of opening up the doors to products of greater complexity. OG of a state *c* is formally expressed as:

$$OG_c = \sum_{p'} \frac{\emptyset_{pp'}}{\sum_{p''} \emptyset_{p''p'}} \left(1 - M_{cp'}\right) PCI_{p'} - (1 - d_{cp}) PCI_p$$

3. Data

To measure economic complexity at a sub-national level, sub-national trade data was sourced from a sub-regional multi-regional Input-Output table (MRIO). This MRIO table was based on the supply-use structure (Eurostat, 2008), and was obtained from the Australian Industrial Ecology Virtual Laboratory (IELab) (Lenzen et al., 2014; Lenzen, Wiedmann, et al., 2013).

The IELab is a unique cloud-environment for the compilation of high resolution sub-national IO tables for Australia, it aggregates and harmonises many sources of economic information into one customised super table (Lenzen et al., 2014; Lenzen, Wiedmann, et al., 2013). The IELab consists of highly detailed Australian data for 1284 industry sectors (Australian Bureau of Statistics, 2012a, 2012b) and 2214 regions (Australian Bureau of Statistics, 2010), with the ability to augment this with additional Rest of the World (ROW) import/export vectors. Using this root classification, users construct customised MRIO tables. In this instance, our custom MRIO table featured 9 sub-regions of Australia (New South Wales, Victoria, Queensland, South Australia, Western Australia, Tasmania, Australian Capital Territory, Northern Territory, and Other territories (comprising Jervis Bay Territory, Christmas Island and the Cocos (Keeling) Islands), and 506 industry (intermediate) sectors that corresponded to the ANZSIC06 industry sector classification (Australian Bureau of Statistics, 2006). International trade import/export vectors were added from the EORA world MRIO database (EconSearch, 2015; Lenzen, Geschke, Kanemoto, & Moran, 2011; Lenzen, Kanemoto, Moran, & Geschke, 2012; Lenzen, Moran, et al., 2013). Data sources used to create, harmonise, and concord the MRIO table included the core IELab dataset, the ABS 5206 national IO tables, ABS5220 state accounts (Australian Bureau of Statistics, 2008, 2014, 2015) , state and sub-state economic information from EconSearch (EconSearch, 2015), and balancing constraints. Results for monetary transactions were given in AUD millions (1,000,000). The time period considered was 2009, as this matches the latest time period used in *The Atlas of Economic Complexity.*

The technical layout of a supply-use input-output table is as follows:

	Industry	Product	Int. Export	Final Demand	Total
Industry		$\mathbf{V}$			$\vec{g}$
Product	$\mathbf{U}$		$\vec{E}$	$\mathbf{f}$	$\vec{q}$
Int. Import	M				

where **U** is a product-by-industry use matrix, **V** is an industry-by-product supply matrix, $\vec{E}$ is a vector of international exports, M is a series of vectors of international imports, **f** is final demand of products, $\vec{q} = \mathbf{U}\mathbf{1}^i + \vec{E} + \mathbf{f}_p\mathbf{1}^f$ is total use by product, $\vec{g} = \mathbf{V}\mathbf{1}^p$ is total use by industry, and $\mathbf{1}^i$, $\mathbf{1}^f$, and $\mathbf{1}^p$ are summation operators $\{1,1,\ldots,1\}^{\mathrm{T}}$ for industries, final demand categories, and products, respectively.

Within **U**

$$\begin{array}{c} \\ \mathrm{State}_1 \\ \mathrm{State}_{\ldots} \\ \mathrm{State}_9 \end{array} \left\{ \begin{array}{c} \begin{array}{ccc} \mathrm{State}_1 & \mathrm{State}_{\ldots} & \mathrm{State}_9 \end{array} \\ \begin{bmatrix} \overbrace{\mathrm{U}_{1,1} \quad \mathrm{U}_{1,\ldots} \quad \mathrm{U}_{1,9}} \\ \mathrm{U}_{\ldots,1} \quad \mathrm{U}_{\ldots,\ldots} \quad \mathrm{U}_{\ldots,9} \\ \mathrm{U}_{9,1} \quad \mathrm{U}_{9,\ldots} \quad \mathrm{U}_{9,9} \end{bmatrix} \end{array} \right.$$

$\mathrm{U}_{1,1}$ are the internal transactions of State 1, while $\sum \mathrm{U}_{1,2} \ldots \mathrm{U}_{1,9}$ represents the interstate exports of State 1 to the other states. For our EC analysis we used the interstate and international export data, with direct interstate consumption to households excluded.

