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Regional innovation systems: A network analysis of three Australian territories

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Abstract

A well-functioning innovation system is considered a key to economic development on both a regional and a national level. One aspect in studying innovation systems addresses the creation of innovations through innovative activities, leading further to an increased innovative capacity. By means of a case study for three Australian territories this paper studies the structure of the regional innovation systems of New South Wales, Victoria and Queensland. Based on network analysis together with the concept of product-embodied R&D flows applied to three single-region I/O-models, it uncovers differences in innovative activities within and across regions on an industry-level. It shows that the three regional innovation systems perceive of rather distinguished structural features and in the end shape Australia's innovative capacity in quite different ways.

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Regional innovation systems: A network analysis of three Australian territories[1]

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Keywords: regional innovation systems, product-embodied R&D flows, network analysis, centrality, clustering patterns.

1 Introduction

Studying the consequences of the diffusion of various types of innovations on economic development and especially on productivity growth has a long tradition in economic thought (Schumpeter, 1964 [1939] and 2006 [1912]). More recently, in the innovation literature the concept of *innovation systems* appeared (Freeman, 1987 and Nelson, 1993). In a Neo-Schumpeterian tradition, within the innovation systems (IS) framework, the creation and diffusion of innovations are considered a key to economic development. Assuming a holistic perspective, compared to Schumpeter's early individualistic approach (2006 [1912]), the study of IS on different levels of analysis addresses a network of firms, institutions and organisations, which initiate and diffuse innovations (Freeman, 1987). Hence, one characteristic feature of an IS is the support of innovative capacity, which is defined as "a country's [or any other location's] potential [...] to produce a stream of commercially relevant innovations. [... It] also reflects the *fundamental conditions, investments, and policy choices that create the environment for innovation* in a particular location or nation." (Porter and Stern 2002: 5, italics added)

While the production of commodities and the division of labour have become continuously globalised in recent years – leading partly to a global value chain, it seems that innovative activities are still concentrated within a nation's border, used to strengthen its competitiveness through an increased innovative capacity. Especially within advanced economies, the innovation literature (Porter, 2003 and Asheim & Coenen, 2005) suggests that innovative activity tends to dominate on a (sub)national level instead of on a global level. Taking Australia as an example for an advanced

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economy and glancing at its innovative activity, approximated by business R&D expenditures, this can be confirmed: From 2005 until 2012 only about 2% of annual business R&D expenditures were invested overseas, whereas 98% remained within the national borders of Australia and were spent in its different territories. Thus, the use of R&D for strengthening the innovative capacity is considered as a highly relevant competitive policy issue in both a national and a regional context, where regions contribute to their own competitive position and in the end also to that of a country as a whole, acting as a backbone to its technology frontier.

Using three economically important Australian territories as a case study for this paper, namely New South Wales (*NSW*), Victoria (*VIC*) and Queensland (*QLD*), regional innovative activities are addressed. Regional innovative activities both shape the regional innovative capacity and they are considered as an integral part of the Australian innovative capacity. The central purpose of this paper is thus, to focus on the three Australian territories and analyse as well as compare particular aspects of their regional innovation systems (*RIS*) by means of different network measures. It answers the following questions: What is the structure of the RIS and which distinctive features do the RIS exhibit in terms of innovative activities?

To the best of the author's knowledge, there are hardly any studies of the Australian IS and in particular of its RIS – just one example is contained in Nelson (1993). Further, for the purpose of this work it is considered as indispensable to analyse the regional innovative capacity not in isolation from the respective production system. Therefore network measures applied to a single region I/O-framework for the three regions together with product-embodied R&D flows (as an indicator for innovative activities) are used to answer the research questions. The paper adds to the literature on RIS, since network analysis allows one to identify (1) an industry's position in determining the region-wide innovative capacity through product-embodied R&D flows; (2) whether single industries concentrate in terms of innovative activity. Related to this, (3) regional clustering and specialisation patterns of innovative activity are analysed and (4), information on the hierarchical structure of the whole RIS is gained. From a methodical viewpoint, the regionalisation problem of national I/O-data is solved through applying a bi-proportional optimisation technique (Junius & Oosterhaven, 2003). This procedure avoids not only the use of the national technology assumption, but also allows one the use of a maximum of regional data provided by Australia's national statistical bureau (*ABS*).

The paper proceeds as follows: Section 2 contains a brief review of the literature on IS on a subnational level and in particular on the concept of product-embodied R&D expenditures, as a measure of regional innovative activity. Section 3 introduces the method used to answer the research questions. Based on a modified version of Pavitt's functional taxonomy (1984), in section 4 the network measures are applied to study the structure of the three RIS. Section 5 concludes.

2 Regional IS and the concept of product-embodied R&D

IS are studied on different levels of analysis. As the collection edited by Nelson (1993) illustrates, especially early works analysed IS on a national level. Since the innovation and diffusion process are under focus in the IS framework and this process is not limited to a national level, questions have emerged whether this is the adequate level of analysis (Cooke et al, 1997). In Nelson (1993), Malerba (1993) already published a paper where he shows – although in a national context – that Italy's IS is largely shaped at a subnational level, putting therefore the latter into the foreground. Since then, studies of IS have appeared on a sectoral (Breschi & Malerba, 2011 [1997]), local and regional (de la Mothe & Paquet (Eds.), 1998) level of analysis. While the various authors mentioned use a specific terminology to distinguish their respective levels of analysis, there sometimes seems to be no clear-cut distinction. This is the case, because e.g. on a regional level of analysis there are still interdependencies between the RIS and both lower and higher levels of analysis. Ignoring these interdependencies would be against the holistic perspective underlying the study of IS, as explained in more detail below. Since this paper focuses on the study of the RIS of NSW, VIC and QLD, obviously the region is the level of analysis and its industries are the units of analysis. In this context, a region can be defined as a spatial cohesive unit belonging to a larger geographic and supra-local entity – in this case Australia. Thus, this definition includes a political and a statistical dimension. Further, each region disposes of a specific production system, which nevertheless is integrated in Australia's production system, and of a more or less sovereign institutional setting and administrative body.

Keeping in mind the definition of a region, a RIS can be defined as "constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge" Lundvall (1992 [2010]: 2). Lundvall's definition stresses convincingly the holistic character underlying the study of IS. Basically, a system can be described as a collection of different elements which share specific characteristics and these elements are linked together through various relationships (Carlsson et al, 2002). But what are the elements of a RIS? The core elements can be public or private institutions, organisations and firms. More generally, firms, institutions and organisations involved in a RIS set the incentive structure (e.g. private and public funded research) and the formal and informal constraints (e.g. patent system) for innovative activity and participate in the diffusion of innovations. Additionally, the education sector and the university system are fundamental elements of a RIS, not only engaged in the accumulation and utilisation of technological and scientific knowledge but also contributing to competence building. Thus, one characteristic perception in the study of RIS is that innovative activity and learning are interactive and take place between different elements belonging to the system, strengthening thereby its innovative capacity.

A classical policy instrument used to strengthen the regional innovative capacity are R&D expenditures and they permit a consistent approximation of innovative activity. There are various different types of R&D expenditures published by ABS. For the purpose of this work, business R&D expenditures on an industry subdivision level seem appropriate, since innovative activities in Australia are largely conducted in the private sector, especially within firms. Besides, this indicator captures different sources of funds – both of a public and private origin. In 2012 the three territories NSW, QLD and VIC accounted for more than 70% of Australia's total business R&D expenditures. However, simply looking and comparing the levels of different types of R&D expenditures gives only a rather fragmented picture of innovative activities, since the interdependencies between elements of the RIS are ignored. Further, a high share of these territories in Australia's total business R&D expenditures does not provide any information on the structure of the RIS.

To gain deeper knowledge of the RIS structure and their innovative activities, the concept of product-embodied R&D expenditures is used in this paper. This concept is rooted in I/O-analysis and following Papaconstantinou et al (1998: 303) it involves the assumption that: "interindustry transactions are […] the carriers of R&D across industries". Mapping regional innovative activities by product-embodied R&D expenditures implies that interdependencies between elements of an RIS are captured through the linkages reflected in an I/O-table and interaction within an RIS proceeds through intra- and inter-industry transactions as well as deliveries to final demand. In using product-embodied R&D expenditures as an indicator of innovative activity, the focus of analysis is on process and product innovations and they are considered as the outcome of making conscious efforts. Due to problems of measurement, neither other types of innovations e.g. institutional or organisational innovations, nor the fact that innovations might be an unintended outcome of more informal innovative activity such as learning by doing and learning by using are accounted for. Apart from these two shortcomings, the concept exhibits a couple of advantages: One advantage lies in maintaining the holistic perspective of the IS framework. A second advantage, which is also related to this perspective, is that positive externalities possibly activated by innovative efforts in the form of R&D are included implicitly into analysis, and it is presumed that these positive externalities disseminate through intra- and inter-industry linkages. Finally, a third advantage is given by the fact that by sticking to the concept of product-embodied R&D expenditures, a RIS is analysed not in isolation from the regional production system but in contrast, the interdependency between the two systems is part of the analysis.

3 Method

This section focuses on the method used: Section 3.1 summarises data preparation. This is followed by an introduction to the modelling framework in section 3.2. Finally in section 3.3, the network measures as well as their explanatory power in terms of innovative activities are discussed.

3.1 Data – Business R&D Expenditures and National Accounts Data

The indicator used in this paper to approximate innovative activities are business R&D expenditures. ABS provides detailed data on business R&D expenditures on a regional level, ranging from 2005 to 2012. Since the latest I/O-tables available are for 2009-2010, it has been decided to work on this period. The R&D vectors are classified by ANZSIC06 industry subdivision-level. Some values for the regional R&D vectors have been missing, which are estimated by the data of the previous and the following years. If it has not been possible to seriously estimate missing values, industries have been merged, given that they are considered as small according to employment levels.

