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By

GRANT FLEMING
(CONTINUITY CAPITAL PARTNERS)

FRANK LIU
(UNIVERSITY OF WESTERN AUSTRALIA)

DAVID MERRETT
(UNIVERSITY OF MELBOURNE)

And

SIMON VILLE
(UNIVERSITY OF WOLLONGONG)

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THE AUSTRALIAN NATIONAL UNIVERSITY
ACTON, ACT 2600, AUSTRALIA
Tel: +61 2 612 53368
Email: tim.hatton@anu.edu.au
Website: https://rse.anu.edu.au/research/centre-economic-history

Australian Innovative Activity and Offshore Technology 1904 – 2016

GRANT FLEMING, FRANK LIU, DAVID MERRETT, AND SIMON VILLE*

Author Affiliations
* Corresponding Author: Simon Ville, University of Wollongong: sville@uow.edu.au
Grant Fleming, Continuity Capital Partners; Frank Liu, University of Western Australia; David Merrett, University of Melbourne

Abstract

Australia has been a large consumer of patented offshore technology, which has led several authors to criticise the domestic innovation system. We deploy a new dataset of 1.4 million patent applications across a century to evaluate empirically this perspective. Our results reveal that Australians held an important though diminishing share of patents and indicate the shifting contribution among other nations. Using revealed technology advantage, we show that local patenting focussed on areas key to the growth of the Australian economy.

JEL classifications

O13, O31, N77

Keywords

Innovation System; Patents; Revealed Technological Advantage; Australia; Natural Resources

Introduction

Endogenous growth theory focuses on the importance of human capital, creativity and innovation in economic growth (Romer 1986, 1994; Sachs 1997; Acemoglu 2009). Various types of knowledge creation contribute to economic growth in different ways and through alternative mediums, for example individual creativity compared with corporate knowledge production or domestic inventive activity versus knowledge from overseas. It is a common axiom of economic history that innovation has played a critical role in the economic development of many nations, particularly through its impact on productivity (Clark 2007). A substantial historical literature on the role of innovation in the economic development of nations has focused principally on major industrial economies particularly the United States and the United Kingdom where new manufacturing sectors drove historical phases of economic expansion (David 1975; Inkster 1991; Khan & Sokoloff 2007; Lamoreaux & Sokoloff 1999; Mokyr, 1992, 2002; Mowery & Rosenberg 1991). A growing literature on patent activity, as a proxy for innovation, has provided a quantitative edge to historical scholarship. This has focussed largely on a similar set of nations, which have generated the bulk of global patents including Germany (Streb et al 2006; Burhop 2009), Britain (Dutton, 1984), USA (Lamoreaux & Sokoloff 2001), and several comparative approaches (Inkster 2003; Khan 2013; Diebolt & Haupert 2016). A recent literature survey called for more quantitative research on innovation across a broader geographical range of nations, particularly those who have primarily been recipients of foreign patents (Streb 2016; Andersson & La Mela, 2020; Beatty et al. 2017).

Australia provides an instructive context for the study of innovation. It has followed an atypical path of successful development through a specialisation on natural resource industries, particularly agriculture and mining (Ville & Wicken 2013). The resource curse hypothesis of development economists holds that this form of development is unlikely to prove successful due in part to the perception of limited opportunities for innovation in primary industries (Van der Ploeg 2011). Similarly, much of the economic history literature views these industries as merely providing the preconditions to modern economic development, which would be based on new, innovation-rich manufacturing industries (Wrigley 1988; Landes 2003; Clark & Jacks 2007). By contrast, Australia's story is one of successful economic development in the twentieth century although not without a few wrong turns along the way (McLean 2013; Dyster & Meredith 2013).

Several broad studies of innovation in colonial Australia have discussed the role of knowledge transfers from the UK (Todd 1995; Raby 1996; Inkster 1990; Magee 2003, 2015). In addition, Magee (1996; 1998; 1999) has pioneered research on patent activity in pre-Federation Victoria. His principal finding is that the gradual reduction over time in the dominant share of domestic patents and their narrow spread across industries reflected a focus of domestic innovation in areas of comparative advantage rather than a relative decline of the local innovation system.

We extend Magee's work by examining innovation in post-Federation Australia. Colonial Australia with its set of small developing economies and local individual inventors gave way to a larger, more diverse and complex nation, with a wider range of international partners, whose sources of inventive activity are much less well understood (Dyster & Meredith 2013). As the Australian economy diversified, it drew increasingly on international technology particularly in newly emerging industries such as automobiles and information technology. The conventional wisdom holds that Australia's technological performance lagged other countries around the world, especially in the industrial sphere. Local firms often chose to licence foreign technology or, if a subsidiary of an overseas parent, simply adopted that technology rather than commit resources to domestic innovation (Schedvin 1987; Mellor 1958; Stubbs 1968). Thus, Australia was a keen consumer of patented technology from offshore.

This raises a similar question to that addressed by Magee for colonial Victoria: do these trends point to the poor state of Australia's domestic innovation system? We address this question in two stages. We estimate and analyse the annual volume of patents issued in Australia across the twentieth century, distinguishing local inventions from those of the main overseas nations patenting in Australia. We then deploy the Revealed Technological Advantage (RTA) technique to analyse more closely in which technologies and industries Australian inventiveness was concentrated. A new database of patents recently made available by IP Australia permits this first detailed empirical analysis into the role of innovation in the Australian economy throughout the twentieth century.

Patenting in Australia

Patenting in colonial Australia was complex. Prior to Federation, there was no unified patent system. Each colony based their laws on UK legislation but operated independently (Magee 1996). Therefore, a patent had to be registered in each colony to protect the invention, an exercise complicated by differences in patent laws and practices in each colony. As a result, many patentees focussed on protecting their invention in the two largest markets, namely Victoria and New South Wales, and left the technology unprotected in the other colonies (Magee 1996; 1998; 1999; 2015). Similar to the USA, the UK, and Europe, the development of the market for technology required a network of actors and institutions to facilitate innovative activity including financiers, publishers, and patent attorneys (Andersson & Tell 2016). Patent agents in Australia played a critical role in drafting and guiding applications through the patent office, providing legal advice, and promoting cross-jurisdictional patenting (Magee 2015: 145-6).

Colonial Victorian inventions were largely to be found in areas such as agriculture, dairying machinery, construction and general mining equipment, carriage and coaching making, and household products; areas "which, in general, did not require … formal scientific or technological know-how" (Magee 2015: 131). Australia's "great inventors", mostly men, included many engineers but also a broad range of occupations including farmers, teachers and shopkeepers (2015: 135-6). Therefore, Magee (1999) has presented important evidence of patenting activity in a major jurisdiction, which provides valuable insights into the colonial Australian innovation system and its relationship to economic development.

