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Labor networks connecting peripheral economies to the national innovation system

Kirsten Martinus[1]

Abstract

Understanding the characteristics of innovation in peripheral regions is critical to enhancing economic competitiveness and productivity in remote or rural communities worldwide. Metropolitan innovation success stories have limited application or policy relevance in peripheral areas due to a lack of critical mass in industry and population. This has seen an emergent body of literature consider the different dynamics of innovation in these areas. This article contributes both methodologically and conceptually to current academic discourse and debates by exploring innovation across the sparsely-populated large spatial divides of regional Australia through the novel use of social network analysis and econometric modelling. It employs commuting data and a regression of 2000-2013 OECD patent data against select socio-economic variables and commuting indices. It finds that innovative activity is positively linked to population, commuting, and professional employment for smaller communities. This points to the movement of labor as an important factor, playing a role as an inter-regional conduit of tacit knowledge by extending the social capital networks of smaller peripheral communities.

[1] Center of Regional Development, The University of Western Australia. Perth, Western Australia

Key words: innovation systems, long distance commuting, peripheral economies, proximity, social network analysis

Introduction

Proximity has long been a key aspect of the economic geography and regional science research agenda, increasingly associating innovation with a variety of factors other than geography. This has facilitated broader understandings of how different actors and environments might engage across time and space to form an overarching system of innovation for a region or nation (Boschma 2005; Morgan 2004; Lagendijk and Lorentzen 2007; Torre 2008). The connectedness of these actor networks and their institutional frameworks are continually constituted and reconstituted through time and space by the various practices and relations which occur in response to path dependent processes and economic shocks (Plummer and Tonts, 2015; Martin and Sunley 2006; Sheppard 2002).

Research has generally found the propensity to innovate is highly geography-specific and unevenly distributed across regions. This is in part because innovation is supported by the strength of industry clustering, social capital networks, and knowledge spillovers (Abreu et al. 2008; Doloreux 2003; Howells 2005; Lambooy 2005; Simmie 2003; Torre 2008) as well as the tendency for research support and funding to be directed into locations which are already innovation-success stories (Morgan 2007). This has meant highly urbanized cities are more obvious sites of innovation than sparsely populated and low-industrialized areas (Doloreux and Dionne 2008; Virkkala 2007; North and Smallbone 2000). This assumption mirrors those in the related field of urban studies, where research agendas have also focused on key global metropoles in the Global North leaving a geography of structural “black holes” where peripheral cities and towns are located (Robinson 2002).

Likewise, there is limited knowledge regarding innovation processes and mechanisms in peripheral areas such as regional Australia[2] despite the large amount of wealth it generates and number of people both working and residing there (Martinus 2015; Tonts et al. 2013). As in other rural and remote communities around the world (for example, Morgan 2007), the Australian government policy response has been to address issues of unemployment rather than capacity building (Enright and Roberts 2001). Research in regional Australia has focused on understanding industries best suited to regional economic growth and opportunities (e.g., Mardaneh 2012) primarily through grass-roots specific case studies (e.g., Enright and Roberts 2001; Thompson et al. 2011; Woodhouse 2006). While top-down policy approaches to the national innovation system (e.g., Dodgson et al. 2011; Webster 2009) tend to concentrate on Australia's most urbanized cities with little to no attention paid to the nation as a whole, including regional areas.

This study aims to address this lacuna given the critical role innovative activity plays in improving productive capacity and competitive advantage. The significance of this study is weighted by the struggle of peripheral towns, such as those in regional Australia, to remain economically competitive and viable in an environment of declining population and service provision (Beer and Keane 2000; McGuirk and Argent 2011). The research focuses on long-distance labor commuting as a connector between regions. This provides a novel perspective as the link between labor mobility and innovation in studies to date primarily relates to worker migration rather than commuting per se (see Boschma et al. 2009; Cooper 2001; Kaiser et al. 2011; Poschl and Foster 2013; Williams et al. 2004).

This article is organized as follows. First, it reviews literature on innovation systems and its relevance to peripheral economies with particular attention to the concept of proximity.

[2] This article adopts the Australian definition of "regional" as being rural and remote areas outside of key metropolitan areas and their surrounds.

Subsequently, it describes the Australian policy approach to innovation as well as the unevenness of development across regional areas specifically in the context of its growing long-distance commuting workforce. Next, it details a methodology which first maps labor commuting using social network analysis (SNA) and patents across regional Australia local government areas (LGAs) and then regresses innovative activity against several different socio-economic factors and SNA-derived commuting indices. Finally, it presents findings that population, commuting, and professional employment are significant contributors to innovative activity in regional Australia in areas with smaller populations. It concludes that labor commuting may facilitate the transfer of ideas between regions by extending labor networks making spatial distance less relevant. By doing so, it may act as a mechanism for low populous areas to overcome proximity barriers generated by geographically-sparse populations and industry.

Innovation Systems and Regional Economies

The concept of national innovation systems (NIS) first emerged in the work of Freeman and Lundvall, who drew on the Schumpeterian innovation and economic development links embedded in evolutionary economics and Perroux's Growth Pole Model. Defined as the relational networks of "the national education system, industrial relations, technical and scientific institutions, government policies, cultural traditions and many more national institutions" (Freeman 1995, 5), NIS formed the base for the development of the alternative concept of "regional innovation system" (RIS). The latter emphasizing regional and local public and private sector clusters and their links to the national system.

Focusing on the geographic local "stickiness" of knowledge (Ashiem and Isaksen 2002; Maskell and Malmberg 1999), RIS literature sought to balance the top-down perspectives of NIS and the shortcomings of "technopole" literature where a linear innovation approach downplayed the role of agent networks (Cooke 2001). Its focus on face-to-face contact reflected Porter (2000) who suggested dynamic regional clusters of agglomerated industrial specialization most efficiently facilitated knowledge transfer or spillovers. He contended that clusters leveraged intra-regional untradeable interdependences of actors and the knowledge tied to territorially-specific human assets and social capital (Storper 1997; Morgan 2007). In this way, RIS follows a more location-specific "regional capability" approach than NIS (cf. Asheim and Isaksen 2002; Bilbao-Osorio and Rodriguez-Pose, 2004), better incorporating concepts of path dependency as related to the processes driving regional economic development (Fagerberg et al. 2009). Nonetheless, some cautioned against the conflation of clusters and RIS being separate albeit inter-related concepts where RIS constitutes different industry sectoral clusters (Asheim and Coenen 2005).

Despite difficulties in knowing the most appropriate unit of analysis for the "region" (cf. Doloreux and Parto 2005), RIS has provided a useful analytical framework for national and regional development and policy given its capacity to model the complexity of interlinked and interdependent actor networks at different spatial levels (see Howells 2005; Todtling and Trippl 2005). Nonetheless, the implementation of innovation policy is complicated by the various competitive advantages of regional or industry sectorial differences arising from actor collaborations in knowledge creation and organization (Davenport 2005; Todtling and Trippl 2005). Subsequently, research has explored the critical contribution of actor geographic or spatial proximity (Boschma 2005; Morgan 2004) and formal/informal local learning environments (Lambooy 2005; Simmie 2003) to the efficient operation of the innovation system through knowledge spillovers and university, industry, and government actor links (Asheim and Gertler 2006; Audretsch and Feldman 2004). The greater concentration of these factors makes highly urbanized cities - rather than organizationally and network "thin" peripheral or remote towns - the preferred focus for the majority of innovation studies

(Doloreux and Dionne 2008; Martinez-Fernandez and Potts 2008; North and Smallbone 2000; Todtling and Trippl 2005; Virkkala 2007).