It should be noted that the ANZSIC06 industry sector classification includes goods and services industries. This is a distinction from the Standard International Trade Classification Revision 2 at the 4-digit level (SITC4) dataset used in *The Atlas of Economic Complexity* and other prior EC research, as the SITC4 only includes tradable goods. The addition of services export activities provides a more representative description of each state's economic complexity, as exported service industries have the potential to be complex exports.

Due to the nature of MRIO data, exports are given as Port of Exit, rather than State of Origin. However, as total exports (interstate + international) are used for this EC analysis rather than interstate this difference is academic: products created in one State and exported from an interstate port appear as both interstate and international trade, so the total exports from each State are correct. The use of Port of Exit trade data, rather than State of Origin could possibly incorrectly inflate the ECI of states, if large quantities were exclusively shipped to one specific state for export.

However, our EC analysis of only interstate trade, shows similar findings due to high correlations between interstate and International exports. Please refer to Appendix 4 in the online accompanying data for further detail on the correlations between interstate trade data and interstate and Rest of World trade data. Furthermore, if analysis was to focus upon State of Origin rather than Port of Exit, one could use the Leontief inverse (Leontief, 1936) to back calculate the State of Origin of all sectors.

4. Australian economic complexity at national and sub-national levels

In *The Atlas of Economic Complexity*, Australia was ranked 79th out of 128 countries in 2009, with an Economic complexity score of -0.321 (Hausmann, Hidalgo, Bustos, et al., 2014). This analysis implied that the majority of Australia's export products are resource intensive, while being knowledge and skill deficient.

However, our results reveal that interstate trade is more nuanced than international trade, with the sub-national EC of Australia being much more varied. At the interstate level, Australia exports many objects, goods and services that would never be internationally exported due to fragility, perishability, or lack of productive capacity (volume). In addition, Australia's states have no import barriers between them, and somewhat similar levels of technological capacity, thus there is much generalised trade occurring between states. Our EC analysis highlights that the small differences in industrial capability and knowledge are crucial to relative complexity (and thus the future prosperity) of Australia's states and territories.

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Table 1 The contribution of interstate and international export monetary transactions for each state and territory. Monetary values listed in $1,000,000 AU

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Table 1 indicates the contribution of interstate and international export for each state, with roughly half of each state's export generated from interstate sub-national trade. The exceptions to this export split are Western Australia (WA), the Australian Capital territory (ACT), and the Northern Territory (NT), that have 15%, 89% and 77% of their total trade as interstate. This indicates the differing product bundles exported by WA, ACT and the NT compared to the rest of the Australian States.

Table 2 highlights the differences between interstate and Rest of the World (ROW), that is, international export. Due to the aforementioned split between interstate and international export in most states, the proportional share of exports is matched to the economic size of the state. However, the export specialisation of WA, ACT and NT has led to a disproportionally large share of interstate or international export coming from these states and territories.

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Table 2 The percentage differences between interstate and international (ROW) exports

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The exported product mixes of each state also differ. Further information on these are provided in Appendix 4 of the online accompanying data, along with the differences of interstate export data versus interstate and Rest of World export data.

Diversity and Ubiquity

Diversity and Ubiquity are the core measurements of EC modelling. The average diversity score indicates the number of products in which each state or territory has a Revealed Comparative Advantage, while a high average ubiquity score indicates a network of exported goods that are commonly exported together. More specifically, this state or territory is specialised in export goods that are also specialised in by other states and territories. In the Australian context a high ubiquity score means that there is dominance of unsophisticated products exported from that state. Graphically, the juxtaposition of these two values indicates the production capability of each state and territory relative to the other states and territories. Figure 1 and Table 3 plot the relative average diversity ($k_{c,0}$) and ubiquity ($k_{c,1}$) for Australia's states and territories.