By comparison, our knowledge of patenting in post-Federation Australia is scant. There are several intimations of prospective change from the late nineteenth century. By the late 1880s Australia was becoming part of an international patenting market in which patent agents shared information with colleagues overseas and helped to promote international technology transfer (Magee 2015). Big business and foreign enterprise were becoming more important to the Australian economy (Ville & Merrett 2020). Large American global companies, often products of the new industries of the Second Industrial Revolution, were developing internal R&D capabilities within corporate research departments (Chandler 1990). Magee draws attention to the growing prominence of corporate patent applications, particularly by foreign companies, by the final decades before Federation. Finally, science policy and public research institutions began appearing on the horizon by the start of the twentieth century. The Advisory Council of Science and Industry in 1916 – the original form of the Council of Scientific and Industrial

Research (1926-49) and the subsequent Commonwealth Scientific and Industrial Research Organisation (CSIRO) - was established in 1916.

Federation in 1901 brought in its wake a series of national institutions to replace those of individual states. A Federal patent system replaced the colonial practices through the provisions of the 1904 Patents Act. It simplified the process and cut the cost of patenting by establishing a single system and application. Applicants wishing to protect their patent across Australia could now complete a single registration instead of up to six separate ones each with differing conditions such as the length of the patent. The Commonwealth Patent Office was established in Melbourne and began registering patents on 13 February 1904. Patent agents, now termed patent attorneys, continued to play a central role (Hack 1984: 82-5). Existing State patents were recognised under the new regime, and could be re-registered on expiry. Victorian patents, for example, lasted 14 years, therefore Commonwealth registrations in the early years of the office were a combination of new national and the renewal of older State patents.

Data Description

A new dataset on patent applications from the beginning of the Commonwealth Patent Office in 1904 has recently become available – The Intellectual Property Government Open Data (IPGOD) – released by IP Australia. IPGOD covers registry data on all IP rights administered by IP Australia totalling over 1.4 million patent applications 1904-2016. It also provides information about the applicants who filed these IP rights, to allow for research and analysis at the regional, business and individual level (Mita-Khan et.al. 2016). Very few economic historians have used this database.

In order to compare with the colonial period and further extend the length of the series, we have merged the IPGOD data for the twentieth century with Magee's for colonial Victoria. While there is obviously a discontinuity in data sources in 1903-4, we believe that the Victorian colonial data provides a good proxy for Australia. To begin with, as noted above, many applicants focussed on registering their patents with Victoria and New South Wales as the principal jurisdictions. In addition, Victorian patenting was considered more beneficial to the applicant than in NSW, which may explain the former's higher number of patents (Magee 1996: 38; Khan 2013: 48).

While there is an extensive international literature analysing patent data, we should be briefly reminded of some of the shortcomings of patents as a proxy for invention and innovation (Streb 2016; Griliches 1998; Magee 1996; Pavitt 1985). Patents are not homogeneous – in extremis, some may represent a major breakthrough (macro-innovation), others may be a dismal failure. Some inventions may not be patentable, for example the organisational innovations that led to the emergence of modern managerial structures in large firms in the late nineteenth and early twentieth centuries (Chandler 1962). In other cases, the inventor may choose not to patent their invention to maintain secrecy about it or because they knew it would be difficult to imitate. The propensity to patent also varies across industries. Several studies have sought to address the problem of heterogeneity by using the length of the period of a patent as a proxy for quality, focusing on only those that survived for more than ten years (Streb et al 2006; Degner & Streb 2013).

The costs and benefits of patenting vary between jurisdictions, which will also influence the propensity to apply for protection. In our case, the data benefits from being the product of a single jurisdiction and process among all of the Australian states. It also provides consistency across foreign registrations whose own domestic patenting rules would vary from one to another. On the other hand, the decision to seek patent protection by foreign entities could be subject to a range of additional considerations that may limit the rate of registration compared with the domestic patentee (Bertin & Wyatt 1988). Khan's comparative study of patent systems to the early twentieth century suggests that patenting in New South Wales and Australia was of relatively low cost for foreigners and provided them equal treatment with domestic patentees (Khan 2013: 44).

Despite these various shortcomings, however, patents provide very rich quantitative and qualitative data and point to the likely degree of inventiveness of a society and in which sectors it has focussed those endeavours.

Trends in patenting

Figure 1 reveals a gradual rise in the annual number of patents registered in Australia up to World War Two, briefly interrupted by the interwar depression, from an average 1,726 patent registrations per annum between 1904 and 1920 to 2,815 between 1930 and 1945. Thereafter, patent numbers grew more rapidly, save for temporary downturns in the early 1970s and 1990s, and in the last few years to reach an average of 33,896 patents per year between 2010 and 2016. We can also see that the rate of growth of patents in the twentieth century was faster than that of real GDP.[1]

FIGURE 1

ABOUT HERE

[1] A vector autoregression between the first differences of patent registrations and real GDP indicates that real GDP Granger Causes patent registrations. This result is similar to that found by Greasley and Oxley (2010) for New Zealand (1961-1939). See also Greasley and Oxley (2007).

In colonial Victoria, domestic patents accounted for nearly two-thirds of the total across half a century but the local share was in decline as we can see in Figure Two. In the twentieth century, the domestic share of patents decreased from around 60% in the 1920s to less than 20 per cent by the 1970s, only to increase again to around 30% within a decade. The increase in the total number of patents after World War Two coincided with the growing internationalisation of the Australian economy, particularly in terms of foreign direct investment. Nor were the tyranny of distance and the smallness of the Australian market the constraints on foreign patenting that they had been before about 1920 (Khan 2013: 55). .

FIGURE 2

ABOUT HERE

Table 1 provides a detailed quinquennial picture of the leading five foreign sources of patent applications in Australia and compares this with domestic innovation. The UK was the largest source of patent applicants in the early twentieth century. By the eve of World War Two, however, the US had caught up with the UK as the principal source of patents and thereafter has emerged as the dominant source while Britain's contribution has fallen to quite low levels. By the 1990s the United States accounted for nearly one-third of all patent applications in Australia, while no other nation provided as much as 10 per cent. Of other notable contributors, Japan and Germany became of growing importance in the 1970s. This is consistent with the picture of the sustained leaders among foreign patentees in Germany for the earlier part of the period (Degner & Streb 2013: 25-6). Significantly for Australia, all of these nations have focussed their economic expansion on the growth of manufacturing for most of the century.