Indeed, whilst innovation is recognized as a critical component in the health and sustainability of peripheral communities, understanding how they link to a regional system is challenging. As noted by Todtling and Trippl (2005), innovation policy tends to apply a "one size fits all" model of regional development drawing on a variety of regional development and innovation literature with varying degrees of applicability in different regions. These models tend to focus on how the interplay of actors, historic factors and territorial-embedded socio-economic competitive advantages form successful innovation regions.

These "innovation" success stories have only limited applicability in less favorable peripheral regions with very different innovation barriers and capabilities as well as development trajectories and pathways (Doloreux 2003; Todtling and Trippl 2005). Such regions are typically over-reliant on traditional industries dominated by innovation time-deficient small and medium enterprises and characterized by "weakly developed firm clusters, few knowledge providers and a weak endowment with innovation support institutions" (Todtling and Trippl 2005, 1215). As such, there is a need for deeper consideration of regional variations in "industrial specialization and their innovation performance", the geographic constraints and limitations of knowledge spillovers, the high relevance of tacit knowledge for innovation success, and place-bound "political competencies and institutions" (p.1205). Whilst this is true, the RIS analytical framework is fraught with inherent conceptual bias regarding the links between innovation and geography. This makes it difficult to translate to regional environments.

Firstly, the RIS emphasis on formal institutional or "organizational" channels of innovation has led to a research and policy focus on the connectivity of actors, namely government, education and industry (e.g., Mytelka and Smith 2002; Todtling and Trippl 2005). There is little on the influence of labor and its social networks outside of organizational boundaries (e.g., Miguelez and Moreno 2013; Poschl and Foster 2013; Williams et al. 2004). Consequently, peripheral economic areas are seen as operating largely outside the "innovation" system of highly connected dynamic actors, supporting institutions, and critical mass of industry found in core economies or knowledge-intense sectors (Doloreux and Dionne 2008; Vikkala 2007).

The second issue relates to the studying of innovation "systems" as isolated case studies or success stories primarily in high-populous areas and in science and high-tech industries (cf. Ashiem and Coenen 2005). Whilst numerous case studies have unpacked the untradeable characteristics of "sticky" knowledge and actor clustering in peripheral regions (Doloreux and Dionne 2008; Torre 2008; Vikkala 2007), they have yet to document the complexity of socio-economic lives playing out across a wider spatial network. Periphery economies are often not well-endowed with technology-related or science-based industries where there are greater levels of formal research and development (R&D expenditure, patents, etc.) allowing innovation to be more easily mapped. Instead, they tend to have traditionally resource-intense industries and require alternative human resource arrangements. Innovative activity then often draws on very different ways and means to acquire information and knowledge than metropolitan centers (cf. Castellacci et al. 2009). This includes external sources of knowledge where auxiliary benefits are gained vis-à-vis various forms of temporary spatial proximities (cf. Torre 2008). As a result, many advocate broader understandings of different types of proximity (Boschma 2005; Cantù 2010; Davenport 2005) to better connect regions to global "pipelines" of knowledge (cf. Bathelt et al. 2004). For periphery economies, this includes consideration of external knowledge sources outside of firm-based boundaries, locational constraints and high-tech science industries.

A third, and related point to those above, is on the role of proximity in the transfer of "tacit" knowledge which is spatially bound at some level given the designated government-industry-R&D "actors" of significance. Growing research evidence that peripheral regions demonstrate, albeit small, innovation systems has led some to argue that proximity must be viewed outside of its geographic dimension (Lagendijk and Lorentzen 2007; Vikkala 2007). Despite identification of different proximity dimensions (e.g., organizational, cognitive, social, institutional, and geographic; cf. Boschma 2005; Lagendijk and Lorentzen 2007), the RIS discourse is almost exclusively focused on the bricks-and-mortar agents of firms as representative of the actions of an innovative workforce (cf. Bathelt et al. 2004; North and Smallbone 2000; Vikkala 2007). As such, the playground for labor interactions at various proximity dimensions occurs in the *physical or geographic space* dictated by the location of organizations – which is primarily in larger cities. As noted by Boschma (2005), "empirical studies tend to confirm that knowledge externalities are geographically bounded: firms near knowledge source show a better innovative performance than firms located elsewhere" (p.69). This raises questions regarding the self-perpetuating nature of innovative activity when assumptions on the "source of knowledge" are based on the fixed physical location of organizations rather than labor interactions which may occur within and across space.

Indeed, as noted by Lagendijk and Lorentzen (2007), regional success for peripheries depends more on building "localized capacities" through "global connections" and a "local resource base" rather than "local networking and clustering" (p.462). Noting the lack of studies examining the relationship of regions to their broader operational environment, Moreno and Miguelez (2012) found external sources of knowledge to be key drivers of regional innovation. Similarly, North and Smallbone (2000) observed that SMEs in rural communities drew knowledge from whatever sources available. Doloreux (2003) added that knowledge extraction occurred across a variety of local, regional and global networks, and that the diversity of connections outside of the "local" was critical to increasing innovation in peripheral economies which inherently had uneven access to knowledge sources. Vikkala (2007) described these knowledge sources as coming from a range of "clients, non-local knowledge institutes and national technology programmes" (p. 511).

Building innovative periphery regions therefore is partly the result of strategies aimed at overcoming the spatial boundedness of organizational knowledge spillovers; this can be through the social proximity provided by virtual or physical social networks. For example, North and Smallbone (2000) found firms used the Internet to overcome lack of networking opportunities and were "shaped by various aspects of the rural environment" (p.87). While Monge et al. (2008) noted the links between social capital and adoption of innovation, and Sobels et al. (2001) the positive multiplier effect that the cumulative social capital of collaborating networks had on achieving group outcomes. Research in general reports positive links between social capital and regional development (cf. Bryden and Munro 2000; Callois and Aubert 2007), with links between sports and social capital in rural or disadvantaged communities (Skinner et al. 2008; Atherley 2006) pointing to the role of temporal social proximity in generating pipeline connections to regions outside of a communities' immediate operating environment (cf. Bathelt et al. 2004; Lagendijk and Lorentzen 2007).

This article aims to explore innovation in periphery economies by examining labor commuting as an additional dimension in the social proximity discourse for regional communities. That is, can worker mobility assist in transporting ideas between locations (and bringing back ideas to the firm), particularly when there are large long-distance commuting workforces (cf. Faggian and McCann 2009), and how might this change our perception regarding the contribution of peripheral areas to the overall RIS? The remainder of this article explores how extended labor networks might facilitate innovation in regional Australia.