Not shown in Figure 1 is Other Territories (OT) region, as its diversity ($k_{c,0}$) was 30, much lower than the rest of Australia's state and territories. However, OT had the highest ubiquity ($k_{c,1}$=4.1). This combined score indicates that though OT exported a small unique bundle of goods and services, it had very limited export specialisation. Due to its unique position OT will not be discussed for the rest of this paper.

New South Wales (NSW) has the next highest ubiquity score ($k_{c,1}$=3.83), followed by Victoria (Vic, $k_{c,1}$=3.73), and Queensland (Qld, $k_{c,1}$=3.64). The Northern Territory has the lowest ubiquity score ($k_{c,1}$=3.17). However, the Northern Territory (NT) had the highest diversity score ($k_{c,0}$=249), followed by Qld ($k_{c,0}$=238), and Vic ($k_{c,0}$=219). South Australia (SA) had the lowest diversity score besides OT ($k_{c,0}$=138), with a low to moderate ubiquity score of $k_{c,0}$=3.45. It is worth noting that SA had similar ubiquity scores to Western Australia (WA, $k_{c,0}$=3.47) and Tasmania (Tas, $k_{c,0}$=3.46), with their relative levels of diversity distinguishing them.

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Table 3 Diversity and Ubiquity scores for Austrlalia’s states and territories.

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Figure 1 Comparing diversity and ubiquity measures for each state and territory with internal+ ROW export. Other Territories (OT) is not shown as its kc0, Diversity=30

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The high ubiquity from international exporters confirms the situation discussed in Tables 1 and 2, and Figure 2: a large percentage of international export is from a small number of non-complex products - in this case resources and agricultural products. The central hypothesis of economic complexity modelling is to build upon the export of these non-complex products, and move into the export of more complex, knowledge intensive products – this is what has happened over time in Sweden and many other innovation-rich countries. (Schön, 2012; Sjöö, 2014; Taalbi & Ljungberg, 2015; Taalbi, 2014; Tamrakar, 2014)

The Economic Complexity Index (ECI)

Table 4 provides the ECI for each state and territory, the higher the EC score the more relatively complex the state's economy is compared to the rest of Australia. New South Wales has the highest ECI, while the Northern Territory has the lowest ECI. South Australia (SA) is positively placed in Figure 2, and placed close to the middle of Figure 3. This indicates that SA has much room for growth and improvement (opportunity) in expanding its goods and services. However, the OV of 8.46 and ECI of 0.19 indicates this expansion may come at a greater cost (i.e. with greater obstacles to overcome) than for states with a higher ECI and OV.

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Table 4 The Economic Complexity Index and Opportunity value for each state and territory, along with the GSP per capita in current price, Source: 5220.02013-14 ABS (Australian Bureau of Statistics, 2014)

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Figures 2 and 3 complement Table 4, as a pictorial comparison of the ECI of each state and territory to its relative OV (Figure 2), or log GSP per capita (Figure 3). Together these illustrate how complex each economy is and the relative gains from increasing complexity. The positive location of NSW, Vic, WA, QLD and SA, on the OV axis indicates that these states have more to gain from moving into more complex products than the states and territories with negative locations.

From Figures 2 and 3, it is apparent that QLD and VIC have higher OV than NSW, even though NSW has the highest ECI. The reason for this positioning is that NSW is exporting different types and quantities of commodties to the ROW, than QLD and VIC, this in turn has impacts on the overall ECI and OV of NSW. NSW is a more complex economy, but has less to gain (opportunity) to expand its exports into new goods or services.

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Figure 2 The ECI and Opportunity Value for each state and territory. OT is omitted.

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Figure 3 Opportunity value as a function of GSP per capita (log value). OT omitted.

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The Product Complexity Index (PCI)

Figure 4 shows the relative product complexity of the 506 goods and services produced in Australia according to the ANZSIC06 classification. It can be seen that there is fluctuation of product complexity within product groups with the notable exceptions of the 3 blocks of product numbers #227-#244, #246-#284, and #285-#320. The appearance of these blocks of equal PCI are due to these being common products across all states, though this commonality is also likely to be attributable to the aggregation and disaggregation method of the IELab. The higher the PCI score on the horizontal axis of Figure 4, the more complex the good or service is to produce.

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Figure 4 The Product Complexity Index for the 506 goods and services (ANZSIC 06 classification)

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Appendix 5 in the online accompanying data lists the lowest national PCI for the goods and services (the least complex products) for comparison.