ABS publishes detailed I/O-tables only for Australia as a whole and only partly regional data in this field. Therefore the national I/O-table has to be regionalised. As a starting point for the regional procedure, the national I/O-table of 2009-2010 is used. Regarding the treatment of imports, for the purpose of this work, the version where imports are indirectly allocated has been chosen, since this allows one to work on the full technological coefficients and hence the full input structure is reflected, regardless of the origin of inputs. Since the classification of I/O-data IOPC/IOIG 2012 is a bit different from the classification of R&D data, the national I/O-table has been slightly re-classified and adapted to ANZSIC06, working on 44 industries in the end (see Appendix A.1).[3] In order to obtain a more detailed structure in the network analysis, in a next step, industries are classified according to the functional taxonomy introduced by Pavitt (1984) and further extended by Hauknes & Knell (2009). Pavitt's original taxonomy categorises industries to different sectors, according to specific characteristics shared in the innovation process. Indicators used to describe the different sectoral characteristics are sources of innovation, innovation user requirements and the means of appropriation. His taxonomy was developed based on a firm-level dataset of about 2000 significant post-war innovations in the UK. Pavitt (1984) originally identified (1) supplier dominated industries – which in this paper are further split into energy industries and traditional industries – these are mostly technology users, in the sense that in their innovative activities they build on external sources and on their supplier linkages; (2) production-intensive industries[4], which on the one hand use their own sources to finance innovative activities and on the other hand sources of innovative activities are found both up-stream (e.g. specialised equipment suppliers) and down-stream; (3) science-based industries rely heavily on their own innovative activities and on interactive learning and production engineering. Following Hauknes & Knell (2009), two additional sectors are introduced. First, knowledge intensive business services (*KIBS*) are themselves strong sources of knowledge and innovative activity and are expected to contribute much to the innovative capacity. Second, other "traditional" business services, which initially were included by Pavitt in the supplier-dominated industry sector.[5]

After classifying industries to the six different sectors, preparatory steps for the regionalisation procedure have been conducted. First, the export and the import final demand components are merged to a net exports vector, following the commodity-balance approach (Kronenberg, 2012). Second, since the change in inventories final demand component cannot be seriously estimated on a regional level, as discussed in more detail below, in the national table this component has been added to the net exports vector. Based on this re-arranged national I/O-table the regionalisation procedure is conducted. Different procedures for regionalising I/O-tables exist, depending on the amount of regional data available: One extreme consists of completely survey based methods, which require a lot of regional data, and the other extreme consists in estimating regional I/O tables from their national equivalent (hybrid techniques). For this paper, it is decided to apply a semi-hybrid technique – the bi-proportional optimisation technique GRAS (Junius & Oosterhaven, 2003). This is used for two reasons: It allows (1) incorporating the maximum of available regional data; and (2) working on the full regional production structure – covering both interstate and international trade. This would not have been possible if working with alternative regionalisation techniques such as location quotients.

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[3] Despite differences in the classification system, ABS guarantees that both classification systems are harmonised and consistent with each other.

[4] Pavitt further separated these industries into scale-intensive and specialised-supplier ones, but due to the level of aggregation of the data used in this paper, no such distinction can be made.

[5] A detailed list about classifying the single industries to the six sectors is also included in the Appendix A.1.

Basically, GRAS – which stands for *generalised RAS* method – is used for updating I/O-tables. The mathematical procedure of GRAS consists in a constrained minimisation problem: Given the marginal constraints, GRAS estimates the respective regional I/O-table through finding a new matrix, which deviates least from the given national I/O-table and satisfies exogenously given row and column sums.[6] In the context applied here, four pieces of information are required: (1) A not necessarily square matrix to be updated, which corresponds to the national I/O table and (2) row and column sum vectors of this matrix. (3) The regional industry output vectors, which serve as the constraining row and column sum vectors.[7] Based on this information, the regionalisation procedure is started. As a result, three single regional I/O-tables for NSW, QLD and VIC are obtained, reflecting in addition to regional production – where differences in the technological coefficients are accounted for – interstate and international trade. Beyond, as Miller & Blair (2009) amongst others confirm, compared to other regionalisation procedures, the (G)RAS methods provide best results.

3.2 Modelling framework

As a starting point for studying the regional innovative activities and the RIS structure by means of network analysis, an open I/O framework is employed. For each of the three Australian territories analysed, a single region input-output table has been constructed as discussed in the previous section. For regions $r = 1,2,3$ and n industries let matrix Z^r of dimension $n \times n$ denote the value of direct inter-industry flows of goods and services between the n industries. Further, the vector x^r contains regional gross output, y^rcontains total regional final demand and the technology matrix A^r equals $Z^r diag(x^r)^{-1}$, where $diag(\cdot)$ is used as a symbol for the diagonalisation of a vector.[8] Hence, for n industries a coefficient a_{ij}^r of A^r with $i,j = 1,\ldots,n$ shows how much industry j requires from industry i to produce one unit of its own output. A formal description of the market clearing condition of this inhomogeneous linear equation system for each region r is given by

$$A^r\,x^r + y^r = x^r \qquad [1].$$

The solution of this system corresponds to $x^r = (\mathbb{I} - A^r)^{-1} y^r$, where $(\mathbb{I} - A^r)^{-1} \equiv \mathcal{L}^r$ corresponds to the regional Leontief-Inverse and $\mathbb{I}$ is the identity matrix of dimension n. A single coefficient ℓ_{ij}^r of $\mathcal{L}^r$ can be interpreted as the direct and indirect change in some regional industry i's output x_i^r, required for a unit increase in the final demand for industry j's commodity y_j^r.

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[6] For a more formal description of the GRAS algorithm the reader is referred to Junius & Oosterhaven (2003).

[7] To obtain these pieces of information the following steps have been taken: First, the regional industry total intermediate use vectors have been estimated by weighting the national industry intermediate use vector with regional employment levels. Although not used in network analysis, for the estimation procedure all final demand component totals are required. ABS on an annual basis provides regional data on gross state products, private and public final consumption expenditures, private and public gross fixed capital formation, international trade as well as different components of primary inputs and gross valued added. Using this data, secondly, missing final demand totals for net exports of interstate trade and change in inventories are calculated. In a last step, the regional vectors containing the aggregate sum of primary inputs are estimated. Following ABS (2012), this is achieved through splitting the regional totals into the different industry values, assuming that regional industry shares are equivalent to their national counterparts.

[8] In the following, Z^r includes both domestic and imported (interstate and international) intermediate commodities. As already mentioned, in a regional context this implies that the technology matrix A^r reflects the full technological structure of a region and not just the use of local inputs by regional producers.

Starting from system [1], there are different possibilities to formally link the regional production system to R&D expenditures. The option taken in this paper is to construct vertically integrated industries or subsystems.[9] The concept of a *subsystem* originates from Sraffa (1960) and Pasinetti (1973) and was used e.g. by Kalmbach & Kurz (1985) and Dietzenbacher & Los (2002) for studying inter-industry linkages in different contexts. It is based on the idea that the respective regional production system can be split into as many subsystems as commodities are produced in total – which in the case treated here corresponds to 44 subsystems. Each of these vertically integrated industries produces exactly one commodity as its net output. Of all the other commodities, production within a subsystem equals exactly the amount of means of production used up to satisfy its own total final demand or some of its components $\bar{y}^r$ (Dietzenbacher & Los, 2002).[10] The transformation procedure into vertically integrated industries is denoted by

$$S^r = diag(x^r)^{-1}\mathcal{L}^r diag(\bar{y}^r) \qquad [2].$$

The rows of matrix S^r include the shares of total output of industry i dedicated to the j different subsystems. A column j of matrix S^r formalises vertical integration and for industry j it specifies the shares of industries' outputs embodied both directly and indirectly in its own final demand. As a basis for studying properties of the RIS, in a next step the regional R&D flow matrix $\mathrm{X}^{\mathrm{r}}_{\mathrm{R}\&D}$ is derived from S^r as follows:

$$X^r_{R\&D} = diag(\rho^r)S^r \qquad [3]$$

Hence, by pre-multiplying S^r with the diagonalised vector ρ^r, containing the industries' amounts of R&D expenditures, matrix $X^r_{R\&D}$ is obtained. It provides the key for analysing the regional innovative activities, reflecting the product-embodied R&D intensities of each vertically integrated industry. Thus, one entry $x^r_{R\&D,ij} = \rho^r_i s^r_{ij}$ of matrix $X^r_{R\&D}$ includes the amount of subsystem i's R&D expenditures embodied directly and indirectly in industry j's final demand or some of its components. In its rows, matrix $X^r_{R\&D}$ shows the product-embodied intra- and inter-industry R&D spillovers and in its columns both direct and indirect intra- and inter-industry R&D capital acquisitions are included.

To get a first idea of the regional innovative activities, the distribution between intra- and inter-industry product-embodied R&D flows is examined. This property shows the general interaction patterns of innovative efforts *between* and *within* industries and whether single industries (1) acquire much R&D capital from or distribute much of their own R&D efforts to other industries or in contrast (2) whether they rely heavily on intra-industry R&D activities. In order to study this property, some normalisation procedures are applied to system [3]. This is necessary, since for a cross-region comparison of the structural relationships within an RIS, the R&D flow matrix has to be invariant to scale effects:

$$\bar{X}^r_{R\&D} = X^r_{R\&D} diag(e^T X^r_{R\&D})^{-1} \qquad [4a]$$

$$\underline{X}^r_{R\&D} = diag(X^r_{R\&D} e)^{-1} X^r_{R\&D} \qquad [4b]$$

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[9] This allows maintaining the final demand side despite concentrating particularly on the production structure, respectively on direct and indirect inter-industry linkages.

[10] Although accounting for interstate and international imports in constructing regional I/O-tables, the final demand vector $\bar{y}^r$ in the following includes just private and public consumption expenditures as well as private and public gross fixed capital formation.

In $[4]$, e denotes the summation vector of dimension $n \times 1$ and superscript T is used to indicate the transpose of a matrix. The normalisation proceeds along columns in $[4a]$ – each coefficient is divided by the respective column sum which makes $\bar{X}^{r}_{R\&D}$ suitable for examining the degree of vertical integration. Similarly, in $[4b]$ each coefficient of the original matrix $X^{r}_{R\&D}$ is divided by its row sum and this matrix is used for comparing the degree of inter-industry product-embodied R&D spillover effects to intra-industry flows.