Framing Innovation across Regional Australia

Australia has followed global policy trends with knowledge development and innovation becoming critical platforms for improving its productivity and, in turn, global economic competitiveness (APEC 2003, 2004; Dodgson et al. 2011). Innovation policy in Australia has undergone considerable changes in the last fifteen years moving from a primarily nationally driven system “sponsoring grand ‘technology citadels’” to one where the States have increasingly taken a “bottom-up approach to building intense innovation environments, local clusters and knowledge hubs” (Garrett-Jones 2004, 3). Despite this, questions regarding Australia’s capacity to innovative have persisted causing concern over growing metropolitan-regional socio-economic disparities and the need to remain globally competitive. This has led to increased policy efforts to more broadly understand the overarching national innovation system (see Dodgson et al. 2011).

A 2011 report (Department of Industry, 2011) found that whilst Australia was increasingly productive relative to the US, manufactured products tended to be low value-add and specializing in low-to-medium technology sectors, such as basic metals (upstream processing e.g., primary aluminum and steel) and food/beverage (final stage processed food). The report noted collaboration significantly contributed to Australian business productivity (more than triple); with businesses that collaborated 78% more likely more to record rises. This figure rose to 242% more likely to increase productivity for business collaborating with research organizations (or similar). Furthermore, a greater diversity in knowledge sources was found to substantially impact Australian business innovation levels across all innovation types - goods and services; operation processes; organizational/managerial methods; and marketing methods. Whilst the report highlighted the features of Australia's innovation system, its lack of geographically disaggregated data does little to allow an understanding of the relational dimensions within the urban system itself. Indeed, the highly urbanized nature of the Australian urban system (McGuirk and Argent 2011) implies that the majority of data was gleaned from businesses and institutions located in major cities.

Increasing interest in understanding Australia's regional innovation systems has generated calls to take innovation outside of its standard "science and technology" realm to recognise the substantial contribution to innovation of other industries, such as humanities, arts and social sciences (Haseman and Jaaniste 2008), as well as the range of community, industry and institutional actors and processes (Cutler 2008). Such a position is further justified with observations that innovation processes in peripheral locations are highly subject to the local characteristics. Many of these have resulted from the need to overcome "barriers" in the traditional RIS sense, making it more difficult to draw from the experiences of larger metropolitan regions or the peripheries of other countries (cf. Doloreux and Dionne 2008; Martinez-Fernandez and Potts 2008; North and Smallbone 2000). Garrett-Jones (2004) highlighted the disadvantaged nature of many rural areas in terms of innovation with State and Federal allocating financial resources according to population, in particular to the most populous states of New South Wales and Victoria.

Settlement across regional Australia is characterized by uneven patterns of development with some cities and towns absorbing the bulk of population and wealth at the expense of others (Martinus 2016; Tonts et al. 2013) as well as the population decline of economically productive remote and/or rural locations (see Haslam-McKenzie 2011; Morris 2012). From an economic perspective, the uneven patterns of development appear to be worsening with observations that the two-speed dichotomy between the *haves and have nots* (Stimpson 2001) is shifting to a three-speed one producing *the fast moving, slow moving and the rest* (Corden 2012). Research has debated and ascribed observations of Australia's regional urban geography to various ideological and theoretical constructs such as post-productivism landscapes, amenity or resource-led development, the sponge cities hypothesis, and sea/tree change movements (Argent et al. 2008; Connell and McManus 2011; Luck et al. 2010; Smailes 2002; Tonts et al. 2013). This development unevenness is compounded by an increasingly long-distance commuting labor force (LDC) or, as colloquially known, FIFO (fly in/fly out), BIBO (bus in/bus out) and DIDO (drive in/drive out).

The LDC option enables highly-paid labor (primarily highly specialized) to live far from work locations in comparatively amenity-rich regional towns (see Argent et al. 2009) reflecting in part the vast remoteness and low infrastructure provision across much of regional Australia (Argent et al. 2008; Martinus 2016). As such, the use of LDC hinders regional development in resource-endowed areas which, in an earlier era, would have injected human and capital resources into towns (cf. Martinus 2016; Storey 2001). Coined "cancer of the bush", its erosion of communities has sparked a national inquiry into broader industry and regional impacts (Commonwealth of Australia 2013). Indeed, LDC has enabled an environment where regions are not only unable to tap into resource wealth by attracting worker families, but their small and declining populations do not fit the criteria for government funds to improve community socio-economic infrastructure and amenity (Morris 2012; Storey 2001).

Introduced in the 1970s and often associated with the mining industry, in Australia, LDC is entering the labor arrangements of other industries, such as agriculture, construction, social and health services. It is providing essential services to rural communities which otherwise have limited labor pools and poor levels of infrastructure, services, and amenities compared to Australian capitals and major cities (Commonwealth of Australia 2013). While greater access to specialized labor markets may suggest resource efficiency and productivity, Australia is experiencing decreasing productivity since the 2000s primarily due to declines in mining, agriculture, and utilities industries (Koutsogeorgopoulou and Barbiero 2013). Concern that Australia may begin to fall behind globally has generated considerable policy and academic debate on the development of factors influencing productivity such as human capital (leadership, higher education, skills), innovation (knowledge exchange systems, stimulation) and infrastructure (Green et al. 2012; Koutsogeorgopoulou and Barbiero 2013). The increasing reliance of rural communities on innovation to raise productivity, remain economically viable and promote sustainability in Australia's harsh environmental conditions and under increasing global competition builds a strong policy case for better understanding the role of peripheral economies in the broader innovation system.

The data and regression variables

Acknowledging the complexity of factors contributing to innovative activity, this research explores the relationship of various independent variables to innovative activity through a regression analysis of data from regional Australia. It uses the Australian Bureau of Statistics (ABS) spatial unit of Local Government Area (LGA) as this most closely fits the RIS concept of a region being "meso-political unit[s] set between the national or federal and local levels of government that might have some cultural or historical homogeneity but which at least had some statutory powers to intervene and support economic development, particularly innovation" (Cooke 2001, 953). The study area of regional Australia was defined as those areas outside the seven Australian capital cities and their extended metropolitan regions. This aligns with postcodes provided by the Federal Government as "regional Australia/low population growth metropolitan areas" for purposes of General Skilled Migration (Australian Government 2014).

LGAs in the Northern Territory and Australian Capital Territory were excluded as outliers as they did not significantly contribute to OECD patent statistics used to measure innovative activity. This left a total of 398 regional LGAs across the States of Western Australia (WA), Queensland (QLD), New South Wales (NSW), Victoria (VIC), Tasmania (TAS) and South Australia (SA). These LGAs are diverse in structure comprised of regional towns of various sizes and different industrial structures from diverse economies with high amenities to single industry resource towns (Martinus 2016). Despite this, the towns in each LGA are typical regional communities characterized by low populations, low density urban development and low levels of industry agglomeration. The wide dispersion of population and industry across the vast Australian regional landscape also contributed to the choice of the LGA as the most appropriate spatial unit encapsulating the broad social network of residents living and working in constituent towns and surrounding areas.

An ordinary least squares multiple regression was employed as the outcome (dependent variable) of 2000-2013 historic cumulative (summed) patent (number of persons) data was continuous. The regression of 13-year cumulative data against contemporary 2011 ABS socio-economic data was based on two related assumptions. Firstly, that a LGAs' unique mix of contemporary social, economic and political factors taken at any particular time period (in this case 2011) was not an isolated snapshot with no relation to past social, institutional, political and economic dimensions and influences (cf. Amin 2002; Martin and Sunley 2006; Martinus 2016; Tonts et al. 2013). Secondly, that a LGAs *potential* for future innovation (cf. Olaru and Purchase 2015) is related to *cumulative* urban and economic development path dependent processes shaped by this unique mix of factors and best captured by independent variable data taken towards the end of the 2000-2013 patent activity period (in this case 2011 ABS data).