TABLE 1

ABOUT HERE

Revealed Technological Advantage

The propensity to register a patent in Australia is measured by the Revealed Technological Advantage (RTA) index, which enables a closer look at a nation's innovativeness than is possible by evaluating the raw patent data. RTA is defined as a nation's share (per cent) of patents in a particular sector or technology class divided by its share (per cent) of total patents. Specifically, RTA_{ij} is defined as follows:

$$RTAij = (\frac{Pij}{\sum_i Pij})/\frac{\sum_j Pij}{\sum i \sum_j Pij}$$

Where P_{ij} is the number of patents registered by country *i* in technology field *j.* The RTA is used in technology studies because it normalises the number of patents for cross-sectoral and cross-national group variations, and variations over time (see Soete 1987; Cantwell 1989, 1991; Cantwell and Vertova 2004; Patel & Pavitt 1994). The RTA index has a lower bound of zero, and in principle no upper bound. A RTA greater than 1 indicates that a country has a RTA, or competitive advantage, in that area of technology.[2]

The IPGOD database categorises patents according to the World Intellectual Property Organisation's International Patent Classification (IPC) which "…provides for a hierarchical system of language independent symbols for the classification of patents and utility models

[2] Cantwell and Vertova (2004: 515) note that RTAs calculated over a small number of patents can lead to skewed distributions whereas RTAs calculated over larger number of patents resemble normal distributions. We calculate RTAs over five-year periods in order to increase the sample size for each country and avoid skewness in RTAs.

according to the different areas of technology to which they pertain."[3] Each patent filer can identify a primary and a number of secondary uses for their innovation and the IPC code will be assigned by the relevant national authority (in Australia's case, IP Australia). We deploy both the primary and secondary uses patent data in our analysis. There are 8 major technology sectors or IPC classes disaggregated into 22 subclasses (and further disaggregated within subclasses). Any categorisation of technology classes will suffer from a degree of unevenness due to the differences in the propensity to register patents across classes and because the breadth of coverage of technologies covered in any defined class will vary (Cantwell & Vertova 2004: 514-15).

As noted above, the IPC classes are based on the type of innovation not its applicability to a particular industry. Therefore, a patent in hydraulic engineering can include a technique for soil shifting (IPC class E – Fixed constructions) but be used primarily in the mining sector. Thus, our analysis of patents using IPGOD does not fit neatly into industry codes such as the Australia and New Zealand Standard Industrial Classification (ANZSIC) codes. This mismatch is commonly encountered in empirical work on other nations (Streb, Baten, and Yin, 2006). To address the problem, we have examined evidence from the leading patentees in particular IPC classes and across different sub-periods, which will help identify the industries to which patents relate.

There were 1.38 million patent registrations between 1920 and 2016 which in aggregate filed for patents in 4.2 million primary and secondary IPC classes. The IPGOD100 file contains data on the country of patent filer, but in the earlier years also had a large number of observations where country was not identified. In order to maximise the sample size by country we merged

[3] https://www.wipo.int/classifications/ipc/en/. Accessed 23 August 2021 at 18.03.

IPGOD100 with dataset IPGOD129, which records patents registered in Australia which were first registered overseas (foreign transfers). For patent registrations with an unassigned country code under IPGOD100, we matched the Australian Application Number in IPGOD100 to the Australian Application Number in IPGOD129. If the patent is a foreign transfer and has an identified country of origin, we assigned the observation to that foreign country code.

The data set biases the RTA analysis against Australia and towards foreign patent registrations, as the remaining unassigned patent registrations (which are excluded from our analysis) are either Australian patent filers or offshore patent filers which first filed the patent in Australia (for example, a foreign national or foreign entity). A casual examination of these patent registrations by name indicates that the majority are individuals and are located in the first half of the twentieth century.

The data is organised by 5-year spans, from 1920 (the first year of available IPC class data) and ending in 2016 (after which IP Australia made major changes to the availability of data on patentees in the IPGOD database).

TABLE 2

ABOUT HERE

Table 2 summarises the RTA results for Australian and the ten largest offshore country patent filers. The number of IPC subclasses in which Australian RTAs were to be found was initially similar to the nineteenth century but then fell from the mid 1930s to the end of the 1960s. The results suggest a reduction in the number of areas in which Australia held a technological advantage – the only consistent RTAs were to be found in physics and electricity. Thereafter, the number of Australian RTAs rose appreciably and was higher than that of foreign nations for the remainder of the period. This growth in the number of areas of technological advantage occurred despite the domestic share of total patents declining, as we saw above.

The increased number of RTAs later in the century was not at the expense of a focus on those subclasses in which Australia held a technological advantage. The second column for each country in Table 2 shows the number of IPC technology classes where a country registered a patent. Dividing the number of RTAs by the number of IPC technology classes shows that Australia had an RTA for most subclasses in which any patents were registered (i.e. at least 50 per cent of IPC technology classes). This was especially the case towards the beginning and end of the century. Australia had nine quinquennials where RTAs existed in more than 50 per cent of those classes in which a patent was registered. The US, despite its dominance of total patents, showed slightly less focus on its areas of advantage (eight quinquennials above 50 per cent). Of the remaining leading offshore patenting nations in Table 2, only Canada and New Zealand – both resource-based economies – had more quinquennials than Australia where RTAs exceeded 50 per cent.

Table 3 provides evidence of which technology classes Australia and the ten largest offshore patent registration countries held an RTA and how sustained was that advantage. The shaded cells show those technology classes in which a country held an RTA in more than 50 per cent of quinquenniums.[4]

TABLE 3

ABOUT HERE

[4] Specifically, there are 19 periods comprising 18 quinquenniums (1920-2014, excluding 1940-44) and 2015-16.

Scholars have suggested that countries may have path dependent technology profiles, especially smaller economies, and this seems to be borne out by Australian experience (Patel and Pavitt 1994; Cantwell 1989; Vertova 1999). In three categories – agriculture, building, and physics – Australia maintained an RTA for most of the period under review particularly during the earlier and later decades.[5] Of these, agriculture represents one of Australia's principal areas of sustained comparative advantage in international trade. Building on its wool legacy of the colonial period, meat, dairy, wheat, and seafood have also become important sources of more diversified export income since Federation (Dyster & Meredith 2013: 67, 142, 191). CSIRO was an important patentee finding solutions to a wide range of challenges for primary producers including in the areas of biological weed control, parasites in livestock, and the development of trace elements for soil quality (Schedvin 1987; Collins 2002). This was particularly the case after World War Two; our results show it to have been the largest patent filer for every subsequent decade except the 1980s. In an era when the individual farmer-inventor, typical of colonial Australia, was no longer a match for the larger scale and scientific nature of research, the fragmented pattern of farm ownership created a potential for market failure that was addressed by public bodies.

The persistent RTA in building, particularly after 1960, can be mostly attributed to filings made by large firms working in housing, commercial and infrastructure construction, a largely non-tradeable sector dominated by domestic firms. Leading patentees included Assa Abloy (building locks and security), John Lysaght (steel construction products), CSR (building products) and Caroma (bathroom fittings). The rapid expansion after World War Two of the

[5] Australia also held an RTA>1 in Microstructural technology and nanotechnology for 4 out of 5 periods, between 2000-04 and 2015-16.

demand for housing and commercial premises along with the development of major infrastructure programmes to modernise the expanding economy and alleviate congestion primarily lay behind this innovativeness. Some companies filing in this sector were also applying their expertise to the mining industry in areas such as conveyors and cables.