5. Discussion

The upcoming and ongoing exit of the automotive and heavy vehicle manufacturing industries from Victoria, South Australia and Tasmania will have major impacts on the economic structure and prosperity of these states. Our EC analysis has found that among these three states, Victoria is the best situated to shift into other complex industries. Likewise, South Australia, with a positive OV has the immediate ability to shift into other complex export products but has to overcome larger barriers (i.e. incur higher costs) and this industry shift will likely take a longer time. Tasmania is the least well positioned state to respond to this economic restructure due to its negative opportunity value.

Our analysis extends the economic picture painted by Wood and Lenzen (2009) into the year 2009. In the 25 year time period of Wood and Lenzen (2009), the Australian economy had evolved increased efficiency of resource use and employment, smaller primary and manufacturing sectors and larger and better linked tertiary and service sectors. Our EC analysis confirms that this trend toward linked tertiary and service sectors has continued. Our results also show that there has been greater development in specialised trade occurring within the sub-national Australia (and thus Australia as a national entity). Comparing this papers EC results for each state and territory against the results of Wood and Lenzen's (2009) 1975-1999 national model, provides the insight that all states and territories have developed and are at different stages of complexity and structure, with both local and global developments in the intermittent decade having had impacts.

Our EC analysis also confirms Hausmann and Hidalgo's national EC analysis, finding that the majority of states (especially Western Australia) export primarily resource-intensive goods. However, our analysis also shows that interstate trade has many complex industries and products that are not internationally exported. Expansion into international export of these products will strengthen both national and sub national EC.

The results and analysis in the paper must be taken with a caution, as the small number of states and (much economically smaller) territories, with only 506 industry ANZSIC06 sector's may not provide a big enough model for the EC calculation process to work correctly. This means that our model may have produced uncertain values for Diversity and Ubiquity, which in turn will affect the ECI and PCI values given in this paper. Future research should align the subnational EC analysis presented here to with global results. This would also allow placement of Australia's regional complexity at a global scale, and produce more robust values for Diversity, Ubiquity, ECI and PCI.

In addition, a limitation of EC theory, is that there is no theoretical integration of the importance of historic relationships, population density bias and geographic proximity when trade occurs (R Boschma & Frenken, 2010, 2011; Furman, Porter, & Stern, 2002). These factors act as additional drivers of innovation and collaboration for economic actors, but are absent from EC theory. Future studies could use network analysis to examine these impacts within a longitudinal EC framework. These are especially important when discussing the sub-national case of Australia, as the complexity analysis is showing bias towards the eastern states, away from the more geographically distant WA, NT, and SA. Future research could use the data found in the $\mathbf{U}$ matrices of MRIO tables and the EC analysis methodologies of Wood and Lenzen (2009) (i.e. measures of multipliers and transactions, and calculating forward and backward linkages) to take account of these relationships. However, this analysis would be very data and processing intensive. Currently, no MRIO time series database is available at a high enough resolution of data. This could probably be a reason why Hausmann and Hidalgo's EC analysis is focused only on trade data.

A further limitation is that the importance of relationship capital is omitted in the EC theory. Relationship capital[6] impacts cultural collaboration propensity – where Australia ranks 24th (29th) out of 31 OECD countries for collaboration between SME's (large firms) and Researchers (Office of the Chief Economist, 2015). In fact, the likelihood of having any form

[6] For definition and discussion about relationship capital see (Roos, Pike, & Fernstrom, 2012) and (Roos, 2014)

of collaborative arrangement in place peaks at 9%, which is for a firm aged between one and four years (Office of the Chief Economist, 2015).

In addition to this there are national organisational capital aspects that impact national prosperity e.g. policy landscape, rules, regulations, systems, processes etc. This can be exemplified with the negative impact of a rapidly shifting policy landscape, like in Australia, where uncertainty will originate from the inability to predict the performance of new institutions, the actions of other players, or what will be gained or lost if present behaviour is changed (Culpepper, 2008).