For example, labor mobility as embodied by the various independent commuting variables of the model can be viewed as a product of the well-worn paths between places of residence and work associated with generations of interchange based on some initial first connection (cf. Sheppard 2002; Warf, 2008). Non-spatial proximity in sparsely populated LGAs is therefore created as spaces are pulled together through the gradual and continual exchange of commuters. As carriers of ideas, information and knowledge, commuters shape the 'social, institutional, political and economic dimensions' of 'territorially bounded spaces' and 'change the relative position of places and actors located within them' (Lagendijk and Lorentzen 2007, 460). This model assumes that measuring the outcome of this influence is best understood at the end of the period rather than the beginning, and that this outcome is related to the processes at play which influence a regions' innovation levels.

Table 1 outlines the dependent and independent variables for the regression, which can be expressed by the following equation:

$$Y = X_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16} + \beta_{17} X_{17} + \beta_{18} X_{18} + \varepsilon$$

INSERT TABLE 1

Regression independent variables were constructed using various indicators from ABS 2011 census data, where X_0 is the constant, $\beta_j X_j$ represents the coefficients (β_j) and associated independent variables (X_j) where j is number between 1 and 18, and ε is the residual error.

Acknowledging difficulties in measuring innovative activity and "economically useful new knowledge" (Acs et al. 2002, 1069) and that not all inventions are patented, the regression dependent variable acting as the innovation proxy was constructed using patent data. Patent data has been consistently identified as a good indicator of innovative activity (Hagedoorn and Cloodt 2003) and employed in a variety of studies on innovation (Bilbao-Osorio and Rodriguez-Pose, 2004; Bottazzi and Peri 2003; Fritsch and Franke 2004; Miguelez and Moreno 2013). The LGA location of innovations were gleaned from the postcode information of addresses filed on patent applications in the January 2014 edition of the OECD REGPAT database (OECD 2014) covering the period 2000 to 2013 (see Maraut et al. (2008) for OECD database construction method). This database represents high value patents which may generate regional bias in the data, producing limitations to this analysis. However, it was still deemed most appropriate as: 1) it was used to provide an *indicator* of regional innovation (rather than exact measure); and, 2) this research is part of a larger global cross-national comparative study requiring comparable country patent information. There were 2340 persons who filed sole and collaborative patent applications across the 398 regional LGAs during the 13-year period.

The number of persons involved in patent activity over the 13 years (Y) was chosen as the dependent variable representing innovation patterns across regional Australia capturing instances of collaboration between different and within the same LGAs. It was assumed that these cumulative totals would highlight regional differences in innovative capacity given that, in any one year, data was sparse and therefore did not necessarily represent the relative potential of LGAs to innovate (or not). That is, the model assumed more innovative LGAs produced more patents in the 13 years than less innovative LGAs. Y was normalized by calculating the percent each LGA contributed to total number of persons involved in patent applications across the whole of regional Australia. Z-score standardisations were also tried. However, inherent differences in how the variables (dependent and independent) were distributed or clustered around their respective means, as well as the possibility of both negative and positive z-scores, made interpreting model outputs difficult. The simple percent rank order proportion (on a 0 to 100 scale) was found to improve interpretation and legibility of regression results, providing a more useful model.

Regression independent variables were chosen to represented factors associated with knowledge development and innovation, specifically ethnic diversity, connectivity (physical and virtual), industrial structure and education levels (cf. Martinus 2010) as well as an index of remoteness. Labor commuting profiles for the regression analysis were derived from a 568x568 matrix of ABS 2011 journey-to-work regional and metropolitan LGA data detailing where labor resides and works throughout Australia (ABS 2011). Social Network Analysis (SNA) was applied to this matrix to unpack the geography of commuter movements across the total 568 LGAs, as well as construct several commuting variables to allow regional LGAs to be interpreted within a national commuting framework of workplace and residence LGAs. There were four separate commuting variables used. The first two summed all work movements between LGAs allowing the total commuters residing (X_1 or *OUTLAB*) and working (X_2 or *INLAB*) in each LGA. The second two represented the sum of LGAs associated with these commuter movements, that is, the social network analysis[3] (SNA) metrics of in-degree (X_3 or *INLGA*) and out-degree (X_4 or *OUTLGA*) centrality. These variables were indicators of a LGAs' extended network of ideas and social capital given the relationship between labor connectivity and innovation (Bottazzi and Peri 2003; Cooper 2001; Fritsch and Frank 2004; Howells 2005; Kaiser et al. 2011; Miguelez and Moreno 2012; Simmie 2003), as well as an understanding of the implicit competitive advantages enabling each region to become a place of work or residence (Martinus 2016; Tonts et al. 2013).

Drawing on links between urban density (agglomeration), innovation and regional growth (cf. Martinus 2010), the population size variable (X_5 or *POP*) explored whether low populations

[3] Conducted using NodeXL.

were a disadvantage in generating innovation. It reflected the unevenness of population distribution across regional Australia which has occurred over decades of migration and regional economic restructuring (Martinus 2016), such that high populations generally reflected high amenity areas along the coast or in-land tree-change locations.

The variables of X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12} and X_{13} (or respectively *MAN*, *AG*, *MIN*, *ARTS*, *HEAL*, *ED*, *ICT* and *PROF*) relate to industries of employment of residents given the large role industry and economic competitive advantage play in driving innovative activity (Bathelt et al. 2004; Porter 2000) as well as the relationship between places of work and residence resulting in the historic redistribution of wealth (Martinus 2015; Tonts et al. 2013). An index of regional industrial diversity (RDI) using these variables was initially considered, but it was replaced by the normalization of individual industry sectors (as percent of employment in each LGA; see Table 1) as the RDI did not add to the fit of the model. AG and MIN sectors are employed in the regression as the industries driving the majority of regional Australia's historic development (Tonts et al. 2013), and other sectors (MAN, ARTS, HEAL, ED, ICT and PROF) for their value-add component or the innovation-support services they performed.

The education variables of X_{14} (or *POSTBACH)* and X_{15} (or *CERT*; see Table 1 for breakdown of qualifications) test the links between education attainment and innovation (Martinus 2010; Stadler 2012) with previous research noting that innovative regions attract the largest numbers of educated persons (Dakhli and De Clercq 2004). The research hypothesized that regions with the highest levels of education in 2011 would also have the most patents over the 13-year period. The internet connectivity variable (X_{16} or *INT*) examined the relationship between innovation and access to global information and social networks (Martinus 2010; North and Smallbone 2000). The model assumes that historically more connected communities had higher levels of connectivity in 2011 given their earlier access to communications infrastructure than highly remote communities.

The X_{17} (or *NONOCE*) variable investigates the relationship between non-Oceania overseas-born residents and innovation, given links between ethnic diversity and innovation (Niebuhr 2010). The *NONOCE* variable was chosen as it increased the models' statistical significance more than an initially constructed regional ethnic diversity index variable, perhaps due to the low numbers of non-Australians in regional towns. The model assumed that migrants were highest in regions with a history of migrant attraction due to the availability of work, cultural support as well as migrant welcoming community (Jordan et al. 2010; Lyas et al. 2013). The normalized variable (placed on 0 to 100 scale) of Australia's remoteness and accessibility index (X_{18} or *ARIA*) was included to test whether more regions with better road connectivity and access were also more innovative.