As already discussed before, I/O-analysis studies structural interdependencies. Emphasising this perspective, Leontief (1991 [1928]: 185, italics added) spoke of "the entire *network* of the circular flow". It seems thus natural to study the structural properties of a RIS by means of graph theory and network measures. The use of network analysis has been a prominent tool within qualitative input-output analysis as put forth by Leoncinig & Montresor (2000) or, more recently, in Titze et al (2011) amongst others. However, these works consider only binary directed networks. Yet, different directions and different values assigned to inter-industry linkages in an I/O-table reflect different characteristics and different importance of the industries in the whole network. Therefore it is considered as essential in this paper not to dichotomize these linkages, but to work on a weighted directed network. The basic concept used is a weighted directed graph (*digraph*), which is defined as follows: A weighted digraph G consists of a pair (V, X) where V is a finite and non-empty set of elements v_i called nodes (i.e. industries) and X is a finite set of elements $v_i v_j$ called edges (i.e. inter-industry linkages) with $i, j = 1, \dots, 44$.. A weighted digraph is described by two functions $f_1, f_2 \colon X \to V$ and to each $v_i v_j \in X$, a weight $w_{ij} > 0$ is assigned (Harary et al, 1965). Figure 1(a)-(b) illustrates two exemplary weighted digraphs G_1 and G_2, where for sake of simplicity weights are assumed to be the same for each $v_i v_j \in X_1, X_2$ and which share the same set of nodes $V_1 = V_2$, but which differ in the set of edges, formally $X_1 \subset X_2$.

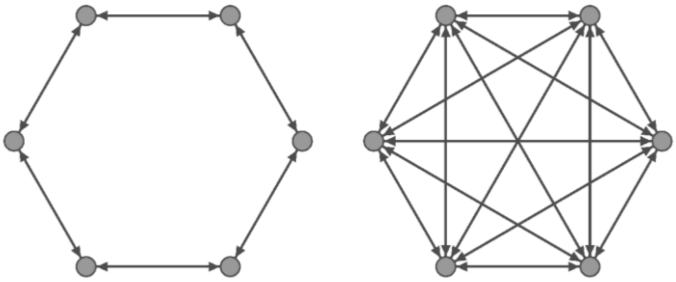

Figure 1(a)-(b): Regular Digraph vs. Complete Digraph. Author's own illustrations.

Apart from graphical visualisation, weighted digraphs are frequently characterised by their adjacency matrix $W(G)$, which is a square matrix with one row and one column for each node of V, in which the entry $w_{ij} > 0$ if edge $v_i v_j$ is in X, while $w_{ij} = 0$ if $v_i v_j$ is not in X. Since self-loops are excluded by definition in weighted digraphs, $w_{ii} = 0$ holds for all i.

To derive the regional weighted adjacency matrices W^r, in a first step [2] is plugged into [3], leading to:

$$X^r_{R\&D} = diag(\rho^r) diag(x^r)^{-1} \mathcal{L}^r diag(\bar{y}^r) \qquad [5a]$$

According to its definition, the Leontief-Inverse $\mathcal{L}$ can be written as $\sum_{i=1}^{\infty} \mathbb{I} + (A^r)^i$ and applying in a second step Eulerian power series to system $[5a]$, matrix $X^r_{R\&D}$ is split into different layers as follows (Schnabl, 1995):

$$\begin{aligned} X^{1,r}_{R\&D} &= diag(\rho^r)\ diag(x^r)^{-1} A^r\ diag(\bar{y}^r), \\ X^{2,r}_{R\&D} &= diag(\rho^r)\ diag(x^r)^{-1} A^{r^2}\ diag(\bar{y}^r), \qquad [5b] \\ X^{3,r}_{R\&D} &= diag(\rho^r)\ diag(x^r)^{-1} A^{r^3}\ diag(\bar{y}^r), \\ &\vdots \qquad\qquad\qquad\qquad . \end{aligned}$$

To make structural relationships comparable across regions, the first layer matrix $X^{1,r}_{R\&D}$[11] is normalised:

$$\tilde{X}^{1,r}_{R\&D} = X^{1,r}_{R\&D} \left(e^T X^{1,r}_{R\&D} e\right)^{-1} \qquad [6a]$$

This system is already quite similar to the regional weighted adjacency matrix, but still contains self-loops. Let d be a $n \times 1$ vector containing all elements from the main diagonal of $\tilde{X}^{1,r}_{R\&D}$. For the network representation of the RIS as a weighted digraph, $[6a]$ is finally corrected for self-loops and the regional weighted adjacency matrix W^r for $r = 1, 2, 3$ is given by

$$W^r = \tilde{X}^{1,r}_{R\&D} - diag(d) \qquad [6b].$$

Based on $[6b]$ different network measures are introduced in the following section, which help to characterise and compare fundamental structural properties of the RIS' innovative capacity.

3.3 Network Measures

Strength Centrality: The first network measure is a modification to the distribution of intra- and inter-industry product-embodied R&D flows given in $[4a]$ and $[4b]$. In contrast to the former, strength centrality reveals only direct linkages between industries. Strength centrality is a local property of a single node providing information about "the importance of a vertex [i.e. a node] in a network" (Newman, 2004: 2). Since W^r is not symmetric, one has to distinguish between in-strength and out-strength, defined as follows:

$$s^{r,IN} = e^T W^r \qquad [7a]$$
$$s^{r,OUT} = W^r e \qquad [7b]$$

In-strength $s_i^{r,IN}$ of a regional industry i refers to an industry's product-embodied R&D capital acquisitions, whereas out-strength refers to product-embodied R&D spillovers. In general, a node i is considered as an out-central node if $s_i^{r,OUT} > s_i^{r,IN}$ and thus, if it has a comparatively high degree of

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[11] Concentrating just on the first layer of $X^r_{R\&D}$ in deriving W^r does not mean that indirect inter-industry linkages are completely ignored in the following but these are set aside for a moment.

pervasiveness. If in contrast a single industry's degree of pervasiveness is lower than its absorptive power, which means that $s_i^{r,OUT} \leq s_i^{r,IN}$, it is considered as an in-central node.

Network Hierarchy and Strength Centralisation: While a regional industry might have a high in-strength, a high out-strength or both, there is no information whether this stems from a single strong linkage to another industry or, in contrast, from a relatively equal distribution of strength between its adjacent industries. To check whether a regional industry is linked to others within a relatively uniform hierarchy, or whether its linkages to others do constitute a rather strict hierarchy, in-strength (out-strength) for an industry i (j) is evaluated together with a concentration measure – the column-wise (row-wise) GINI-Index $GINI_j^{r,IN}$ $(GINI_i^{r,OUT})$. After arranging either all elements w_{ij}^r of each column j (or of each row i) in W^r in ascending order, the respective GINI-Index of a single regional industry $i, j = 1, \dots, n$ is given by

$$GINI_j^{r,IN} = \frac{2\sum_i i w_{ij}^r - (n+1)\sum_i w_{ij}^r}{n\sum_i w_{ij}^r} \qquad [8a]$$

$$GINI_i^{r,OUT} = \frac{2\sum_j j w_{ij}^r - (n+1)\sum_j w_{ij}^r}{n\sum_j w_{ij}^r} \qquad [8b].$$

$GINI_j^{r,IN}$ $(GINI_i^{r,OUT}) \in [0,1]$ and the higher its value, the more concentrated are inter-industry product-embodied R&D capital acquisitions (spillovers) of a single industry.

While the GINI-Index calculated in $[8a]$ and $[8b]$ describes a local property of an industry, it does not reveal the hierarchical structure of the *entire* network. Therefore the GINI-Index is extended to the entire network to gain information whether innovative activities are concentrated to a few industries or whether innovative activities are relatively evenly distributed amongst industries. In calculating the GINI-Index, elements of the in-strength and out-strength vectors are sorted in ascending order and the modified vectors are denoted by $\bar{s}^{r,IN}$ and $\bar{s}^{r,OUT}$. Due to the asymmetry of W^r, one again has to distinguish between two versions of the GINI-Index:

$$\overline{GINI}^{r,IN} = \frac{2\sum_i i\bar{s}_i^{r,IN} - (n+1)\sum_i \bar{s}_i^{r,IN}}{n\sum_i \bar{s}_i^{r,IN}} \text{for } i = 1, \dots, n \qquad [9a]$$

$$\overline{GINI}^{r,OUT} = \frac{2\sum_i i\bar{s}_i^{r,OUT} - (n+1)\sum_i \bar{s}_i^{r,OUT}}{n\sum_i \bar{s}_i^{r,OUT}} \text{for } i = 1, \dots, n \qquad [9b]$$

If $\overline{GINI}^{r,IN}$, respectively $\overline{GINI}^{r,OUT}$ approaches 1, then an RIS exhibits a strict hierarchy and otherwise for a low GINI-Index close to 0, all industries contribute in a relative equal way to the regional innovative capacity.

Clustering Pattern – Network Motifs: In a further step it is interesting to know whether there is strong interaction in terms of innovative activities between smaller groups of industries. The following measures allow one to detect clustering between industries within an RIS and to identify patterns of specialisation in innovative activities. The idea behind is that within clusters which share strong linkages amongst each other this leads to mutual synergies of innovative activities and the dissemination of positive externalities through a high concentration of R&D. Before discussing these measures, the concept of a subgraph g^r for each region $r = 1, 2, 3$ is introduced: Following Harary et al (1965), a subgraph is defined as a weighted digraph g^r, for which $\bar{V} \subset V$ and $\bar{X} \subset X$. Hence, both nodes and edges of a subgraph are a strict subset of G^r. Further, a subgraph g^r is complete, if each node v_i of g^r is adjacent to v_j for $\forall\, v_i, v_j \in \bar{V}$. Such a complete subgraph g^r is called a cluster or a clique and in the following cliques of order 3 – also called triangles – are examined. In a network, where the direction between edges matters and therefore the adjacency matrix is asymmetric, as is the case in this paper, there are eight possible patterns of triangles for each node and its adjacent nodes, as exemplified in Fagiolo (2007) and shown in Figure 2.