The physics RTA was mostly associated with the subclasses ‘Measuring and Testing (40%) and ‘Computing, Calculating or Counting’ (26%). To understand more clearly what types of firms were filing Australian patents, we cross-matched ‘Measuring and Testing’ with the name of the patentee. The top 20 out of 2,651 Australian filers (total 10,990 patents) registered as much as 30% of all patents, particularly CSIRO (7%), universities and research institutes (6%), telecommunications companies Standard Telephone & Cables (STC) and Amalgamated Wireless Australasia (AWA) (9% combined), and mining companies (Rio Tinto, BHP, Minelab) (2%). The results suggest that physics patents were particularly associated with the domestic electricity, communications, and mining industries and the work of the CSIRO. Australia also periodically held an RTA in the electricity class, most of which came under the subclasses of ‘electronic communication techniques’ (46 per cent) and ‘basic electricity elements’ (33 per cent). As with physics, the primary patentees were CSIRO and the leading telecommunications companies, which also points to the rise of general purpose technologies associated with the electricity and communications industries. In particular, AWA and STA were leaders in the introduction of telephony and wireless communication (Given 2017). AWA continued to be a leader in communications throughout the century, for example in radio, television, aeronautical navigation, defence electronics and fibre optics, all of which generated patents. Public sector organisations supported private industry innovations, outstandingly the development by the CSIRO in the 1990s of ‘wifi’ (CSIRO).

In addition to the classes mentioned above, there was a strong rise in the number of new RTAs from the 1960s, particularly in activities related to engineering where there was a high propensity to patent new technologies: transporting; engines/pumps; general engineering; earth, rock drilling; heating, lighting; and weapons/blasting. Closer inspection of the pattern of patenting within these sectors points to a strong association with the mining industry. Francis (2015) examines patent activity and innovation in the Australian mining industry between 1994 and 2011. Mining technologies resulted in patents in a range of IPC subclasses including those in which Australia held an RTA. For example, autonomous vehicles in mining patents were filed in B (transporting), E (mining) and G (physics).

In the first half of the twentieth century, Australian public policy was oriented towards broadening the industrial base of the economy, particularly to bolster manufacturing. Protectionism was the main tool of policy. By the 1960s this experiment appeared to have failed, particularly as Australia faced increasing competition from low cost regional competitors. In the following decade, tariffs began to be wound back. At the same time, newly industrialising economies, particularly Japan, presented fresh opportunities for Australian-based mining companies. New technologies and changing polices presented opportunities to develop a wider range of resources and new fields of exploration. These included the development of the Pilbara iron industry, and the expansion of bauxite, nickel, natural gas and petroleum. Mining's share of GDP and exports rose while investment in the sector increased sharply as a percentage of GDP (McLean 2013: 231). David Lee's major study of the Australian mining industry of this period is entitled, *The Second Rush* (2016), while Ian McLean (2013, ch 9) identifies mining as an important source of prosperity for Australia. Mining was the sector with the most rapidly growing labour productivity, particularly in the second half of the twentieth century (Madsen 2015: 41-2).

The success of the modern mining industry was reliant upon high levels of innovation. A key trend, beginning in the 1960s, has been the growth of an outsourced model where the major mining companies have become largely project managers and used third-party firms for most parts of the supply chain. Some of these firms have evolved to serve the mining sector, while others have brought technological knowhow developed elsewhere and applied it to the expanding mining sector. Changes in regulation, for example, have attracted technology firms to the sector; worker safety has generated technology around clothing, soil stability, blast location, and underground communications. Cooperative Research Centres were also highly innovative as forms of public-private cooperation. Major Australian private sector mining patentees included BHP and Rio Tinto (IP Australia 2019).

Specialisation, Concentration and Complementarity

Our broad knowledge of the technological capabilities of the main foreign innovators suggests their specialisations have generally differed from Australia. Cantwell (2000), for example, noted that there was distinct technological specialisation by the interwar period for the USA (vehicles; transport; food and drink' electrical equipment' coal/petroleum), Germany (chemicals; pharmaceuticals; scientific equipment; engines), UK (food and drink; chemicals; mechanical engineering; transport (e.g. aircraft); rubber and plastics) and Switzerland (pharmaceuticals; chemicals). This is consistent with what we know of the economic and business history of these nations in the twentieth century and with the technology class overlaps we identified above for Australia and these main technology producers.

To more formally examine the degree of technological specialisation or concentration for each nation's patent activity in Australia, we use the reciprocal of the coefficient of variation (see Cantwell and Vertova 2004). Specifically, we define 1/CV (coefficient of variation) as follows:

$$\frac{1}{CV_{RTAi}} = \frac{\mu_{RTAi}}{\sigma_{RTAi}}$$

Where μRTAi is the mean of the RTA distribution of country *i* across technology sectors for each quinquennial period, and σRTAi is the standard deviation of the RTA distribution for country *i* across technology sectors for each quinquennial period. A low value of 1/CV indicates that country *i* has a concentration of RTAs in few technology classes in Australia. By contrast, a high value of 1/CV indicates a more diversified technology relationship between country *i* and Australia.

Figure 3 and Appendix Table A1 report 1/CV values for the top five offshore patent filing countries and top ten offshore patent filing countries. The level of technological diversification was either low from the beginning (Australia, Germany Japan, Switzerland) or was falling over time (UK, US), both of which point to technological specialisation by each country. This is consistent with prior research that generally indicates greater concentration of innovative activities by countries as the twentieth century developed (Cantwell & Vertova 2004).

FIGURE 3

ABOUT HERE

Next, we calculate cross country correlations of RTAs, comparing Australia as the host with overseas innovators (Patel and Pavitt 1994). If there is no correlation, then the countries have different patterns of specialisation. Positive correlations indicate similar patterns of specialisation. Negative correlations indicate complementary patterns where the recipient country draws on the overseas country for technology in particular fields. Table 4 reports correlation coefficients between Australian and the ten country RTAs. Notably, Australia had a different pattern of technological specialisation to most countries prior to 1940, with no correlations significant. From the 1970s, significant negative correlations are found between Australian RTAs and US RTAs indicating that Australia drew on the US for a range of patented technologies where it did not have technical proficiency. There are also examples of five-year periods where UK and Swiss RTAs were negatively correlated with Australian RTAs.

These results are consistent with Patel and Pavitt's for 18 OECD countries during 1963-8 and 1985-90, which show that Australia's only positive correlations (at 5%) of technological specialisation were with other resource-based economies Canada, Finland and Norway in raw material-based technologies (Patel & Pavitt 1994: 767-70). Our results similarly show positive correlations largely with Canada and New Zealand. In particular, positive, significant correlations existed with New Zealand – an economy focussed on primary industries - for most of the period of our study with the exception of the mid 1930s to the 1960s. Weaker positive correlations existed with Canada for much of the 1970s to 1990s.

TABLE 4

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Conclusions

We locate our paper within an existing literature on the importance of knowledge as a driver of growth and the use of patents as a measure of innovative activity. It responds to the call for broader empirical work on innovation and patenting, and specifically extends our knowledge of colonial Victoria into twentieth-century Australia. By the start of the twentieth-century, the newly-federated nation of Australia had already gone through rapid expansion of its primary industries and might have been expected to progress to becoming a modern industrial economy. It did not and instead remained largely a natural resource economy. In the eyes of some it would be feted to be a low income economy lacking the sparks of technology-driven industrial growth, a destiny apparently confirmed by a heavy consumption of offshore patents. In fact it became a highly successful and wealthy resource-based economy along with the likes of Norway, Finland, New Zealand and Canada. Our paper has addressed the technology conundrum in this story – why was a resource-based economy with an apparently weak innovation system so successful?