Other ABS variables of employment type (owner, employee, contributing family member) were also considered to explore the links between entrepreneurship and innovation. However, they were excluded as they were not statistically significant and did not improve the overall fit of the model. The remainder of the article documents the findings of the regression analysis.

Labor connectivity and innovation across regional Australia

Table 2 summarizes population and patent data by State share, highlighting a pattern of more populous states being the most innovative. This is confirmed by patents per head of population with the densest states generating more innovation per person (VIC and NSW have 24 and 9 persons per km^2 respectively). VIC and NSW also had the highest gross expenditure on R&D (GERD) – being 30 and 26 percent of total national expenditure compared to WA, QLD, and SA who had 17, 14 and 7 percent respectively (the latest figures being 2008/09; ABS 2010). Innovation per person for the remaining states appeared to have little relationship to density (TAS, QLD, SA and WA having respectively 7.5, 2.6, 1.7 and 0.9 persons per km^2 in 2011) (ABS 2015). The regional areas of each State had considerably lower patents per head, and exhibited a different pattern with regional LGAs in NSW, VIC and WA generating the highest number of patents per 100 population.

INSERT TABLE 2

Figure 1 illustrates the network of labor commuter flows (both in and out) between regional and metropolitan LGAs across Australia, where larger spheres denote LGA of work (i.e., higher in-commute) and smaller shapes denote LGAs of low in-commute. There is a concentration of workers travelling to regional LGAs adjacent to the capital cities as well as to the north of Western Australia and Queensland. In contrast, the areas with the largest out-commute workforce are found along the coast (many are residential locations) and in remote in-land locations (many are both work and residential locations).

INSERT FIGURE 1

Table 3 displays similar information to Figure 1 for the top 30 LGA by patent levels (of total 398 regional LGAs). Regional NSW was by far the most innovative having 53 percent of the top innovative LGAs. QLD and VIC occupied 20 and 17 percent of the top spots respectively. Whilst the top three LGAs by patent activity also had some of the highest populations and out-commuting labor (indicating residential locations), there was no clear relationship between population, patent levels and commuting.

INSERT TABLE 3

Table 4 summarizes the descriptive statistics for the variables. The gap between minimum, maximum and standard deviation values highlights the considerable variation in the variables between regions. Where all LGAs were connected to the national network of mobile workers, there were large differences in the economic structure with some LGAs more dominated by a single industry. This is evident in the regional percentage share of MAN, MIN and AG, with mining most dominant in the LGA of Laverton, WA (34 percent of its employment structure), agriculture in the Wheatbelt shire of Kent, WA (39 percent), and manufacturing in mining Shire of Wiluna, WA (16 percent). Accordingly, %INT is assumed to reflect levels of historic connectivity given the links of internet uptake to infrastructure provision and general residential or cultural attitudes to being "globally" connected. The lowest connected LGA (only 13 percent of residents) was the Indigenous community of Napranum QLD, and the highest was the mining LGA of Roxby Downs, SA (86 percent).

INSERT TABLE 4

Similarly, %NONOCE reflected the attraction of LGAs to overseas migrants for work, family or cultural reasons, the highest non-Oceania born levels (29 percent) found in the opal mining LGA of Cooper Pedy, SA and the lowest (0 percent) associated with various remote and Indigenous communities. The education variables of %CERT and %POSTBACH demonstrate general education levels of the community resulting from the specific needs of industry, presence of education facilities or the attraction of place to educated workers (see Faggian and McCann 2009). The outliers in these variables also represented the smallest LGAs. The highest and lowest %CERT being respectively Cherbourg, QLD (96 percent) as the only Indigenous community with a vocational education facility and the small mining and agricultural LGA of Sandstone, WA (43 percent); with the highest and lowest %POSTBACH being respectively Sandstone, WA and Cherbourg, QLD.

Table 5 gives the results for different regression models, where M1 uses all 398 regional LGAs, and M2 and M3 and use populations under 70,000 (384 LGAs) and 50,000 (372 LGAs) persons respectively. The *P-value* for all models is close to zero, indicating their statistical significance. The relatively large *F-statistic* (critical *F-value* is around 3) signifies that at least one of the variables is not zero and the models explain some of the total variability (i.e., some statistic usefulness). The null hypothesis was therefore rejected. Whilst the majority of the variables were insignificant, they were included as they improved the fit of the model (adjusted R^2). The adjusted R^2 value demonstrates that the variables account for 56 to 68 percent of the overall variance, albeit the fit of the model decreased as higher population LGAs were removed.

The variables of %POP and %PRO were significant in all models, suggesting their high value (positive correlation) to regional innovation. %PRO was consistently significant across all models, with other variables demonstrating different significance levels. Interestingly, %POP was highly significant in high and low populous LGAs, but only slightly significant in moderate size LGAs (M2). In the latter, both the number of other out-going LGAs connections and in-coming labor flows were highly significant suggesting that the number of workers and diversity in LGA connections might compensate for the lower population in facilitating innovation. Diversity in LGA outgoing connections and incoming labor numbers were also significant in small LGAs (M3). Whilst the lower value of %POP between M1 and M2 pointed to the declining influence of population as larger populations were excluded, there appeared to be a critical mass of population needed under which %POP (or agglomeration factors) began to matter. The lower significance of %POP in M2 suggested that innovation is driven by other sources (such as the number of LGAs workers are commuting to and the size of the incoming labor force). The significance of %INLAB suggests there is an advantage gained via commuting, either through direct collaboration in patent activity or in the increase of worker ideas a community has access to. Surprisingly, internet connection and level of remoteness are insignificant in all models. In terms of industry of employment, %PRO had the largest positive impact on innovation activity in all models, and %MAN was found to negatively impact on innovation in M2 and M3 size LGAs.

INSERT TABLE 5

Figure 2 highlights several interesting points in the relationship between the most significant variables of share of population and labor in-commuting against share of persons involved in patent applications. Firstly, the leading regional innovators appear to be either residential LGAs with some of the largest populations and relatively low numbers of in-commuting workers (Townsville, Toowoomba, Cairns, Mackay and Greater Bendigo) or have moderate populations and share of worker inflow (Port Stephens and Hawkesbury). A second tier of innovators have relatively low shares of populations and in-commuters suggesting sea or tree change lifestyle locations (Busselton, Wingecarribee, Great Lakes and Armidale-Duresque). Secondly, the uncertain relationship between innovative activity, commuting, and population with some moderately populated LGAs recording little to no innovation and high in-commute (for example, Isaac and East Pilbara); and other LGAs with low shares of population and in-commute having a moderate share of persons involved in patents (Esperance).

INSERT FIGURE 2A

INSERT FIGURE 2B

Discussion

Given that lack of population is often cited as the reason that rural or remote communities are not considered in conversations of innovation generally, it is not surprising that population size had an influence in all models. Understanding the variables that were both significant and insignificant generates insight into the key factors driving the numbers persons involved in patent applications as a proxy for innovation across regional Australia. One of the more surprising findings to emerge was the insignificance of internet connectivity and remoteness levels, and the significance of the size of the labor force and diversity of outgoing worker connections to other LGAs. This indicates that the extended social network of regional LGAs through LDC is resource for innovation, with traditional forms of problem-solving, such as face-to-face consultation, just as important in less connected and remote LGAs as they are in large metropolitan centers.