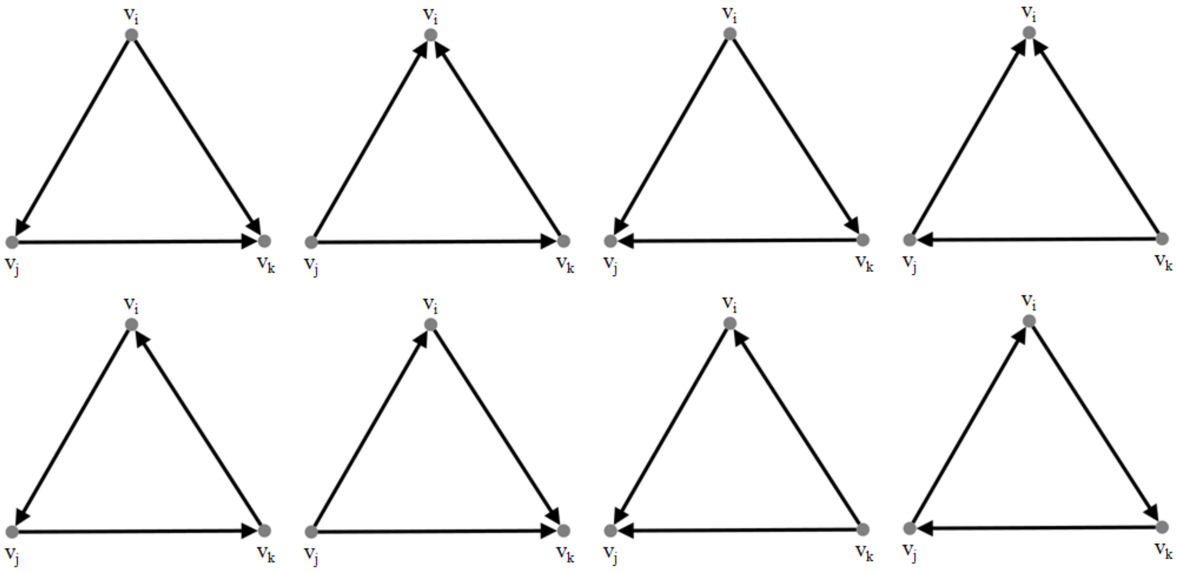

Figure 2: Triangle patterns in a weighted digraph. Based on Fagiolo (2007).

The first network motif for a more detailed characterisation of clustering patterns, called subgraph-intensity, is formally based on Onnela et al (2005) and given by

$$I(g^r) = \left[\prod_{i \neq j \in l_{g^r}} w_{ij,R\&D}^{r} \right]^{1/|l_{g^r}|} \qquad [11a]$$

with $|l_{g^r}|$ denoting the number of linkages of a particular subgraph g^r which in the case of studying triangles always corresponds to 3. Similarly to Fagiolo's (2007) clustering coefficient, subgraph-intensity counts the weights between all different kinds of triangles in the network and mathematically it is given by the geometric mean of the weighted linkages between industries belonging to this cluster. By studying triangles, both direct and indirect linkages between industries are now again accounted for. The higher $I(g^r)$, the more intense are linkages within the respective cluster. Extending the original idea of Onnela et al (2005), for this paper an algorithm has been developed, which is favourable compared to conventional clustering coefficients, because it further provides the following information: First, it allows to determine the different patterns of interaction within a cluster as shown in Figure 2 and second, all three industries involved in a cluster can be identified.

In addition to subgraph-intensity, it is interesting to know, first, whether a high subgraph-intensity arises because one industry has a high degree of pervasiveness. This implies that within a triangle product-embodied R&D flows originating from this industry are rather high compared to the other two industries belonging to the cluster. Second, it is interesting to know whether product-embodied R&D flows are relatively equally distributed and therefore all three industries contribute about the same to the innovative activities within the cluster. In order to check this, a further network motif called subgraph-coherence is needed (Onnela et al, 2005):

$$Q(g^r) = \frac{I(g^r)\left|l_{g^r}\right|}{\sum_{i\neq j\in l_{g^r}} w_{ij,R\&D}^{r}} \qquad [11b]$$

$Q(g^r)$ is defined as the ratio of the geometric to the arithmetic mean of weighted linkages within any triangle. For any regional subgraph g^r, $Q(g^r) \in [0,1]$, and the higher $Q(g^r)$, the more equally distributed are product-embodied R&D flows within a regional cluster.

4 Empirical results

This section applies the network measures discussed in the previous section to characterise the structure and compare the innovative capacity as an integral part of the RIS of the three Australian territories NSW, VIC and QLD. In a first step, the distribution between intra- and inter-industry R&D activities is compared, as illustrated in Figure 3(a)-(b).

The distribution between intra- and inter-industry R&D activities in a horizontal direction is rather homogenous across regions compared to differences (1) in a vertical direction, (2) between and (3) within sectors. In a vertical direction, especially within the energy industry sector results vary across regions. For instance, while in NSW and VIC these industries have a low ($\leq 25\%$ intra-industry product-embodied R&D capital acquisitions), medium-low (between 25% and 50%) or medium-high ($> 50\%$ and $\leq 75\%$) degree of vertical integration, for QLD there are a few exceptions to that: Both Coal Mining and Oil and Gas Extraction (07) perceive of an even higher (>75%) degree of vertical integration. Thus, within QLD's RIS these two natural resource-related industries seem to build to a large extent on their own R&D sources for strengthening the innovative capacity. Concerning product-embodied R&D spillovers, for all three territories the energy industry sector has high or medium-high product-embodied R&D spillovers except for the service-related energy sector industry Exploration and other Mining Support services as well as Electricity Supply (26) in NSW and QLD, where between 25% and 50% of R&D expenditure remain within the industries. As predicted by Hauknes & Knell (2009), results confirm that in general both the traditional and the service industry sector have a low or at least a medium-low degree of vertical integration, with a few exceptions: In NSW the Pulp, Paper and Printing industry (15-16) draws heavily on intra-industry R&D efforts and compared to that, acquires below 25% of its total invested R&D capital from other industries. This is also the case for

Finance (62) in NSW and VIC, which in QLD has a medium-high degree of vertical integration. Further, Wholesale Trade (33-38) in NSW, Motion Picture and Sound Recording Activities & Telecommunication Services & Library and Other Information Services (55&58&60) in NSW and VIC as well as Insurance and Superannuation Funds & Auxiliary Finance and Insurance Services (63-64) in VIC exhibit a medium-high degree of vertical integration. And surprisingly, some KIBS industries are characterised by rather equalised inter- and intra-industry product-embodied R&D capital acquisitions. This suggests that for some service and KIBS industries, there is no clear-cut distinction between sectoral patterns of intra- and inter-industry innovative activities. Other KIBS such as Computer System Design and Related Services (70) and Internet Publishing and Broadcasting in QLD do rely heavily on their own R&D capital investment with a share of more than 75% in total R&D capital investment. In contrast to a medium-low, medium-high or high degree of vertical integration, KIBS distribute lots of their own innovative activities to other industries. Across all regions, the share of product-embodied R&D spillovers in total R&D expenditure is either between $50 - 75\%$ or even higher. For the traditional industry sector, inter-regional differences concerning product-embodied R&D spillovers are hardly observable, which is also the case for the service industry sector, whereas the intra-sectoral variation within the two sectors is comparatively high. It reaches from industries with low inter-industry linkages such as Building Construction (30) or Health Care and Social Assistance (84-87) to Wood Product Manufacturing (14) which distributes more than 75% of its R&D expenditures to other industries.

A more homogenous picture can be drawn for the science-based industries across all three regions: the degree of vertical integration is either medium-high or even high and concerning the distribution of innovative activities to other industries less than 50% of R&D capital investment from Basic Chemical and Chemical Product Manufacturing (18) remain within the industry while the opposite can be observed for Machinery and Equipment Manufacturing (24). This suggests that the Pavitt-Taxonomy does not reflect this sectoral pattern. For production-intensive industries, the degree of vertical integration is mostly either medium-low or medium-high, except for Transport Equipment Manufacturing (23) in VIC and Metal Ore Mining (08) as well as Polymer Product and Rubber Product Manufacturing (19) in QLD, with an above 75%-share of intra-industry R&D capital investment. In contrast, 08 in VIC has a low degree of vertical integration. As concerns product-embodied R&D spillovers, across all regions production-intensive industries distribute more than 75% of their R&D expenditure to other industries and just for 23 the opposite can be observed – more than 75% of its R&D investment remain within the industry.