We have interrogated a century long data set of patents in Australia, identifying the industry applications of many of these patents and separating out local from foreign patentees. The falling domestic share of total patents reflected Australia's participation in an increasingly global innovation market where even the USA's domestic share in its own national patent system declined significantly (Khan 2013: 59). Our results point to the clustering of domestic patents in several sectors that were critically important to the economic development of twentieth-century Australia, notably agriculture, mining, building, electricity and telecommunications. Domestic RTA was strong in these sectors, suggesting well-founded specialisation of innovation. Foreign technological leadership in Australia shifted during the twentieth century, with Australia relying relatively less on Great Britain and more on technology from USA, and to a lesser degree Japan and Germany. These patents were spread across sectors where Australian firms were unlikely to develop a strong comparative advantage. Thus, while Australia was indeed a large consumer of offshore patented technology in an era of growing international technology transfer, domestic innovativeness complemented that from overseas and was concentrated in several key areas of the Australian economy.

These results are largely consistent with Magee's findings for the appropriateness of domestic patenting in colonial Victoria. They concur with broader empirical studies that technical advantage is shaped by a nation's stage of economic development and, specifically, where there are plentiful natural resources, the focus is strongly on these sectors (Degner & Streb 2013: 32-3). By extending Magee's work into the twentieth century, our results are consistent with inferences from Cantwell (1989) that shifts in national technological orientation is a relatively long game. However, there were changes as well as continuity in the patterns of innovation and growth – Australia's resource-based industries became far more reliant on advanced technologies than in the colonial era, which has enabled much more diverse production, particularly in mining after 1960. Large corporations in these primary industries were well placed to undertake research into new technologies often supported by public sector bodies – CSIRO and the universities. It may well be that public sector innovation has been a distinctive element shaping the modern innovation system in Australia and boosting the quantum of research and development (Treasury 2005, Chart 1). Future research might, therefore, focus on the growing and cooperative role of public sector bodies alongside leading corporations.

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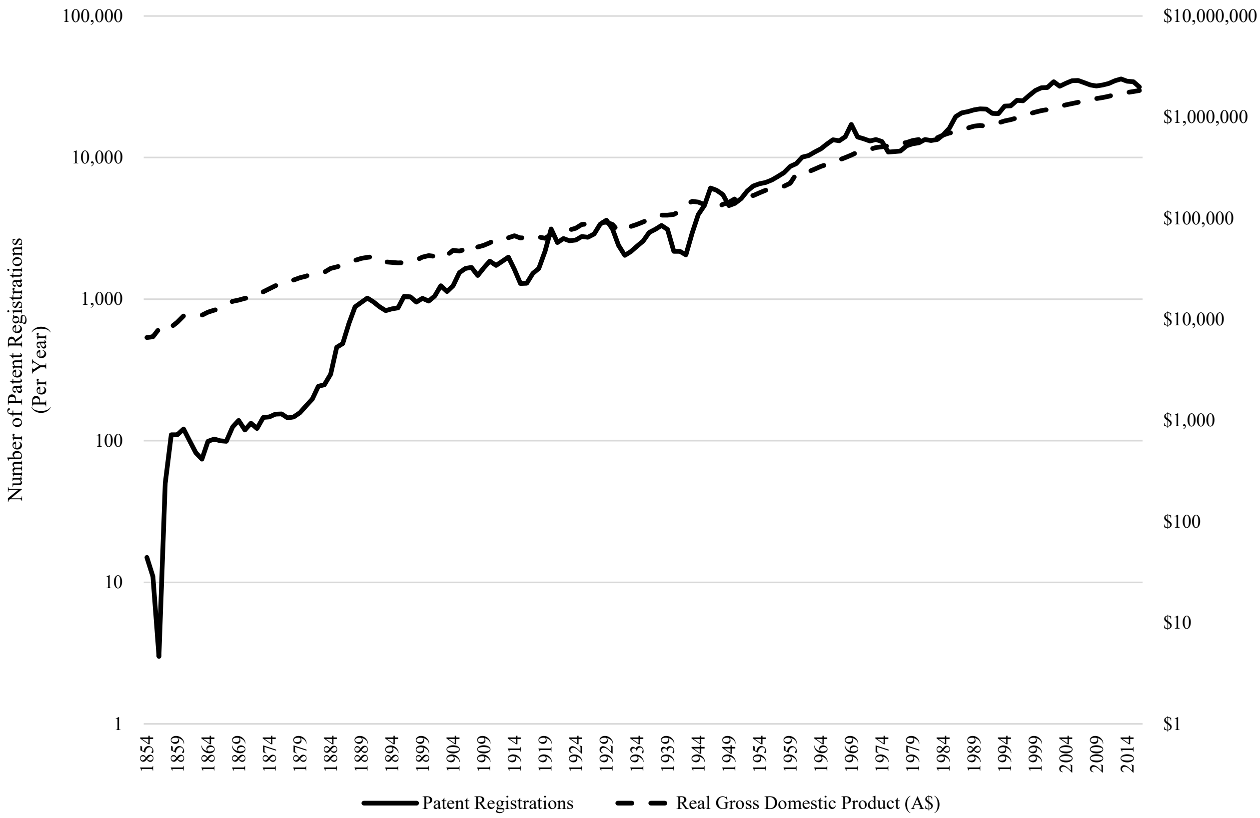
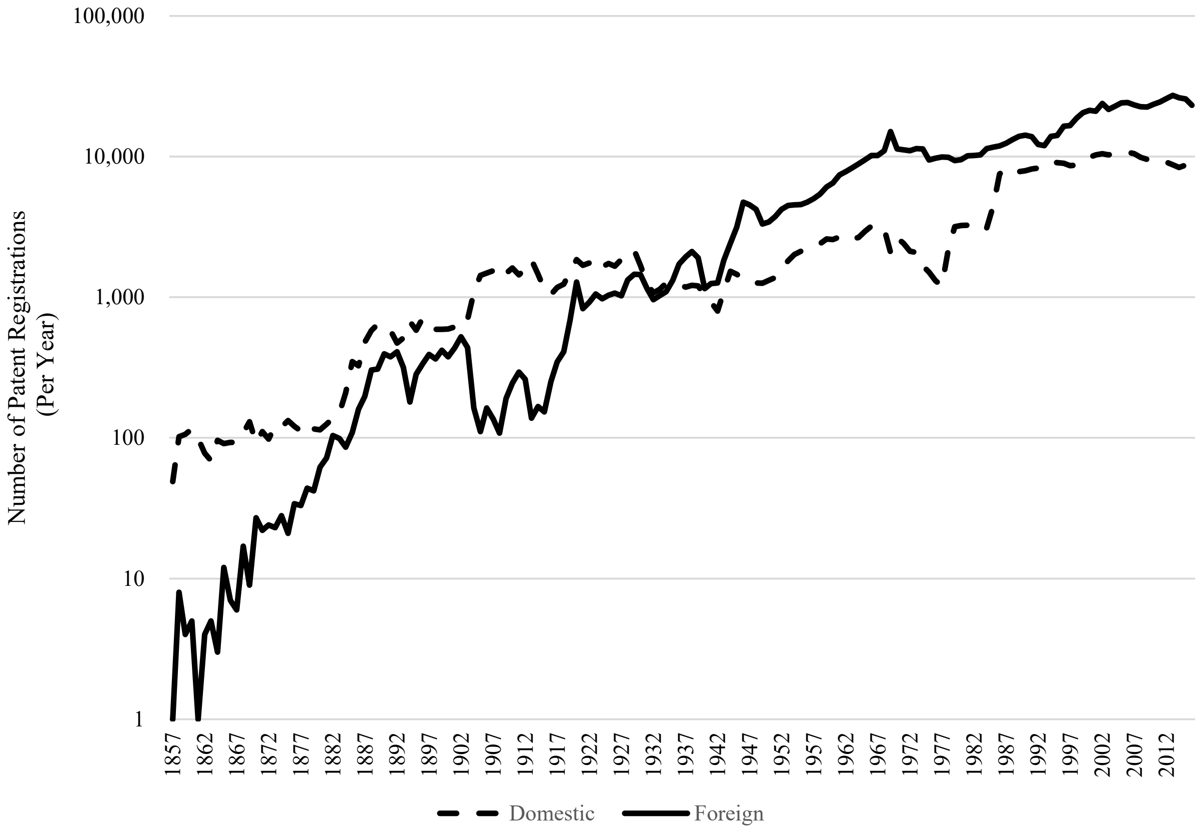
Figure 1 Total patents and GDP (log scale), 1854-2016