Unpacking drivers of innovation in peripheral communities is critical to moving beyond preconceptions that innovation does not occur in regional LGAs. The significance of the various commuting and PROF variables not only suggests that regional LGAs find economic advantage in the extended networks of labor, but that commuting works to increase innovation through the whole regional and metropolitan system. This may be either through direct collaborations with workers from other LGAs or the transfer of ideas between workers of connected communities with the employment sector of professional, scientific and technical services playing a large role in knowledge dissemination and the generation of innovative outcomes. Furthermore, smaller LGAs appear to derive benefit from not only the size of extended social structures of in-commuters, but from the numbers of different LGAs their workers are travelling to. This aligns with previous Australian and international research findings that diversity in knowledge sources increases innovation (Department of Industry 2011) in peripheral areas (Doloreux 2003), suggesting that knowledge sources for small regional LGAs is related to both their overall workforce and the LGAs they come from.

Whilst the high population coefficient in M1 reflects positive industry and population agglomeration effects in facilitating innovation, it is not impacted by worker movements.

This implies that the benefits of extended labor networks have no impact on amenity-rich LGAs (where there are large resident populations commuting elsewhere for work), although working residents commuting elsewhere for work increase the innovative capacity of destination LGAs. Commuters then appear to act as knowledge conduits between two LGAs, such that the knowledge resources (or capital) in LGAs where workers live is developed and commercialized in LGAs where they work. The insignificance associated with the extended labor networks of larger regional LGAs is most likely because they already have the critical population mass and social network structure to support patent "self-generation".

Such findings point to the capacity of commuting labor to transfer ideas between regions allowing tacit knowledge to transcend "time, space, and organizational boundaries" (see Nonaka and Toyama 2003, 2). This produces positive feedback mechanisms for innovation in all regional communities where commuting labor generates "social network effects" in both work and residential LGAs (cf. Kaiser et al. 2011). The interactions of commuters from different LGAs at the workplace allows knowledge to travel between regions, enhancing the regional or national innovation system as local knowledge capacity increases via inflows of external knowledge. In this way, commuting as a subset of labor mobility can facilitate innovation and technological progress by increasing knowledge dissemination in the same way that "job-hopping" does (see Cooper 2001; Poschl and Foster 2013). Thus, as suggested by Morgan (2007) and Williams et al. (2004), research on innovation should look beyond the usual measures of institutional capacity and R&D expenditure when evaluating innovation systems to include an understanding of labors' role, mobility and networks. Doing so will better capture the function of social networks in mediating production relationships and shaping landscapes of uneven development (cf. Williams et al. 2004). This will improve understandings of how global pipelines might connect clusters of different sizes to drive regional development (cf. Bathelt et al. 2004).

Concluding Comments

Understanding the complexities of a nations' innovation system has become a key factor in the formulation of effective policy targeting national productivity and global competitiveness for both metropolitan and regional areas. Nonetheless, the importance of proximity in facilitating knowledge spill-overs and innovation has meant a research focus on the dynamics of agglomerated urban centers of major metropolitan regions, with little attention paid to the different mechanisms in sparsely populated peripheral regions. This is highlighted through the Australian case study where overall higher levels of government and business investment in R&D is reflected in more patents per head of population in New South Wales and Victoria overall, but yet not in the regional areas of VIC where patent levels in other less populated states are higher (namely WA and QLD). Given the contribution of peripheral areas to Australia's gross domestic product (often through their resource endowments), further exploration of the unique factors driving the innovation process in these regions, and the industry sectors they are associated with, is both warranted and well overdue.

A rising feature of Australia's economy is its mobile labor force. This mobility acts to exacerbate uneven geographies of development between regions with amenity- and infrastructure-endowed locations absorbing the bulk of regional population and economic investment at the expense of poorly-serviced ones. This has major implications regarding the perception of a regions' capacity to generate knowledge spill-overs and innovation. This study challenges assumptions that remote and rural economies either operate external to the national innovation system or do not contribute to innovation in core urban areas by exploring the relationship of commuting and other variables with innovative activity. It finds that population, labor in-commute, diversity of out-commuting LGAs and professional, technical, and scientific services were significantly correlated to the numbers of people involved in patent applications. Manufacturing was negatively correlated. This led to the conclusion that the extended labor networks in peripheral communities provide a resource for innovative activity in LGAs where workers worked rather than where they lived. This effect was found to be stronger in smaller LGAs who also derived more benefit from the diversity of LGAs their workers were traveling to than their own population size. This latter effect was slightly less significant in very small LGAs.

Through the innovative application of social network analysis and econometric modelling, this article provides deeper insight into the role of labor commuting, and the way it appears to extend the innovative capacity of sparsely populated regions over and above what would be expected based on population size. This is hypothesized to occur as the flow of workers decreases the distance or geographic proximity between regional communities, with the temporary worker exchange of ideas becoming a resource for innovative activity. Incorporating the labor dimension into the institutional and organizational proximity discourse of innovation studies is therefore important for peripheral communities as the long distance mobility of labor provides a mechanism to transfer “sticky” knowledge and ideas between regions and across large geographic distances. The external networking activities of commuters act as critical inter-regional conduits to overcome barriers of organizational “thinness” associated with the inherent lack of industry and population in peripheral areas. This implies further research is needed on the contribution of regional place-based advantages to differences in the innovative under- or over- performance of regions based on population size, as well as the lag effects of socio-economic variables during different periods of invention. Such understandings are critical in understanding how low populous peripheral communities might form part of the innovation system; the implications of which reach far beyond Australia into other agglomeration-challenged remote or rural communities world-wide.

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KIRSTEN MARTINUS is a Research Fellow in the Centre of Regional Development, School of Agriculture and Environment of Geography at The University of Western Australia, Perth, WA 6009. E-mail: kirsten.martinus@uwa.edu.au. Her research interests include the uneven distribution of resources and productivity, as well as labour and corporate networks.