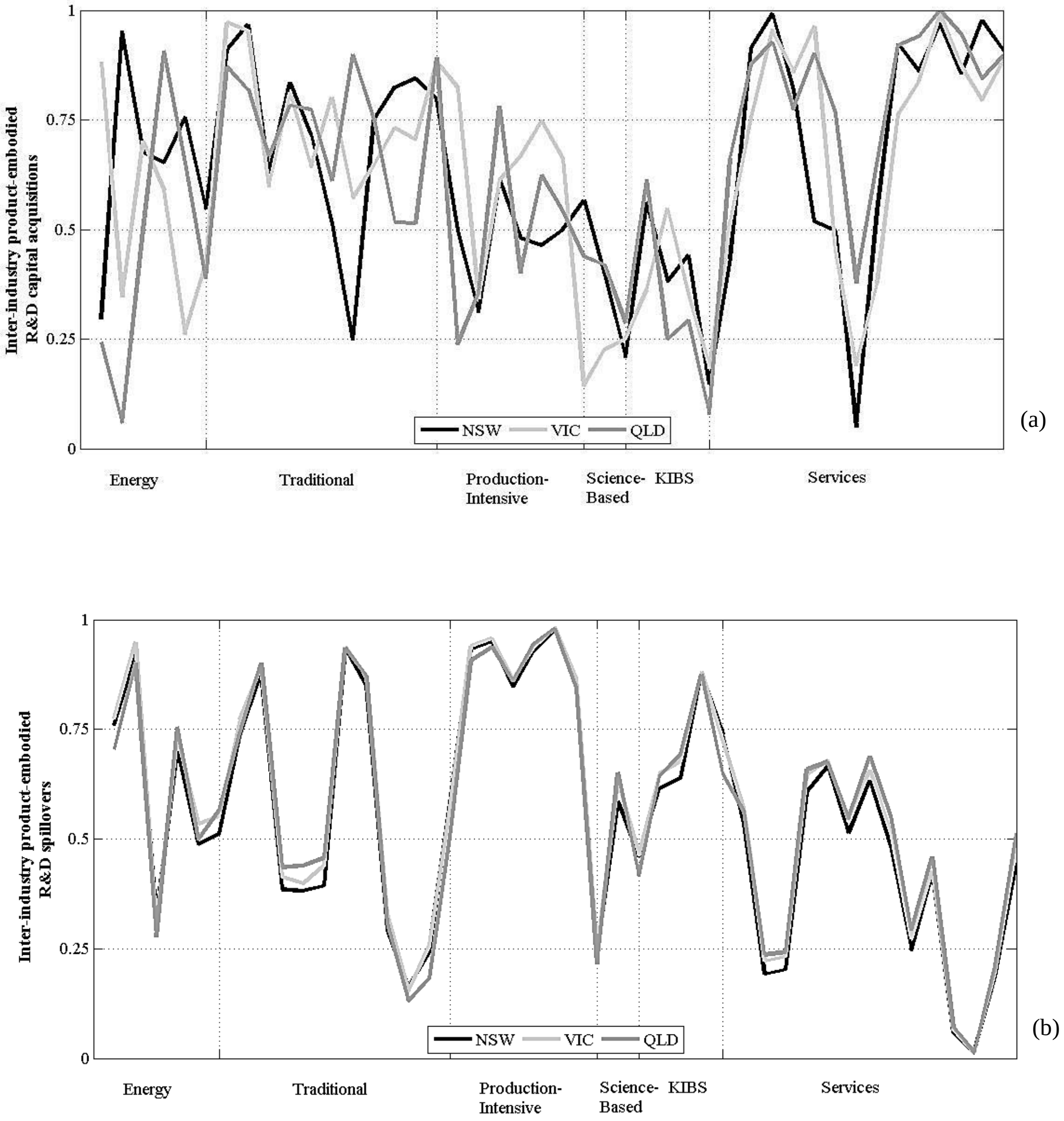

Figure 3(a)-(b): Distribution between intra- and inter-industry product-embodied R&D activities. Author's own illustrations.

While the degree of vertical and horizontal integration provides information on the distribution between intra-industry and inter-industry innovative activities, a high (low) degree of vertical, respectively horizontal integration does not per se qualify an industry as independent (dependent) within the RIS structure. Concentrating on direct linkages and setting aside intra-industry linkages, based on strength-centrality a detailed comparison between industries concerning the degree of absorptiveness and pervasiveness is achieved. According to matrix $[6a]$, inter-industry linkages represent 87.4% of total innovative activities within NSW' RIS and 76.9%, respectively 85.9% within VIC's and QLD's RIS. Table 1 shows the average sectoral in-strength and out-strength. Together with strength centrality, single and outstanding values of the GINI-Indices for some industries as given by $[8a]$ and $[8b]$ are reported, which gives an idea whether their absorptive power and degree of pervasiveness is concentrated to a few inter-industry linkages or whether their in- and out-strength are balanced in terms of interaction with other industries. Therefore, industries are aligned along quartiles $Q_{0.25}$, $Q_{0.5}$ and $Q_{0.75}$. Beyond, four different concentration levels, according to the value of the respective GINI-Index are distinguished: (1) low, if $GINI_j^{IN}$ ($GINI_i^{OUT}$) $\leq Q_{0.25}$; (2) medium-low, if $Q_{0.25} < GINI_j^{IN}$ ($GINI_i^{OUT}$) $\leq Q_{0.5}$; (3) medium-high, if $Q_{0.5} < GINI_j^{IN}$ ($GINI_i^{OUT}$) $\leq Q_{0.75}$ and (4) high, if $GINI_j^{IN}$ ($GINI_i^{OUT}$) $> Q_{0.75}$.[12]

	Average In-Strength			Average Out-Strength		
	NSW	VIC	QLD	NSW	VIC	QLD
Energy Sector	0.41%	0.47%	1.70%	0.27%	0.80%	2.36%
Traditional Sector	1.71%	1.52%	2.01%	0.82%	0.63%	0.79%
Production-Intensive Sector	0.65%	0.85%	0.95%	1.16%	1.98%	2.04%
Science-Based Sector	2.02%	2.34%	3.08%	6.48%	8.16%	7.01%
KIBS Sector	0.50%	0.39%	0.36%	4.17%	4.42%	6.39%
Service Sector	3.97%	3.23%	2.81%	2.79%	1.23%	0.66%

Table 1: Average Sectoral Strength Centrality. Author's own calculations.

Both within NSW' and VIC's RIS the service industry sector has the highest average in-strength, while in QLD it is only 2nd ranked. Across all regions, industries belonging to that sector e.g. Rental, Hiring and Real Estate Services (66-67), 84-87 as well as Retail Trade (39-43) have a high absorptive power and are ranked amongst the top-10 industries concerning in-strength. Compared to this, their degree of pervasiveness is rather low and they are in-central nodes, as can be seen from Figure 4(a)-(c). This supports results from the distribution between inter- and intra- industry product-embodied R&D acquisitions. In contrast, other service sector industries such as 55&58&60 and 62 have a comparatively low in-strength and the latter across all regions is an out-central node and further can be found among the top-10 industries ranked in terms of product-embodied R&D spillovers. Yet, in general for the service industry sector the average sectoral degree of pervasiveness as determined by out-strength is rather low, except for NSW contributing on average 2.79% to total product-embodied R&D spillovers. In terms of the GINI-Index of single service sector industries, the picture is rather heterogeneous within the sector. On the one extreme there are industries such as 33-38, 39-43 or Education and Training, which concerning both in- and out-strength exhibit either a low or medium-low concentration in their innovative activities. The other extreme refers to e.g. 62 and 63-64, which are just strongly linked (medium-high or high concentration) to a few other industries regarding both their product-embodied R&D capital acquisitions and spillovers – except for the 63-64 in VIC, where

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[12] A complete list of industries' in- and out-strength as well as the corresponding GINI-Index can be found in the Appendix A.2.

$GINI^{OUT}$ is medium-low. However, apart from this exception, results for $GINI^{OUT}$ do not vary across regions, while for $GINI^{IN}$ some differences can be observed.

Compared to the service industry sector, KIBS industries across all regions have on average a rather low in-strength, but interestingly their average out-strength is 2nd ranked within all RIS and further, all KIBS industries are out-central nodes (see Figure 4(a)-(c)). The high average degree of pervasiveness results especially from Professional, Scientific and Technical Services (Except Computer System Design and Related Services) (69) as well as 70, which across all regions are found among the top-10 industries. Concerning hierarchy in terms of the degree of pervasiveness within the KIBS industry sector, the picture across regions and within the sector is homogeneous: Product-embodied R&D spillovers originating from the single KIBS industries are shared amongst other industries in a rather balanced fashion, except for 70, which within all regions has a medium-high $GINI^{OUT}$. Yet, there are a few intra-sectoral and regional differences concerning $GINI^{IN}$. While 69 in QLD and VIC as well as Publishing (except Internet and Music Publishing) in QLD perceive of a medium-low $GINI^{IN}$, for the other industries product-embodied R&D capital acquisitions are concentrated to a few inter-industry linkages, belonging either to the 3rd quartile or lying between the median and the 3rd quartile.

Science-Based Industries have on average the highest in-strength in QLD and are 2nd ranked compared to other sectors in NSW and VIC. Thus, additionally to a high or medium-high degree of vertical integration for the two single industries, strength-centrality now reveals that compared to other sectors, product-embodied R&D capital acquisitions are still high on average. It is especially 24 which is decisive for that high average in-strength. As Table 1 further shows, within all three RIS, science-based industries have on average the highest out-strength and contribute most to total product-embodied R&D spillovers – the two industries belonging to this sector are in all RIS out-central nodes (Figure 4(a)-(c)). More in detail, with respect to out-strength 24 is ranked among the top-5 compared to all other industries and further it can be observed that also 18 across all regions is among the top-10. Concerning hierarchy in terms of in-strength, this is rather equalised with a value of $GINI^{IN}$ for both industries below the median. Further, $GINI^{OUT}$ is low or medium-low, signalising that product-embodied R&D spillovers are equally distributed to other industries and that these industries contribute not only strongly but also in a rather equalised fashion to the respective regional innovative capacity.

Production-intensive industries in all three RIS are either 4th or 5th ranked in the inter-sectoral comparison concerning average in-strength, while the average out-strength is either 3rd or 4th ranked. Except for 23 in NSW and QLD as well as 08 in VIC, all production-intensive industries are out-central nodes. Despite a generally low average strength centrality some industries in this sector are contributing strongly to the regional innovative capacity. For instance Primary Metal and Metal Product Manufacturing (21) as well as Fabricated Metal Product Manufacturing in NSW's and QLD's RIS, 19 and 23 in VIC as well as Non-Metallic Mineral Product Manufacturing (20) in QLD are ranked among the top-10 industries concerning product-embodied R&D spillovers. Thus, the discrepancy within the sector concerning out-strength is rather high. Also concerning in-strength, there is one outstanding exception to the low average: Across all regions, industry 23's in-strength exceeds the sectoral average tremendously. In addition to a low average strength centrality, $GINI^{IN}$ and $GINI^{OUT}$ for the single industries vary enormously. Pervasive industries such as 21 and 20 highly concentrate their R&D spillovers to a few other industries. The same can be observed across regions for $GINI^{IN}$ in 19. In contrast, for other industries both $GINI^{IN}$ and $GINI^{OUT}$ are either medium-low or medium-high.