Notes: Magee (1996) 1854-1903 Victoria; 1904-2016 IP Australia
Legend: Left hand-side: Number of patent registrations per year, log scale. Right hand-side: Real gross domestic product (A$ millions), log scale.

Figure 2 Domestic and Foreign Patent Applications, 1857-2016



Notes: Magee (1996, 1999) 1857-1903 Victoria; 1904-2016 IP Australia

Legend: Number of patent registrations per year, log scale

Table 1 Patent Activity by Country and Time Period, 1857-2016

Year	AU	Percent	UK	Percent	US	Percent	DE	Percent	JP	Percent	CH	Percent	Other	Percent	Total
1857-1903	14,075	66%	3,113	15%	1,910	9%	218	1%	2	0%	14	0%	1,872	9%	21,204
1920-24	8,472	63%	453	3%	132	1%	29	0%	3	0%	4	0%	4,433	33%	13,526
1925-29	9,468	62%	1,248	8%	1,003	7%	271	2%	6	0%	24	0%	3,357	22%	15,377
1930-34	6,406	53%	1,621	13%	1,560	13%	546	5%	6	0%	26	0%	1,924	16%	12,089
1935-39	6,081	40%	2,399	16%	2,317	15%	1,448	10%	12	0%	70	0%	2,741	18%	15,068
1940-44	5,374	40%	2,415	18%	3,546	27%	29	0%	1	0%	63	0%	1,867	14%	13,295
1945-49	6,672	25%	4,532	17%	5,634	21%	28	0%	-	0%	174	1%	9,591	36%	26,631
1950-54	8,107	28%	5,481	19%	5,313	19%	765	3%	3	0%	424	1%	8,413	30%	28,506
1955-59	11,679	31%	8,286	22%	9,529	25%	1,530	4%	41	0%	890	2%	5,533	15%	37,488
1960-64	13,048	25%	9,565	18%	16,938	33%	2,855	5%	397	1%	1,387	3%	7,769	15%	51,959
1965-69	14,233	20%	9,820	14%	22,721	32%	4,446	6%	1,633	2%	1,495	2%	15,802	23%	70,150
1970-74	10,920	16%	7,873	12%	19,914	30%	4,461	7%	3,521	5%	1,577	2%	18,814	28%	67,080
1975-79	9,422	16%	5,089	9%	16,339	28%	3,651	6%	3,881	7%	969	2%	18,392	32%	57,743
1980-84	15,757	23%	6,936	10%	21,745	32%	5,332	8%	6,082	9%	1,315	2%	10,063	15%	67,230
1985-89	35,982	36%	7,939	8%	27,615	28%	6,001	6%	8,172	8%	1,368	1%	12,012	12%	99,089
1990-94	42,037	39%	7,231	7%	32,225	30%	5,053	5%	7,414	7%	1,215	1%	12,880	12%	108,055
1995-99	44,469	34%	7,273	6%	44,221	34%	6,226	5%	8,067	6%	1,051	1%	19,551	15%	130,858
2000-04	51,479	32%	7,960	5%	60,816	38%	7,018	4%	9,133	6%	847	1%	24,806	15%	162,059
2005-09	51,470	31%	7,139	4%	66,377	39%	5,802	3%	8,547	5%	639	0%	28,233	17%	168,207
2010-14	44,213	26%	6,165	4%	74,978	44%	4,283	2%	8,220	5%	525	0%	33,021	19%	171,405
2015-16	17,131	26%	2,107	3%	25,030	38%	1,171	2%	2,374	4%	125	0%	17,929	27%	65,867
Total	412,420	30%	111,532	8%	457,953	33%	60,945	4%	67,513	5%	14,188	1%	257,131	19%	1,381,682

Legend: AU=Australia; UK=United Kingdom; US=United States of America; DE=Germany; JP=Japan; CH=Switzerland.

Table 2 Number of RTA > 1 by Country and Time Period, 1920-2016

Period	AU		UK		US		DE		JP		CH		FR		NL		SE		CA		NZ	
	RTA	IPC	RTA	IPC	RTA	IPC	RTA	IPC	RTA	IPC	RTA	IPC	RTA	IPC	RTA	IPC	RTA	IPC	RTA	IPC	RTA	IPC
1920-24	7	12	9	18	9	17	9	13	1	1	2	2	6	14	2	3	6	7	0	0	10	13
1925-29	9	15	11	20	7	20	7	18	3	5	10	12	9	18	4	9	7	11	5	9	8	17
1930-34	10	15	12	20	8	20	3	18	2	2	7	10	9	18	2	14	9	14	8	9	13	19
1935-39	5	14	15	20	8	20	4	19	3	3	10	18	8	18	5	18	9	14	8	10	11	16
1945-49	2	19	11	20	11	20	6	11	0	0	8	19	8	19	5	17	12	18	8	10	8	16
1950-54	2	20	11	20	11	20	9	19	4	4	6	20	7	20	4	18	12	19	9	18	8	17
1955-59	5	20	12	20	11	20	10	20	5	14	5	20	11	20	6	18	11	20	11	19	9	18
1960-64	7	19	9	20	13	20	10	20	7	18	3	20	12	20	6	20	10	20	9	20	11	18
1965-69	4	20	10	20	12	20	5	20	7	19	5	19	11	20	3	17	14	20	11	17	8	18
1970-74	10	20	12	20	13	21	5	20	9	20	7	20	9	20	4	20	11	20	9	20	10	20
1975-79	13	20	8	20	10	21	4	20	11	20	6	20	8	20	4	19	13	20	9	20	10	18
1980-84	10	20	10	20	11	21	5	21	10	20	5	20	6	20	6	20	13	20	8	20	10	20
1985-89	12	20	10	21	8	22	4	21	11	21	7	21	3	20	7	21	14	21	11	20	11	20
1990-94	14	22	8	21	8	22	5	22	8	21	8	21	5	22	9	21	9	20	12	20	14	20
1995-99	15	21	7	22	8	22	7	21	8	22	9	22	3	22	10	22	6	22	9	22	13	20
2000-04	14	22	9	22	6	22	7	22	9	22	6	22	6	22	7	22	5	22	7	21	14	21
2005-09	14	22	14	22	8	22	11	22	6	21	5	22	7	22	10	22	10	21	13	22	11	21
2010-14	11	22	9	22	7	22	11	22	8	22	6	22	9	22	7	21	12	22	10	22	11	21
2015-16	11	22	11	22	7	22	10	22	10	20	8	21	9	22	8	21	11	20	13	22	9	18