A final limitation of EC theory predictive accuracy is the role of economic uncertainty. This type of uncertainty is contributing to limiting national prosperity growth since capital investment and workforce hiring decisions have long term consequences – often 10- to 20-year or more – and consequently policy uncertainty over longer time periods makes it almost impossible to formulate business and investment strategies with sufficient confidence which reduces the ability to commit to stakeholders and hence postpones prosperity driving investments. Together these limitations contribute to understanding why, as articulated in the correlation analysis underpinning the EC theory, change in economic complexity explains (in correlation terms) 70% and not a greater amount of national prosperity.

6. Conclusion

In this paper we have performed a sub-national EC analysis on the states and territories of Australia. We have calculated the ECI, RCA, PCI, OG and OV relating to 9 sub-national economies and 506 exported goods and services. To our knowledge this is the first application of EC analysis to sub national dataset, and the first use of an MRIO database as base data for EC analysis, and the first to include services sectors in EC analysis. Future application of EC analysis at the sub national level could include calculation of the implied comparative advantage for each sector (Hausmann, Hidalgo, Stock, & Yildirim, 2014), and thus identification of the best sectors (the *low hanging fruit* (Hausmann, Hidalgo, Bustos, et al., 2014)) for investment and expansion into; further scenario modelling of the impact of industries exiting or entering sub national markets; and integration of this sub national model into Hausmann and Hidalgo's previous international model (STIC). This would allow the use of the base MRIO table to perform structural decomposition analysis to enable the tracing of the supply chains of complex products to quantify relationships between sub-national and global economies.

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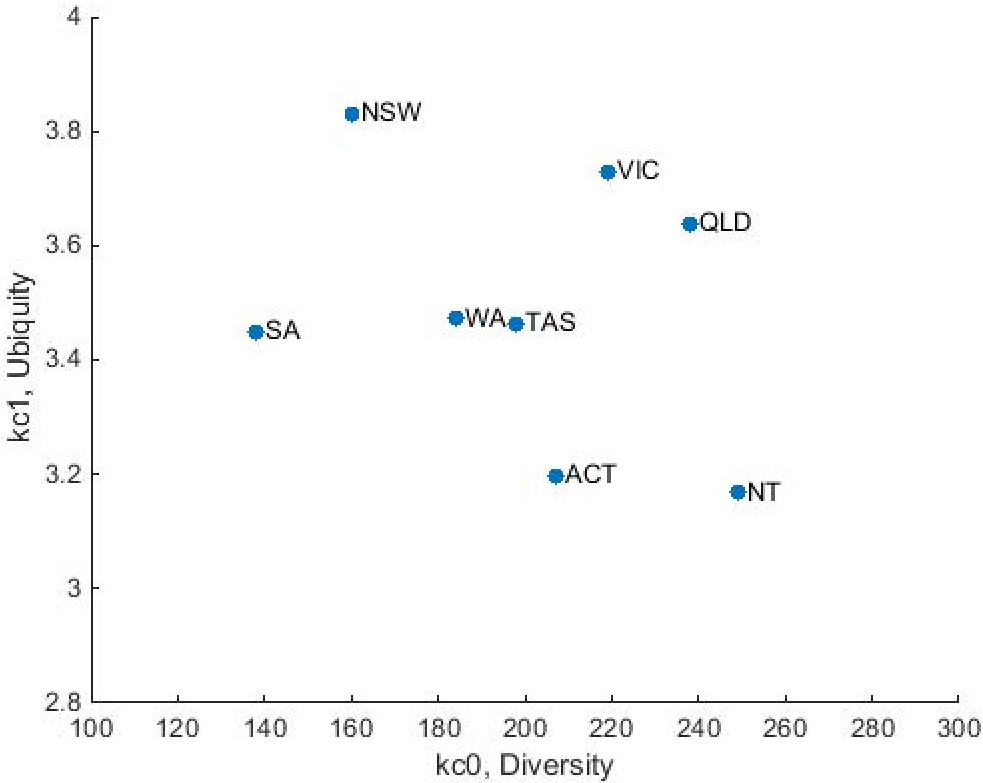
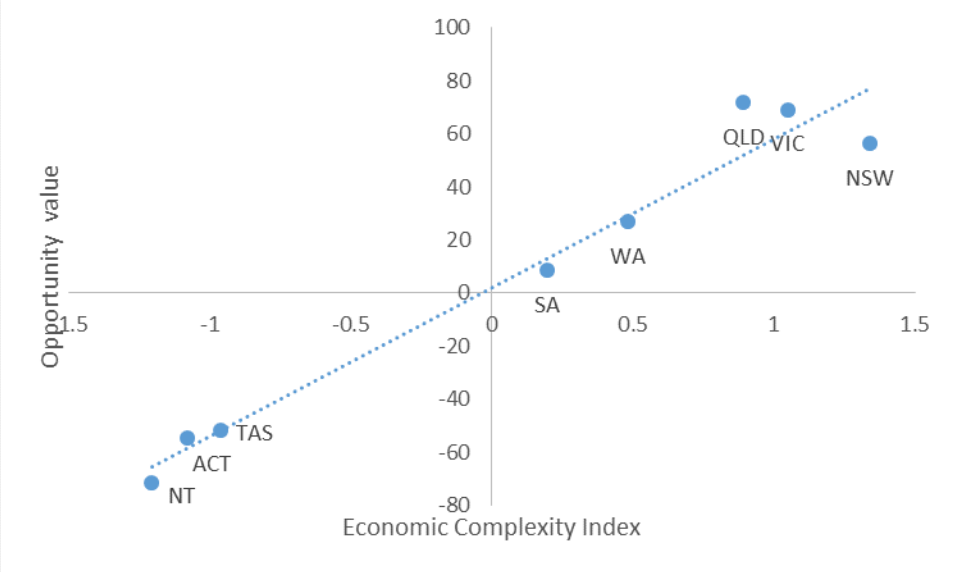