Similar to production-intensive industries, in the energy industry sector both NSW's and VIC's RIS are characterised by a low average in-strength and out-strength. In QLD's RIS this sector contributes on average more to the regional innovative capacity. Product-embodied R&D capital acquisitions are 4th ranked and average out-strength is 3rd ranked compared to other sectors. In QLD this high average out-strength is mainly determined by 07, which among all industries is 2nd ranked within the RIS. Further, there is another industry in this sector in QLD's RIS among the top-5 in terms of in-strength, namely Petroleum and Coal Product Manufacturing, which supports results concerning the distribution between intra- and inter-industry innovative activity. As can be seen from Figure 4(a)-(c), regarding the proportion between in-strength and out-strength of single industries within that sector, for all three regions the picture varies. For instance, while 07 is an out-central for VIC and QLD, in NSW it is an in-central node. In contrast, 26 is an in-central node in NSW and QLD, whereas in VIC its product-embodied R&D spillovers exceed its R&D capital acquisitions. In general, $GINI^{IN}$ and $GINI^{OUT}$ differ strongly both within the sector and in a few cases also across regions. For instance, while 06 and 07 distribute their product-embodied R&D spillovers in all three RIS in a highly concentrated manner and $GINI^{OUT}$ is amongst the 25% highest, the degree of concentration related to in-strength of 07 is in the 1st quartile for QLD's RIS and concentration is medium-low in VIC's and medium-high in NSW's RIS.

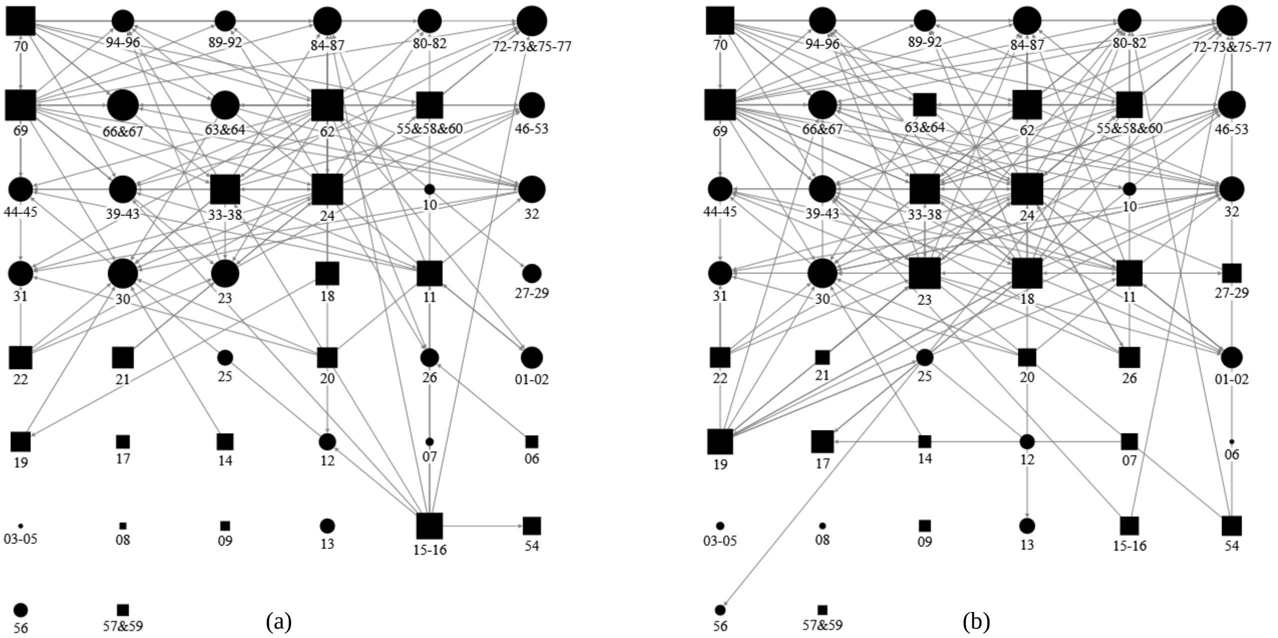
For the traditional industry sector there shows to be a rather homogenous picture across the RIS but within the sector the picture is more heterogeneous. Compared to other sectors within all three RIS, average in-strength is 3rd ranked and average out-strength always is larger than average in-strength. Yet, as Figure 4(a)-(c) highlights some industries such as Agriculture + Acquaculture (01-02) or Textile, Leather, Clothing and Footwear Manufacturing are still in-central nodes while some other industries such as Food Product Manufacturing or 15-16 are out-centrals. Concerning in-strength, remarkably industry 30 within all RIS is ranked amongst the top-5 for all industries, signalising that this industry is strongly dependent on product-embodied R&D capital acquisitions and as the respective distribution between intra- and inter-industry linkages has shown, it truly has a rather low own R&D capital investment level. Concentration within this sector as determined by the GINI-Index ranges from the 1st to the 3rd quartile: On the one hand there are industries, such as 01-02, whose degree of absorptiveness and pervasiveness is solely concentrated to a few other industries and $GINI^{IN}$ as well as $GINI^{OUT}$ are therefore in the 3rd quartile (except for QLD, where $GINI^{OUT}$ is medium-high for 01-02). On the other hand, for instance for 14 or Construction Services (32), $GINI^{IN}$ is within the 1st quartile, whereas its product-embodied R&D spillovers are distributed to only a few industries ($GINI^{OUT}$ is in the 3rd quartile).

As concerns centralisation and the hierarchy of the entire network, the GINI-Index with respect to total in-strength and out-strength, as given in $[9a]$ and $[9b]$, is rather high for all three RIS. As described in Table 2, this signalises that there are just a few driving industries shaping overall innovative activities within the RIS and contributing strongly to the regional innovative capacity.

	In-Centralisation	Out-Centralisation
NSW	0.619	0.754
VIC	0.568	0.665
QLD	0.581	0.684

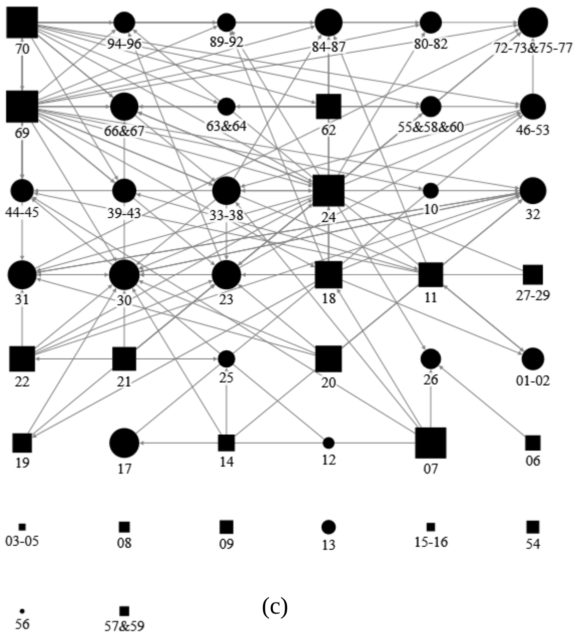
Table 2: Network Centralisation. Author's own calculations.

More in detail, the most unequally distributed hierarchy can be found within NSW' RIS, where 109 out of 1890 inter-industry linkages account for 75% of inter-industry innovative activities, followed by QLD, where 111 inter-industry linkages represent 75% of inter-industry innovative activities. Compared to this, in VIC's RIS the concentration is slightly lower and inter-industry innovative activities takes place in a more balanced fashion. There, 75% of inter-industry innovative activities are accounted for by 162 inter-industry linkages. Put differently, if accounting for total inter-industry innovative activities the weighted digraphs are almost complete, while just a small fraction of linkages determine most of innovative activities within the respective RIS and only a handful of industries determine the regional innovative capacity. The strict hierarchy for all three RIS once more is mirrored in Figure 4(a)-(c), where for sake of simplicity just those linkages are represented which account for 75% of total regional inter-industry innovative activities.



(a)

(b)



(c)

Figure 4(a)-(c): Reduced network for NSW, VIC and QLD. Author’s own illustrations. Note that only those largest inter-industry linkages are drawn, whose weights in sum account for more than 75% of total regional innovative activities. The size of nodes in each regional network is determined as the sum of in- and out-strength and the size of arrows is uniform to maintain clearness. Further, out-central nodes are illustrated with a square symbol and in-central nodes with a circle symbol.

The high concentration of innovative activities within all three RIS raises the question, which industries are the determining ones in terms of their contribution to the overall regional innovative capacity and where the specialisation takes place. As discussed in section 3.3, clustering patterns are studied by subgraph-intensity and subgraph-coherence.[13] For the reduced network of the three RIS, as represented in Figure 4(a)-(c), 138 triangles with a subgraph-intensity greater than zero are found for NSW, 367 for VIC and 144 for QLD. Table 3 reports the average subgraph-intensity and the average subgraph-coherence for these triangles within the RIS.

	Average Subgraph-Intensity	Average Subgraph-Coherence
NSW	0.0047	0.8723
VIC	0.0032	0.7837
QLD	0.0048	0.8500

Table 3: Network Motifs – average sectoral values. Author’s own calculations.