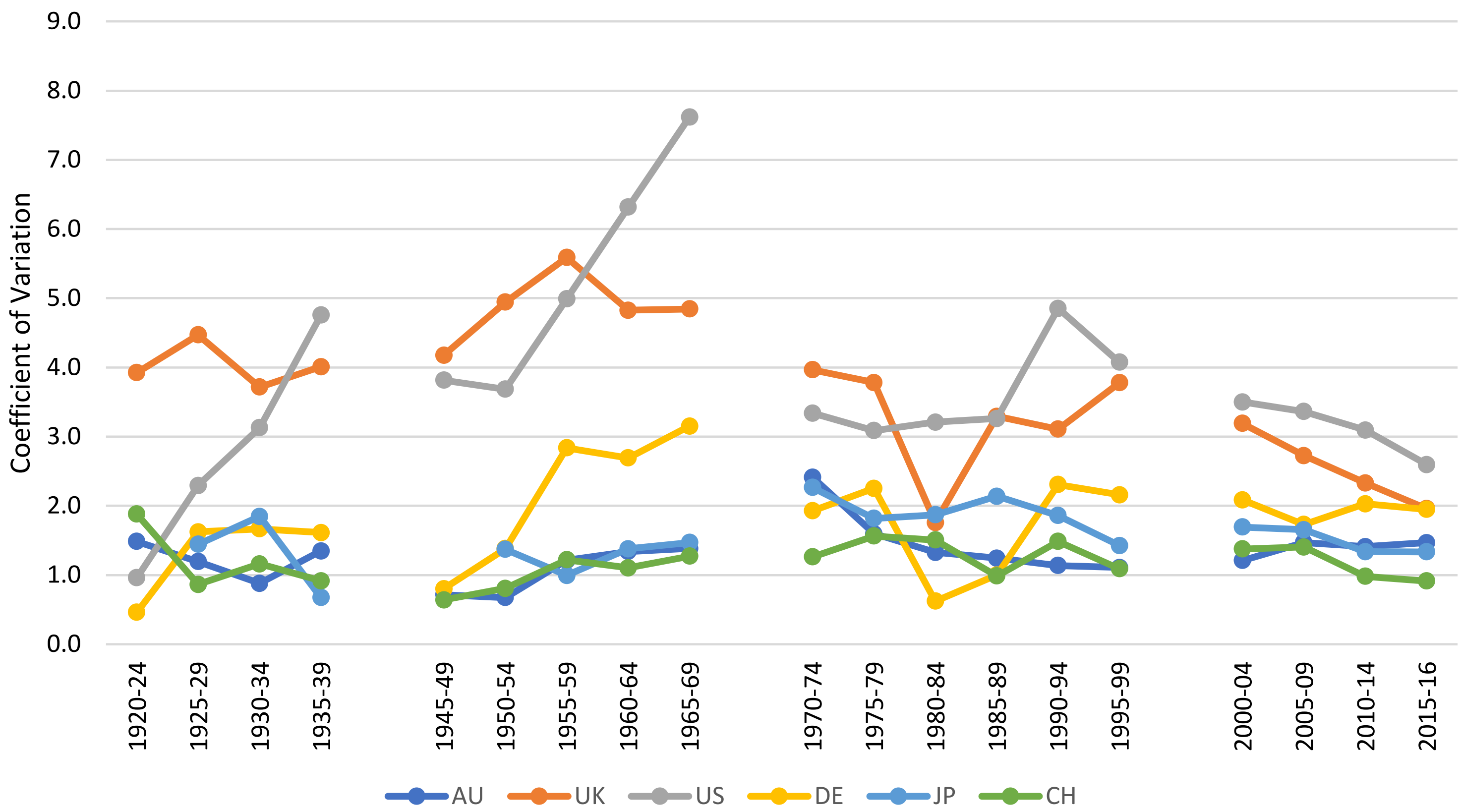
Note: RTA is the number of RTA>1; IPC is the number of IPC Classes in which country X registered patents.
Legend: AU=Australia; UK=United Kingdom; US=United States of America; DE=Germany; JP=Japan; CH=Switzerland; FR=France; NL=The Netherlands; SE=Sweden; CA=Canada; NZ=New Zealand.

Table 3 IPC Technology Classes and RTAs by Country, 1920-2016

IPC Class	AU	UK	US	DE	JP	CH	FR	NL	SE	CA	NZ
01 Agriculture	68%	26%	11%	72%	29%	67%	37%	67%	39%	41%	100%
02 Foodstuffs Tobacco	29%	68%	53%	11%	42%	89%	12%	63%	33%	63%	79%
03 Personal/domestic articles	56%	74%	26%	22%	38%	18%	11%	13%	61%	56%	95%
04 Health, Life-saving, Amusement	17%	74%	61%	41%	21%	88%	67%	0%	76%	40%	44%
05 Separating, Mixing	18%	74%	47%	58%	21%	11%	42%	78%	72%	63%	16%
06 Shaping	56%	42%	53%	32%	64%	17%	53%	11%	83%	75%	58%
07 Printing	53%	58%	47%	37%	100%	56%	16%	7%	13%	14%	59%
08 Transporting	63%	53%	53%	5%	33%	33%	37%	0%	44%	44%	100%
09 Microstructual technology, nanotechnology	80%	17%	88%	43%	17%	0%	17%	25%	75%	100%	67%
10 Chemistry	0%	47%	63%	95%	40%	94%	84%	58%	5%	38%	0%
11 Metallurgy	50%	21%	42%	58%	92%	0%	79%	17%	41%	100%	0%
12 Combinatorial technology	0%	67%	100%	17%	0%	14%	0%	33%	25%	80%	
13 Textiles or flexible materials	6%	89%	32%	24%	62%	69%	22%	24%	38%	20%	72%
14 Paper	13%	17%	89%	28%	15%	44%	39%	33%	100%	63%	18%
15 Building	84%	53%	5%	28%	0%	17%	33%	18%	59%	60%	100%
16 Earth or rock drilling, Mining	56%	33%	79%	13%	0%	0%	43%	62%	100%	100%	8%
17 Engines or Pumps	59%	63%	26%	53%	85%	18%	37%	6%	27%	43%	47%
18 Engineering in general	58%	84%	42%	17%	15%	11%	44%	0%	82%	35%	84%
19 Lighting, Heating	82%	42%	16%	44%	85%	19%	32%	6%	84%	44%	84%
20 Weapons, Blasting	63%	74%	0%	36%	0%	53%	58%	20%	87%	92%	67%
21 Physics	84%	21%	74%	5%	64%	11%	26%	67%	21%	38%	32%
22 Electricity	39%	5%	32%	32%	81%	0%	16%	79%	39%	19%	22%
Count	13	12	10	5	8	7	5	7	11	11	12