NSW
VIC
QLD
SA
WA
TAS
ACT
NT
kc1, Ubiquity
4
3.8
3.6
3.4
3.2
3
2.8
100
120
140
160
180
200
220
240
260
280
300
kc0, Diversity


Opportunity value
Economic Complexity Index
100
80
60
40
20
0
-20
-40
-60
-80
-1.5
-1
-0.5
0
0.5
1
1.5
QLD
VIC
NSW
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SA
TAS
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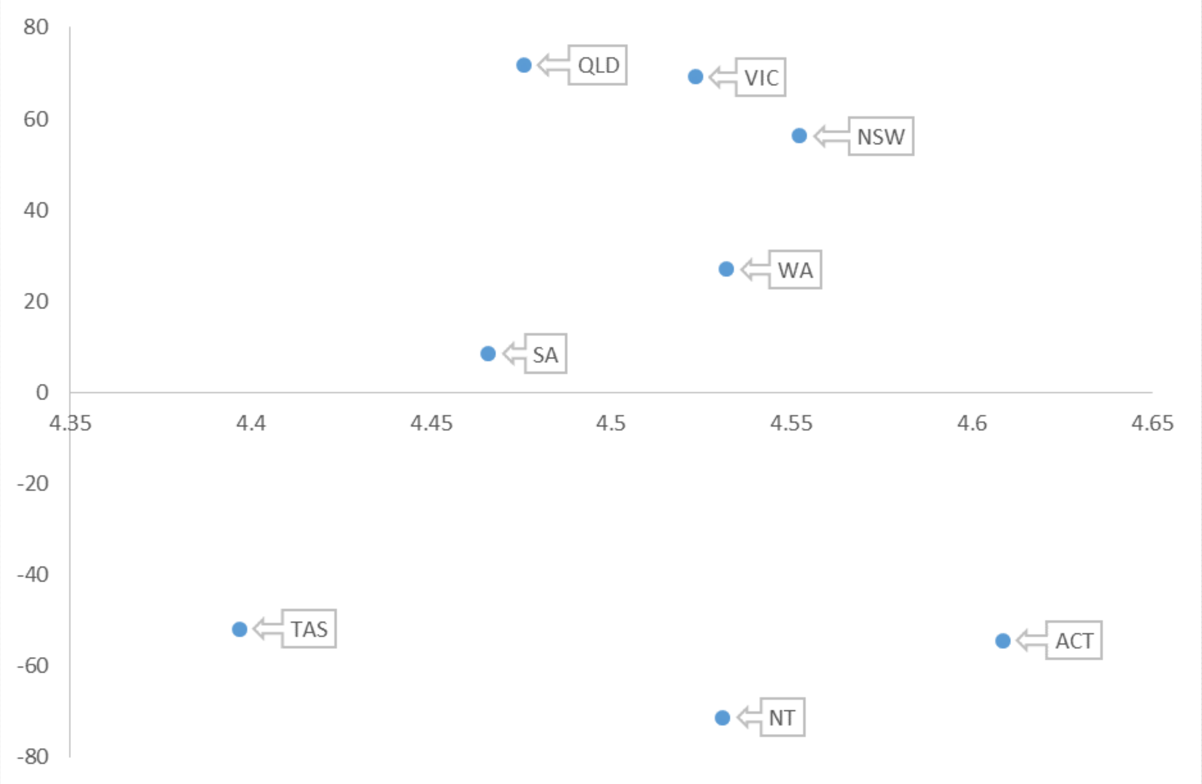