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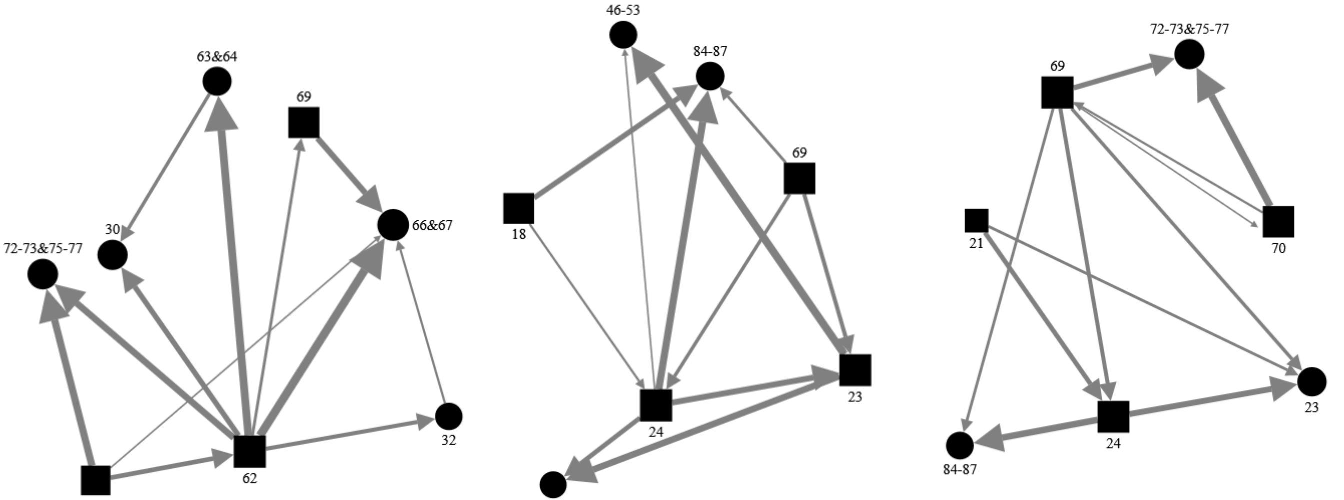
[13] The two network motifs are calculated based on the reduced network – where the associated adjacency matrix accounts for 75% of inter-industry innovative activities.

As concerns the average subgraph-intensity of the different triangles calculated, in QLD's RIS it reaches the highest value, followed by NSW and VIC. Thus, innovative activities within clusters are on average most intensive within QLD. In contrast, for the 2nd network motif, subgraph-coherence, it is observed that in NSW's RIS, industries belonging to the single clusters contribute in the most equalized fashion to the clusters' innovative activities, compared to VIC's and QLD's RIS. In the following, just the five largest clusters for each RIS – ranked in terms of subgraph-intensity – are analysed as illustrated in Figure 5(a)-(c) and a more detailed list including the top-10 clusters can be found in the Appendix A.3.



(a) (b) (c)

Figure 5(a)-(c): Top-5 Clusters.Clustering Patterns in NSW's (a), in VIC's (b) and QLD's (c) RIS. Author's own illustrations. Note, that again the size of nodes is determined by the total strength and the size of arrows now reflects the level of weighted linkages.

As Figure 5(a)-(c) shows, across all regions specialisation patterns in the top-5 clusters concentrate to a few industries. While in NSW's RIS 8 out of 15 possible industries form the five largest clusters, in VIC's and QLD's RIS inter-industry linkages between 7 industries account for the former. Thus, the top-5 triangles form a larger subgraph, which across all regions is connected.

Focusing on the second network motif, one needs to note that although NSW accounts for the highest average subgraph-coherence, two of the five largest clusters exhibit a rather low subgraph-coherence, whereas in VIC's and QLD's RIS, a lower average subgraph-coherence does not mirror in their five largest clusters. Within NSW's RIS the subgraph-coherence for the five largest clusters ranges from 0.2669 to 0.8631 and subgraph-intensity lies within $[0.0112,\ 0.0181]$. As can be seen from Figure 5(a), clustering industries consist of only services sector industries and KIBS sector industries, with two exceptions – two traditional sector industries, namely 30 and 32. However, 30 is only an absorbing industry, in the sense that despite participating in the 2nd largest cluster with 62 and 63-64 it just receives product-embodied R&D flows. Contrary, 32 both is an absorbing as well as a pervasive industry. Regarding the degree of pervasiveness of clustering industries, for NSW's RIS 62 and 70 are the two most pervasive industries within the five largest clusters, in the sense, that they account for highest product-embodied R&D spillovers. On the other hand, industries with the highest absorptive power in the five largest clusters are 66-67 as well as Administration Services and Support Services & Public Administration and Safety (72-73&75-77).

In contrast to the outstanding role of 62 in NSW's RIS both in VIC and QLD, this industry plays a comparatively inferior role and cannot be found among the five largest clusters and more in general, compared to NSW's RIS, in VIC and QLD the service industry sector does not dominate the five largest clusters. Both in VIC's and QLD's RIS, specialisation within the five largest clusters takes place mainly amongst science-based industries, production-intensive industries and KIBS industries, as can be seen from Figure 5(b)-(c). Focusing on VIC's RIS, subgraph-intensity lies within [0.0092, 0.0136]. Although average subgraph-coherence is lowest compared to both QLD's and NSW's RIS, product-embodied R&D flows are relatively equally distributed within the five largest clusters – subgraph-coherence ranges from 0.6832 to 0.9268, exceeding except for the 3rd largest cluster average subgraph-coherence. Concerning product-embodied R&D spillovers within the clusters, the science-based industry 24 is the most pervasive industry, followed by the KIBS industry 69. Industries with the highest absorptive power within the specialisation clusters are found within the service industry sector, namely 84-87 as well as Transport, Postal and Warehousing.

For QLD's RIS (see Figure 5(c)), the subgraph-coherence within the five largest clusters exceeds for three of them the total average. Subgraph-intensity for the five largest clusters lies within [0.0104, 0.0122] and subgraph-coherence ranges from 0.6475 to 0.9610. Remarkably, QLD's RIS is the only one, where among the five largest clusters, there is one triangle in which no service sector industry participates (the 5th ranked cluster). With a subgraph-intensity of 0.0104 and a subgraph-coherence of 0.899, this 5th largest cluster is formed by 21, 23 and 24. Generally, highest linkages within the five largest clusters in terms of product-embodied R&D spillovers either have their origin within 24 or 69. In contrast to this high degree of pervasiveness of the former two industries, the industries with the highest product-embodied R&D capital acquisitions are found in the production-intensive industry sector, namely 23 as well as in the service industry sector (72-73&75-77).

5 Conclusions

The aim of this paper is to analyse and compare the structure of NSW's, VIC's and QLD's RIS. Therefore network analysis constitutes an appropriate tool: It has been shown, that applying different network measures within an empirical case study helps to crystallise distinctive features of the three Australian RIS. By working on weighted digraphs in combination with single-region I/O-models and the concept of product-embodied R&D flows both differences between regional innovative activity and similarities across regions have been uncovered. Thus, network measures used in this paper allow studying the structural characteristics of the RIS without blending the empirical structure. Beyond, by means of this analysis it has been achieved to maintain the holistic perspective underlying the IS framework, stressing the importance to account for structural dependencies.

Based on a modified version of Pavitt's functional taxonomy, empirical results are discussed. Pavitt's functional taxonomy has proved successful for some empirical results and less appropriate for other empirical results. Deviations in empirical results from the (modified) sectoral characteristics might be (1) due to structural differences in Australian territories' sectors, compared to the originally observed sectoral characteristics in the UK or (2) due to deep structural changes experienced in Australian industries since 1984, such that the original sectoral characteristics no longer fit the data perfectly. However, testing Pavitt's functional taxonomy has not been the subject-matter of the current paper. In any case, it provides a good framework to classify industry innovative activities and to connect this early stage of the innovation process with sectoral characteristics appearing in its later stages.

Facing difficulties in terms of regional data availability and completeness, the number of industries included in analysis has been cut back. Still, this paper addresses a comparatively large industry sample. Further, it has become evident that this industry sample, together with the used network measures, is large enough to discover not only regional differences but also inter-industry differences, and as demonstrated by empirical results, sometimes these differences are tremendous. While the distribution between intra- and inter-industry product-embodied R&D flows in a vertical direction uncovers the dependence of industries on their own vs. external sources to finance innovative activity, in a horizontal direction this distribution shows the degree of product-embodied R&D spillovers. Concerning strength centrality, this helps to determine and compare the degree of absorptiveness and pervasiveness of single industries. Apart from observed sectoral patterns, some single industries prove as exceptionally pervasive within the respective RIS, while others have turned out to be highly absorptive. Further, the GINI-Index is used to gain information about concentration of inter-industry linkages.

Surprisingly, across all regions a rather limited number of inter-industry linkages determine a good part (75%) of the innovative capacity. Related to this rather strict hierarchical pattern within each RIS, specialisation patterns have been detected. Concerning clustering in innovative activities, results vary across regions. While in NSW's the service industry sector plays an outstanding role within the clusters, in VIC and QLD the science-based industry sector, the production-intensive and the KIBS industry sector are dominating.

Summarising, in doing a detailed network analysis it became evident that the RIS of each Australian territory studied, has its own structural characteristics and the innovative capacity is characterised by regional differences. To single out these differences is a first step towards implementing efficient policy measure targeted towards strengthening the innovative capacity since in the end, each RIS contributes in a different way to Australia's technology frontier and therefore to its competitiveness.