Note: Measures percentage of five year periods in which country X had an RTA>1
Legend: AU=Australia; UK=United Kingdom; US=United States of America; DE=Germany; JP=Japan; CH=Switzerland; FR=France; NL=The Netherlands; SE=Sweden; CA=Canada; NZ=New Zealand.

Figure 3 Coefficient of Variation, Australia and Top Five Countries 1920-2016



Legend: AU=Australia; UK=United Kingdom; US=United States of America; DE=Germany; JP=Japan; CH=Switzerland.

Table 4. Correlation Coefficients between Australian and Foreign RTAs by Time Period, 1920-2016

Period	UK	US	DE	JP	CH	FR	NL	SE	CA	NZ
1920-24	-0.49	-0.04	0.49***			-0.10		-0.38		0.45***
1925-29	-0.17	-0.03	-0.37		0.15	0.06	-0.51	0.25***	-0.03	0.37***
1930-34	-0.13	-0.51	-0.52		-0.01	0.34***	-0.21	0.23**	0.34***	0.58***
1935-39	0.06	-0.14	0.00		-0.23	-0.03	0.57***	0.46***	-0.02	-0.13
1945-49	-0.43	-0.25	-0.34		0.01	-0.40	0.38***	-0.28	-0.40	-0.33
1950-54	-0.21	-0.13	-0.37		-0.25	-0.36	0.80***	-0.31	-0.25	-0.06
1955-59	-0.06	-0.41*	-0.29	-0.38	-0.31	-0.05	0.76***	-0.17	-0.30	0.12
1960-64	-0.27	-0.33	-0.01	-0.15	-0.43	-0.02	0.87***	-0.06	-0.08	0.15
1965-69	-0.06	-0.45*	0.36***	-0.07	-0.41*	-0.08	0.77***	-0.32	-0.60*	0.18**
1970-74	-0.18	-0.23	0.05	-0.15	-0.10	0.02	0.61***	-0.10	0.16*	0.41***
1975-79	-0.16	-0.52*	-0.04	-0.04	-0.11	-0.37*	-0.20	0.20**	0.06	0.91***
1980-84	-0.06	-0.79**	-0.12	-0.03	-0.13	-0.35	-0.23	-0.05	-0.08	0.95***
1985-89	-0.33	-0.86**	-0.22	0.06	-0.19	-0.39*	-0.28	-0.13	-0.05	0.84***
1990-94	-0.46**	-0.85**	-0.09	-0.15	-0.20	-0.25	-0.24	-0.21	0.17**	0.77***
1995-99	-0.37*	-0.75**	-0.22	-0.08	-0.17	-0.26	-0.27	-0.19	-0.05	0.82***
2000-04	-0.18	-0.76**	-0.19	-0.17	-0.27	-0.24	-0.24	-0.25	0.01	0.59***
2005-10	0.03	-0.73**	-0.18	-0.19	-0.35*	-0.29*	-0.27	-0.22	-0.22	0.75***
2010-14	0.14*	-0.57**	-0.08	-0.17	-0.29	-0.19	-0.38*	-0.09	-0.19	0.66***
2015-16	-0.01	-0.49**	-0.07	-0.19	-0.21	0.02	-0.20	-0.30*	-0.27	0.48***

Legend: UK=United Kingdom; US=United States of America; DE=Germany; JP=Japan; CH=Switzerland; FR=France; NL=The Netherlands; SE=Sweden; CA=Canada; NZ=New Zealand. Significance levels: *** <1%; **<5%; *<10%.

Appendix Table A1 Coefficient of Variation of RTAs by Country and Time Period, 1920-2016

Period	AU	UK	US	DE	JP	CH	FR	NL	SE	CA	NZ
1920-24	1.48	3.92	0.96	0.46		1.88	1.36	1.31	1.05		1.41
1925-29	1.19	4.47	2.29	1.62	1.44	0.86	1.17	1.11	1.15	0.89	0.95
1930-34	0.88	3.72	3.13	1.67	1.85	1.16	2.13	0.90	0.72	1.02	1.27
1935-39	1.35	4.01	4.76	1.61	0.67	0.92	1.45	1.48	1.19	1.42	1.28
1945-49	0.72	4.18	3.81	0.80		0.64	1.54	1.26	1.28	1.32	1.29
1950-54	0.67	4.94	3.69	1.38	1.37	0.81	2.06	1.11	1.12	0.74	1.13
1955-59	1.21	5.59	4.99	2.84	0.99	1.22	1.37	1.10	1.09	1.41	0.89
1960-64	1.34	4.83	6.32	2.69	1.38	1.10	1.96	1.06	1.04	1.09	0.95
1965-69	1.39	4.85	7.62	3.15	1.47	1.27	2.76	0.99	1.26	1.48	0.90
1970-74	2.41	3.97	3.34	1.93	2.27	1.26	1.67	0.93	1.25	0.81	1.02
1975-79	1.60	3.78	3.09	2.25	1.82	1.56	2.78	1.03	1.08	0.96	0.98
1980-84	1.33	1.76	3.21	0.62	1.87	1.51	2.55	1.24	1.16	1.24	1.07
1985-89	1.24	3.29	3.26	1.00	2.14	0.99	3.35	1.22	0.99	1.41	1.00
1990-94	1.14	3.11	4.85	2.31	1.86	1.48	2.84	1.23	0.98	1.72	1.22
1995-99	1.11	3.78	4.08	2.16	1.43	1.09	2.48	1.82	1.42	1.87	1.16
2000-04	1.21	3.19	3.50	2.09	1.69	1.38	2.23	0.72	2.01	1.99	1.22
2005-09	1.47	2.72	3.36	1.73	1.65	1.40	2.89	1.07	2.03	0.88	1.30
2010-14	1.41	2.33	3.09	2.03	1.34	0.98	2.42	1.46	1.31	0.73	1.46
2015-16	1.47	1.96	2.60	1.95	1.33	0.91	2.34	1.42	1.11	1.27	1.33

Legend: AU=Australia; UK=United Kingdom; US=United States of America; DE=Germany; JP=Japan; CH=Switzerland; FR=France; NL=The Netherlands; SE=Sweden; CA=Canada; NZ=New Zealand.