Table 1: Regression variable descriptions β_{18}

Variable description		
	Independent variable	
Y	%PER	Percentage of regional Australia persons involved in patent applications 2000-2013 (Source: OECD, 2014)
	Dependent variables	
X_1	%OUTLAB	Percentage of regional Australia out-commuting laborforce of total 2,928,867 persons (Source: ABS, 2011; place of usual residence)
X_2	%INLAB	Percentage of regional Australia in-commuting laborforce of total 393,585 persons (Source: ABS, 2011; place of work)
X_3	%OUTLGA	Percentage of regional Australia out-flow LGAs of total 10,196 connections; measure of connection diversity (Source: ABS, 2011; place of usual residence)
X_4	%INLGA	Percentage of regional Australia in-flow LGAs of total 10,165 connections; measure of connection diversity (Source: ABS, 2011; place of work)
X_5	%POP	Percentage of regional Australian population of total 398 regional LGAs (Source: ABS, 2011; place of usual residence)
X_6	%MAN	Percentage of persons in LGA in manufacturing (Source: ABS, 2011; place of usual residence)
X_7	%MIN	Percentage of persons persons in LGA in mining (Source: ABS, 2011; place of usual residence)
X_8	%AG	Percentage of persons in LGA in agriculture, forestry and fishing (Source: ABS, 2011; place of usual residence)
X_9	%ARTS	Percentage of persons in LGA in arts and recreation services (Source: ABS, 2011; place of usual residence)
X_{10}	%HEAL	Percentage of persons in LGA in health care and social assistance (Source: ABS, 2011; place of usual residence)
X_{11}	%ED	Percentage of persons in LGA in education and training (Source: ABS, 2011; place of usual residence)
X_{12}	%ICT	Percentage of persons in LGA in information, media and telecommunications (Source: ABS, 2011; place of usual residence)
X_{13}	%PROF	Percentage of persons in LGA in professional, scientific and technical services (Source: ABS, 2011)
X_{14}	%POSTBACH	Percentage of persons in LGA with Postgraduate degree, Bachelor degree, Graduate Diploma or Graduate Certificate (Source: ABS, 2011; place of usual residence)
X_{15}	%CERT	Percentage of persons in LGA with Certificate, Advanced Diploma or Diploma (Source: ABS, 2011; place of usual residence)
X_{16}	%INT	Percentage of persons in LGA with broadband or dial-up internet (Source: ABS, 2011; dwellings, location on census night)
X_{17}	%NONOCE	Percentage of non-Oceania born in LGA (Source: ABS, 2011; place of usual residence)
X_{18}	ARIA	Accessibility/Remoteness Index of Australia (ARIA) measuring road distances between populated localities and service centers. Index normalized to fit 0-100 range.

Table 2: Summary of State share of population and patent data

Percentage of Australia	State share of population (%)	State share of patents (%)	Patents per 100 population		Patents per 100 population
Total NSW	33.2	37.4	0.18	Regional NSW	0.06
Total QLD	20.6	16.2	0.13	Regional QLD	0.06
Total VIC	25.5	28.5	0.18	Regional VIC	0.05
Total WA	10.8	10.6	0.16	Regional WA	0.06
Total SA	7.5	6.5	0.14	Regional SA	0.02
Total TAS	2.4	0.7	0.05	Regional TAS	0.05
Total Regional Australia[4]	28.2	9.6	0.06		0.06
Total Australia	100%	100%	0.16		

[4] Using selected states only (excluding Northern Territory).

Table 3: Incommute, outcommute, patent levels and population Top 30 regional LGAs, ranked by population size

Patent level	LGA	Labor In	Labor Out	Population	Distance to nearest capital city (kms)
121-140	Townsville, QLD	1,721	67,634	180,114	1,354
81-101	Toowoomba, QLD	4,430	62,826	155,473	124
61-80	Mackay, QLD	1,811	45,410	115,960	971
61-80	Wingecarribee, NSW	2,692	22,558	46,126	152
61-80	Great Lakes, NSW	1,820	21,608	35,737	251
41-60	Orange, NSW	4,044	16,342	39,419	257
41-60	Busselton, WA	1,046	13,971	31,523	226
41-60	Maitland, NSW	10,051	39,760	69,924	167
41-60	Blue Mountains, NSW	2,532	47,002	78,553	106
41-60	Cairns, QLD	2,541	62,304	162,178	1701
41-60	Shoalhaven, NSW	2,217	49,681	96,203	200
41-60	Hawkesbury, NSW	7,961	35,421	64,353	50
41-60	Macedon Ranges, VIC	2,487	24,838	42,883	69
41-60	Greater Bendigo, VIC	2,804	45,796	101,995	153
21-40	Armidale Dumaresq, NSW	1,763	11,055	25,158	474
21-40	Coffs Harbour, NSW	2,354	32,416	70,972	530
21-40	Port Stephens, NSW	8,927	38,190	67,214	183
21-40	Ballina, NSW	3,255	21,744	40,747	186
21-40	Goulburn Mulwaree, NSW	1,228	13,700	28,363	194
21-40	Mildura, VIC	1,405	22,885	51,822	542
21-40	Rockhampton, QLD	1,273	46,590	112,333	635
21-40	Lismore, NSW	5,490	21,126	44,348	738
21-40	Singleton, NSW	6,872	10,023	23,523	200
21-40	Ballarat, VIC	6,893	43,219	95,185	114
21-40	Baw Baw , VIC	2,372	22,435	43,389	212
21-40	Bunbury, WA	10,668	16,781	32,580	173
21-40	Wagga Wagga, NSW	2,580	23,265	61,781	461
21-40	Byron, NSW	2,520	15,395	30,712	161
21-40	Cassowary Coast, QLD	869	12,292	28,636	1,546
1-40	Latrobe, TAS	1,301	6,565	10,275	274

Table 4: Regression variable summary statistics (398 LGAs) X

Variable		Mean	Standard Deviation	Minimum	Maximum
X_1	%OUTLAB	0.25	0.37	0.00	2.31
X_2	%INLAB	0.25	0.42	0.00	2.93
X_3	%OUTLGA	0.25	0.23	0.01	1.39
X_4	%INLGA	0.25	0.23	0.02	1.51
X_5	%POP	0.25	0.38	0.00	2.94
X_6	%MAN	2.98	2.21	0	15.76
X_7	%MIN	2.37	5.08	0	33.85
X_8	%AG	8.38	7.56	0	39.02
X_9	%ARTS	0.39	0.43	0	5.49
X_{10}	%HEAL	4.26	1.52	0	8.80
X_{11}	%ED	3.49	1.06	0.03	9.65
X_{12}	%ICT	0.25	0.20	0	0.99
X_{13}	%PROF	1.17	0.71	0	4.71
X_{14}	%POSTBACH	26.05	6.00	4.47	57.14
X_{15}	%CERT	73.95	6.00	42.86	95.53
X_{16}	%INT	63.76	11.35	13.19	85.95
X_{17}	%NONOCE	8.73	4.64	0	28.85
X_{18}	ARIA	37.61	27.50	0	100
Y	%PER	0.25	0.55	0	5.60

Table 5: Regression models of number of persons engaged in patent applications 2000-2013 using Australian regional LGAs at different 2011 population size cut-offs