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Appendix

A.1 Industry-Classification

ANZSIC 2006 Classification Industry-Subdivision (modified aggregation level)		**Pavitt-Taxonomy** (modified)
Agriculture&Aquaculture	01-02	Traditional
Forestry and Logging&Agriculture, Forestry and Fishing Support Services	03-05	Traditional
Coal Mining	06	Energy
Oil and Gas Extraction	07	Energy
Metal Ore Mining	08	Production-Intensive
Non-Metallic Mineral Mining and Quarrying	09	Production-Intensive
Exploration and Other Mining Support Services	10	Energy
Food Product Manufacturing	11	Traditional
Beverage and Tobacco Product Manufacturing	12	Traditional
Textile, Leather, Clothing and Footwear Manufacturing	13	Traditional
Wood Product Manufacturing	14	Traditional
Pulp, Paper and Converted Paper Product Manufacturing &Printing (including the Reproduction of Recorded Media)	15-16	Traditional
Petroleum and Coal Product Manufacturing	17	Energy
Basic Chemical and Chemical Product Manufacturing	18	Science-Based
Polymer Product and Rubber Product Manufacturing	19	Production-Intensive
Non-Metallic Mineral Product Manufacturing	20	Production-Intensive
Primary Metal and Metal Product Manufacturing	21	Production-Intensive
Fabricated Metal Product Manufacturing	22	Production-Intensive
Transport Equipment Manufacturing	23	Production-Intensive
Machinery and Equipment Manufacturing	24	Science-Based
Furniture and Other Manufacturing	25	Traditional
Electricity Supply	26	Energy
Gas Supply&Water Supply, Sewerage and Drainage Services &Waste Collection, Treatment and Disposal Services	27-29	Energy
Building Construction	30	Traditional
Heavy and Civil Engineering Construction	31	Traditional
Construction Services	32	Traditional
Wholesale Trade	33-38	Services
Retail Trade	39-43	Services
Accommodation and Food Services	44-45	Services
Transport, Postal and Warehousing	46-53	Services
Publishing (except Internet and Music Publishing)	54	KIBS
Broadcasting (except Internet)	56	Services
Internet Publishing and Broadcasting	57&59	KIBS
Motion Picture and Sound Recording Activities&Telecommunication Services &Library and Other Information Services	55&58&60	Services

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Finance	62	Services
Insurance and Superannuation Funds &Auxiliary Finance and Insurance Services	63-64	Services
Rental, Hiring and Real Estate Services	66-67	Services
Professional, Scientific and Technical Services (Except Computer System Design and Related Services)	69	KIBS
Computer System Design and Related Services	70	KIBS
Administration Services and Support Services &Public Administration and Safety	72-73&75-77	Services
Education and Training	80-82	Services
Health Care and Social Assistance	84-87	Services
Arts and Recreation Services	89-92	Services
Other Services	94-96	Services

A.2 – Strength Centrality and Network Hierarchy

	NSW		VIC		QLD		NSW		VIC		QLD	
	s^{IN}	$GINI^{IN}$	s^{IN}	$GINI^{IN}$	s^{IN}	$GINI^{IN}$	s^{OUT}	$GINI^{OUT}$	s^{OUT}	$GINI^{OUT}$	s^{OUT}	$GINI^{OUT}$
Energy												
06	0.072%	medium-low	0.033%	medium-high	0.143%	medium-low	0.309%	high	0.008%	high	0.679%	high
07	0.083%	medium-high	0.054%	medium-low	0.134%	low	0.029%	high	1.154%	high	10.618%	high
10	0.310%	high	0.497%	high	0.886%	high	0.016%	high	0.015%	high	0.098%	high
17	0.139%	low	1.140%	high	6.935%	high	0.359%	medium-low	1.281%	medium-low	0.905%	medium-low
26	1.047%	high	0.501%	medium-high	1.559%	high	0.227%	low	1.383%	low	0.557%	low
27-29	0.811%	medium-high	0.578%	medium-high	0.523%	medium-low	0.656%	medium-low	0.978%	medium-low	1.293%	medium-low
Traditional												
01-02	1.842%	high	1.940%	high	1.621%	medium-high	0.564%	high	0.201%	high	0.963%	high
03-05	0.064%	medium-high	0.081%	medium-high	0.055%	medium-low	0.009%	medium-high	0.018%	medium-high	0.094%	medium-high
11	1.545%	medium-low	1.503%	low	1.580%	medium-low	1.689%	high	2.533%	high	1.942%	high
12	0.871%	medium-low	0.582%	low	0.302%	low	0.212%	high	0.234%	high	0.181%	high
13	0.454%	low	0.593%	medium-low	0.447%	low	0.177%	medium-low	0.391%	medium-low	0.196%	medium-low
14	0.045%	low	0.054%	low	0.061%	low	0.983%	high	0.353%	high	1.106%	high
15-16	0.145%	low	0.196%	medium-high	0.134%	low	3.221%	medium-low	1.149%	medium-low	0.138%	low
25	0.780%	medium-low	0.854%	medium-low	1.041%	low	0.152%	medium-low	0.366%	medium-high	0.263%	medium-low
30	7.464%	low	5.918%	low	7.920%	medium-low	0.399%	medium-high	0.569%	medium-high	1.684%	medium-high
31	3.010%	medium-low	2.528%	low	4.932%	medium-low	0.207%	medium-high	0.438%	medium-high	1.286%	medium-high
32	2.561%	low	2.424%	low	4.057%	low	1.357%	high	0.688%	high	0.823%	high
Production-Intensive												
08	0.046%	medium-low	0.040%	medium-low	0.106%	medium-high	0.061%	medium-low	0.013%	medium-low	0.320%	medium-low
09	0.012%	medium-high	0.010%	medium-low	0.030%	low	0.253%	medium-high	0.229%	medium-high	0.535%	medium-high
19	0.315%	high	0.813%	high	0.489%	high	1.181%	medium-low	2.798%	medium-low	1.062%	medium-low

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20	0.093%	low	0.129%	medium-low	0.143%	medium-high	1.505%	high	1.097%	high	4.303%	high
21	0.042%	medium-high	0.027%	medium-low	0.145%	high	1.933%	high	0.575%	high	2.794%	high
22	0.321%	medium-high	0.284%	low	0.460%	medium-high	2.408%	medium-high	1.378%	medium-high	3.456%	medium-high
23	3.746%	medium-high	4.645%	medium-high	5.291%	medium-high	0.800%	medium-high	7.801%	medium-high	1.805%	medium-high
Science-Based												
18	0.970%	low	1.247%	low	1.624%	medium-high	1.912%	low	6.056%	low	3.413%	low
24	3.069%	medium-low	3.433%	medium-low	4.543%	medium-high	11.049%	medium-low	10.271%	medium-low	10.599%	medium-low
KIBS												
54	0.474%	high	0.285%	medium-high	0.158%	medium-low	0.626%	medium-low	1.286%	medium-low	0.326%	medium-low
57&59	0.082%	high	0.072%	high	0.038%	high	0.264%	low	0.128%	medium-low	0.340%	medium-low
69	1.020%	medium-high	0.715%	medium-low	0.726%	medium-low	9.094%	low	10.833%	low	14.596%	medium-low
70	0.412%	high	0.507%	high	0.531%	high	6.683%	medium-high	5.424%	medium-high	10.294%	medium-high
Services												
33-38	2.918%	medium-low	2.928%	low	3.440%	medium-low	4.727%	low	4.008%	low	2.360%	low
39-43	3.996%	medium-low	3.997%	low	3.265%	low	0.116%	low	0.469%	low	0.217%	low
44-45	2.976%	low	2.917%	low	2.683%	low	0.008%	low	0.051%	low	0.093%	low
46-53	2.384%	low	4.271%	high	2.242%	low	0.882%	low	1.031%	low	1.850%	low
56	0.298%	high	0.222%	high	0.094%	medium-high	0.250%	high	0.008%	high	0.016%	high
55&58&60	1.776%	medium-high	1.712%	medium-high	1.578%	high	1.787%	low	2.357%	low	0.566%	low
62	1.047%	high	0.814%	high	0.936%	high	27.737%	medium-high	5.564%	medium-high	2.643%	medium-high
63-64	4.561%	high	1.215%	high	0.876%	high	2.112%	medium-high	1.522%	medium-low	0.465%	medium-high
66-67	14.956%	high	5.628%	medium-high	5.273%	medium-high	0.337%	medium-low	0.721%	medium-low	0.246%	medium-low
72-73&75-77	7.501%	medium-high	6.813%	medium-high	7.605%	high	0.873%	low	0.970%	low	0.404%	low
80-82	2.887%	medium-low	2.736%	medium-low	2.489%	medium-low	0.005%	low	0.002%	low	0.000%	low
84-87	6.192%	medium-high	6.028%	medium-high	5.216%	medium-high	0.013%	medium-high	0.011%	medium-high	0.005%	medium-high
89-92	1.663%	low	2.101%	medium-low	1.397%	medium-low	0.011%	medium-high	0.157%	medium-high	0.092%	medium-high
94-96	2.376%	medium-low	3.810%	high	2.195%	medium-high	0.180%	medium-low	0.356%	low	0.277%	low

A.3 – Clustering Patterns – Top-10

r	$I(g^r)$	$Q(g^r)$	**Industry 1**		**Industry 2**		**Industry 3**	
			Row-Index	**Column-Index**	**Row-Index**	**Column-Index**	**Row-Index**	**Column-Index**
NSW	0.0181	0.4017	62	66-67	62	69	69	66-67
	0.0134	0.7029	62	30	62	63-64	63-64	30
	0.0132	0.8631	62	72-73&75-77	70	62	70	72-73&75-77
	0.0115	0.2722	62	66-67	70	62	70	66-67
	0.0112	0.2669	32	66-67	62	32	62	66-67
	0.0097	0.5797	62	63-64	70	62	70	63-64
	0.0084	0.5265	62	32	62	63-64	63-64	32
	0.0084	0.7088	24	84-87	62	24	62	84-87
	0.0083	0.7627	24	84-87	33-38	24	33-38	84-87
	0.0081	0.7544	24	84-87	69	24	69	84-87
VIC	0.0136	0.9268	23	94-96	24	23	24	94-96
	0.0103	0.8637	18	24	18	84-87	24	84-87
	0.0097	0.6832	23	46-53	24	23	24	46-53
	0.0097	0.9168	24	23	69	23	69	24
	0.0092	0.8468	24	84-87	69	24	69	84-87
	0.0091	0.8897	23	72-73&75-77	24	23	24	72-73&75-77
	0.0084	0.9932	23	72-73&75-77	69	23	69	72-73&75-77
	0.0084	0.7354	23	46-53	69	23	69	46-53
	0.0080	0.7454	69	70	69	72-73&75-77	70	72-73&75-77
	0.0078	0.9908	24	30	69	24	69	30

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QLD	0.0122	0.9610	24	23	69	23	69	24
	0.0118	0.6513	69	72-73&75-77	70	69	70	72-73&75-77
	0.0117	0.6475	69	70	69	72-73&75-77	70	72-73&75-77
	0.0112	0.9060	24	84-87	69	24	69	84-87
	0.0104	0.8990	21	23	21	24	24	23
	0.0101	0.9780	24	30	69	24	69	30
	0.0100	0.8065	30	66-67	69	30	69	66-67
	0.0098	0.9536	24	31	69	24	69	31
	0.0087	0.5535	24	72-73&75-77	70	24	70	72-73&75-77
	0.0087	0.8604	20	30	20	32	30	32