80
60
40
20
0
-20
-40
-60
-80
4.35
4.4
4.45
4.5
4.55
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WA
SA
TAS
ACT
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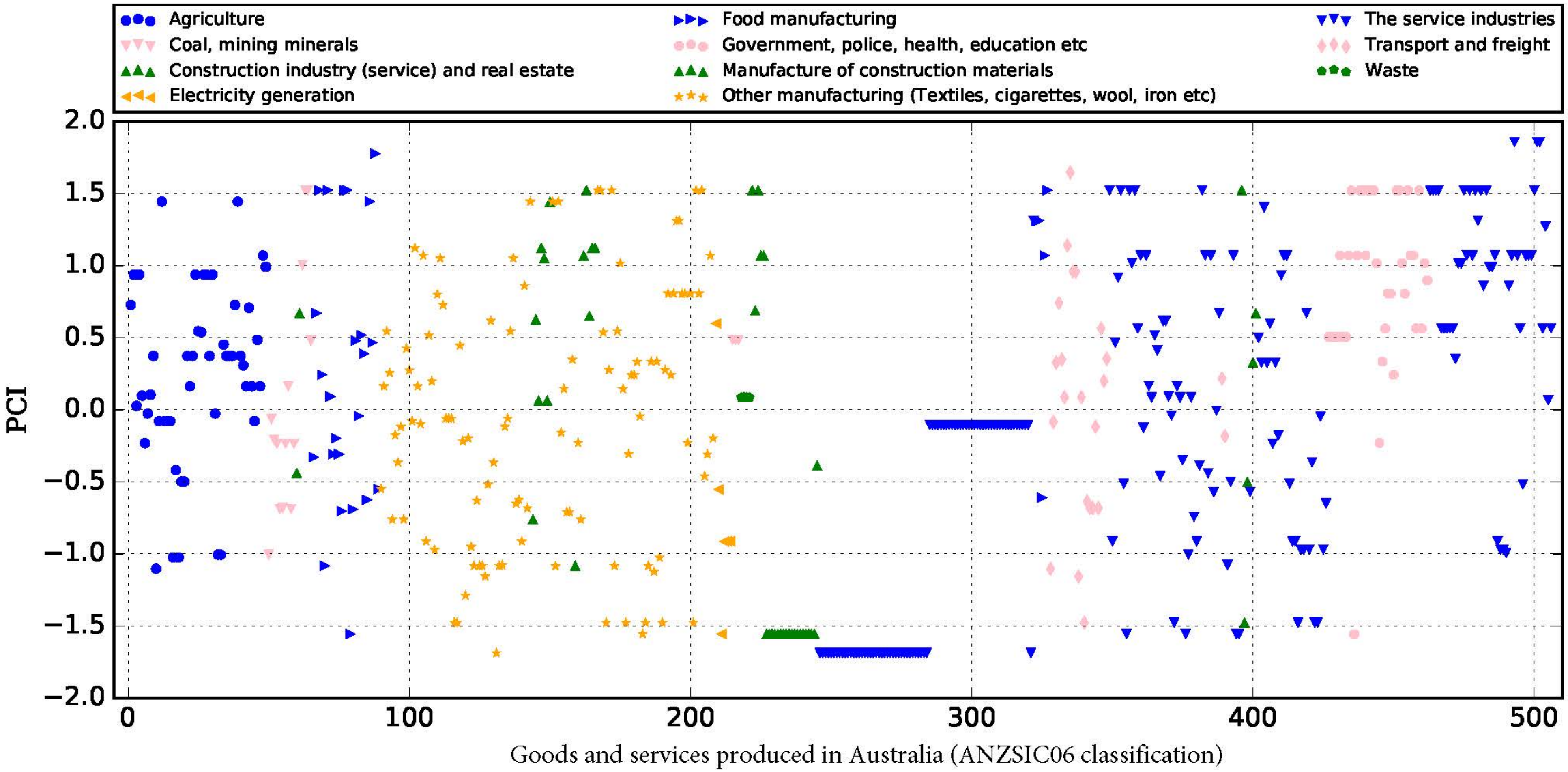