Variable coefficient		All (M1)	Under 70,000 pop (M2)	Under 50,000 pop (M3)
β_0	Constant	-0.12 (0.15)	-0.07 (0.12)	-0.05 (0.11)
β_1	%INLGA	-0.00 (0.11)	-0.06 (0.09)	-0.08 (0.08)
β_2	%OUTLGA	0.12 (0.22)	**0.93***** (0.20)	**0.91***** (0.19)
β_3	%INLAB	0.10 (0.05)	**0.20***** (0.05)	**0.18*** (0.05)
β_4	%OUTLAB	-0.41 (0.26)	-0.14 (0.24)	-0.26 (0.25)
β_5	%POP	**1.44***** (0.21)	**0.48*** (0.22)	**0.83***** (0.22)
β_6	%MAN	-0.01 (0.01)	**-0.02*** (0.01)	**-0.02*** (0.01)
β_7	%MIN	-0.002 (0.00)	-0.002 (0.00)	-0.001 (0.00)
β_8	%AG	0.003 (0.00)	0.002 (0.00)	0.004 (0.00)
β_9	%ARTS	0.02 (0.04)	-0.01 (0.03)	-0.01 (0.03)
β_{10}	%HEAL	-0.02 (0.01)	-0.01 (0.01)	-0.01 (0.01)
β_{11}	%ED	0.02 (0.02)	0.01 (0.02)	0.01 (0.01)
β_{12}	%ICT	-0.06 (0.12)	-0.08 (0.09)	-0.08 (0.09)
β_{13}	%PROF	**0.05**** (0.02)	**0.09**** (0.03)	**0.08**** (0.03)
β_{14}	%POSTBACH	0.003 (0.00)	0.002 (0.00)	0.003 (0.00)
β_{15}	%CERT	0 (omitted)	0 (omitted)	0 (omitted)
β_{16}	%INT	-0.002 (0.00)	-0.002 (0.00)	-0.004 (0.00)
β_{17}	%NONOCE	-0.00 (0.00)	0.00 (0.00)	0.003 (0.00)
B_{18}	ARIA	-0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	F	51.32	32.44	28.69
	P	0.000	0.000	0.000
	Adjusted R^2	0.68	0.58	0.56
	No. of LGAs	398	384	372

Standard errors are in parenthesis; **p*>0.05, ** *p*>0.01, *** *p*>0.001

Figure 1: Labor inflows (left; larger disk denotes greater number of commuter inflows; lines denote connecting LGAs)

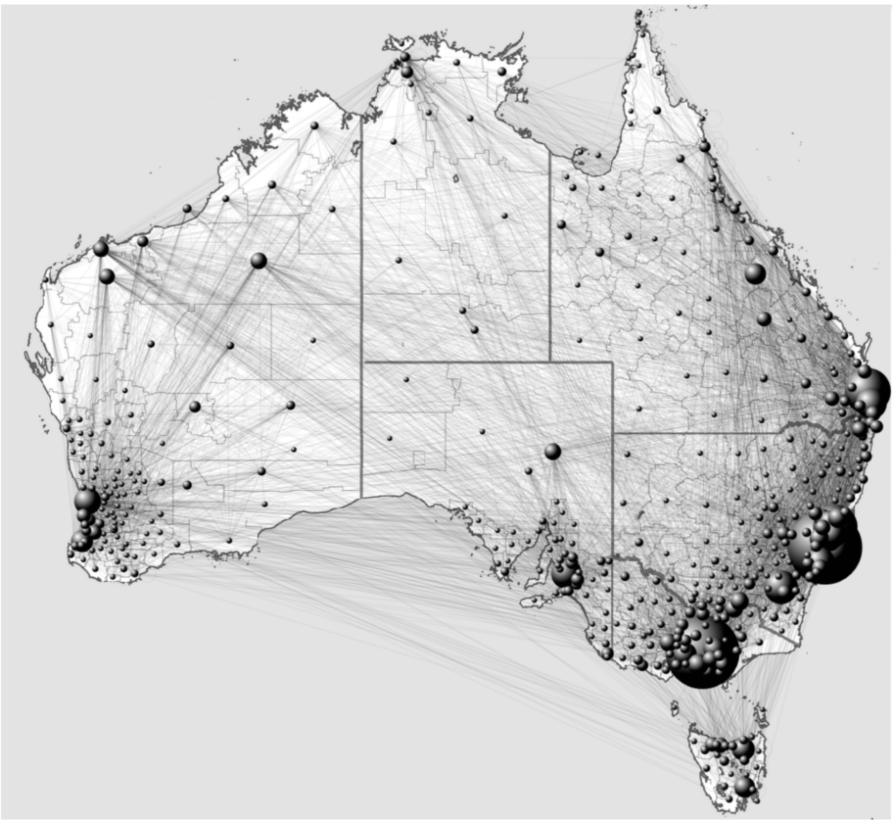
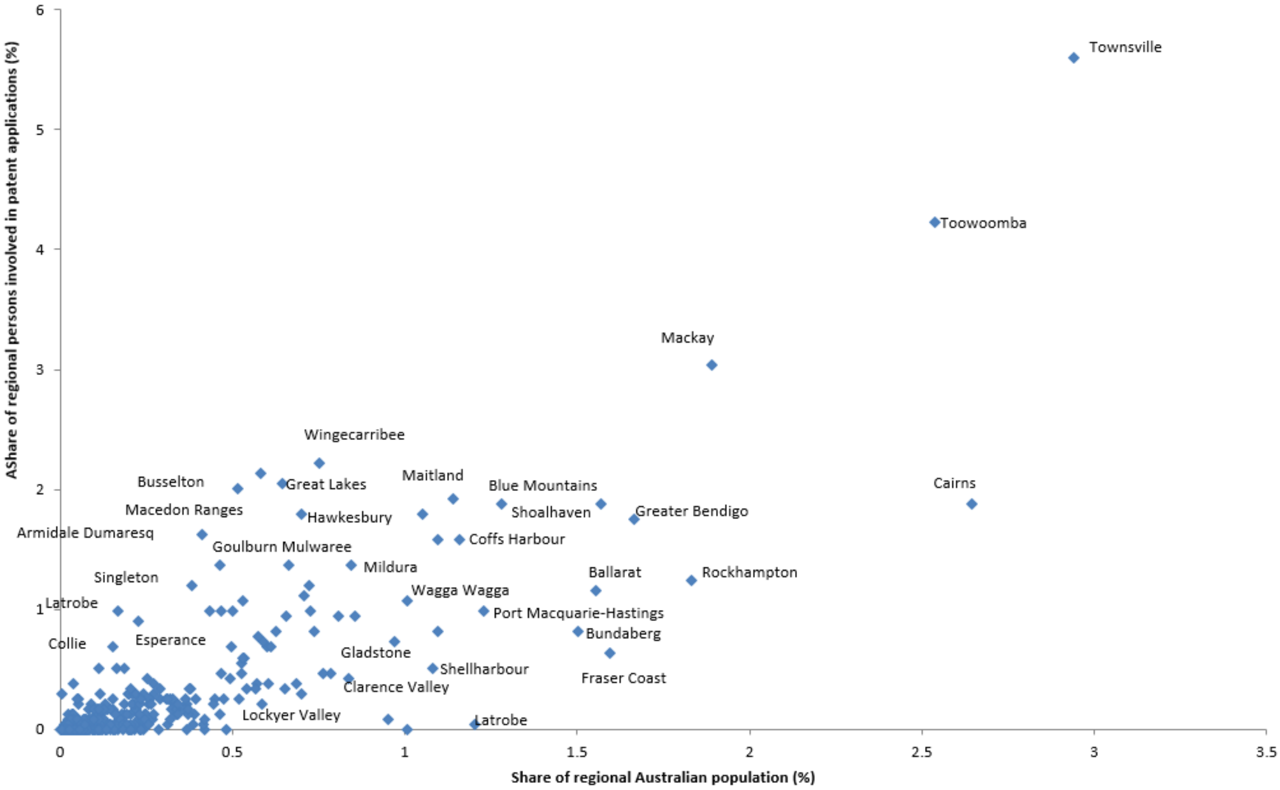


Figure 2: Relationship of share of persons involved in patent applications for all LGAs with: (A) share of regional population; (B) share of regional in-commuting flows.

(a)



(b)