Agriculture
Coal, mining minerals
Construction industry (service) and real estate
Electricity generation
Food manufacturing
Government, police, health, education etc
Manufacture of construction materials
Other manufacturing (Textiles, cigarettes, wool, iron etc)
The service industries
Transport and freight
Waste
PCI
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0
100
200
300
400
500
Goods and services produced in Australia (ANZSIC06 classification)

Table 1 The contribution of interstate and international export monetary transactions for each state and territory. Monetary values listed in $1,000,000 AU

	INTERSTATE	INTERSATE AS % OF TOTAL EXPORTS	ROW	ROW AS % OF TOTAL EXPORTS	ROW+INTERSTATE
NEW SOUTH WALES	45411	56	35283	44	80694
VICTORIA	29585	50	29261	50	58846
QUEENSLAND	22317	48	24201	52	46518
SOUTH AUSTRALIA	12916	46	15139	54	28055
WESTERN AUSTRALIA	16826	15	91771	85	108597
TASMANIA	9800	44	12266	56	22067
AUSTRALIAN CAPITAL TERRITORY	63194	89	8038	11	71232
NORTHERN TERRITORY	69015	77	20102	23	89117
OTHER TERRITORIES	163	3	4718	97	4882
TOTAL	269227	53	240779	47	510006

Table 2 The percentage differences between interstate and international (ROW) exports

	% OF ROW	% OF INTERSTATE	% OF TRADE
NEW SOUTH WALES	15	17	16
VICTORIA	12	11	12
QUEENSLAND	10	8	9
SOUTH AUSTRALIA	6	5	6
WESTERN AUSTRALIA	38	6	21
TASMANIA	5	4	4
AUSTRALIAN CAPITAL TERRITORY	3	23	14
NORTHERN TERRITORY	8	26	17
OTHER TERRITORIES	2	0	1
TOTAL	100	100	100

Table 3 Diversity and Ubiquity scores for Austrlalia's states and territories.

kc0 Diversity		kc1 Ubiquity	
NORTHERN TERRITORY	249	OTHER TERRITORIES	4.10
QUEENSLAND	238	NEW SOUTH WALES	3.83
VICTORIA	219	VICTORIA	3.73
AUSTRALIAN CAPITAL TERRITORY	207	QUEENSLAND	3.64
TASMANIA	198	WESTERN AUSTRALIA	3.47
WESTERN AUSTRALIA	184	TASMANIA	3.46
NEW SOUTH WALES	160	SOUTH AUSTRALIA	3.45
SOUTH AUSTRALIA	138	AUSTRALIAN CAPITAL TERRITORY	3.20
OTHER TERRITORIES	30	NORTHERN TERRITORY	3.17

Table 1 The Economic Complexity Index and Opportunity value for each state and territory, along with the GSP per capita in current price, Source: 5220.02013-14 ABS (Australian Bureau of Statistics 2014)

	GSP per capita, current price ($), 2009	log10(GSP)	ECI	Opportunity value
NEW SOUTH WALES	35,668	4.55	1.34	56.27
VICTORIA	33,371	4.52	1.05	69.20
QUEENSLAND	29,903	4.48	0.89	71.86
SOUTH AUSTRALIA	29,233	4.47	0.19	8.48
WESTERN AUSTRALIA	34,045	4.53	0.48	26.91
TASMANIA	24,938	4.40	-0.96	-51.94
AUSTRALIAN CAPITAL TERRITORY	40,602	4.61	-1.08	-54.46
NORTHERN TERRITORY	33,959	4.53	-1.21	-71.37
OTHER TERRITORIES	-	-	-0.71	-7.95