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Patents, Foreign Direct Investment and Economic Growth in Australia, 1860-2010

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Abstract

We examine the long run relationship between innovation and economic development in Australia, using 150 years of data on patenting activity, and aggregate and sectoral economic indicators. Our initial results point to several important causal relationships, particularly the effects of patents on real GDP and of private capital formation on patents. We delve deeper at the sector level and find important causal relationships of patents with real foreign direct investment (FDI) since World War Two. Australia's dependence on FDI for private capital formation served as an important stimulus for knowledge creation in key sectors including agriculture and mining.

Introduction

History provides a valuable setting for examining the complex, and often long term, relationship between innovation and economic growth. Indeed, it is a common axiom of economic history that innovation has been critical to the economic development of many nations, especially through its impact on productivity (Clark 2007; Madsen 2010). An extensive historical literature exists. Reflecting the role of technology in manufacturing industries, much of it has focussed on the relationship between technology and industrialisation among the developed western powers, particularly the USA, Japan and Western Europe (for example, David 1975; Inkster 1991; Mowery & Rosenberg 1991; Mokyr, 1992, 2002; Lamoreaux & Sokoloff 1999 Khan 2007).

Australia provides a distinctive alternative setting for analysing the relationship between innovation and economic development, as a nation that followed an atypical path of development based on natural resource industries, particularly pastoral and mining, rather than manufacturing. The resource curse hypothesis of development economists holds that this is an unlikely road to development due in part to the belief that limited opportunities exist for innovation in primary industries (Van der Ploeg 2011). Similarly, much of the economic history literature views primary industries as providing little more than the preconditions to modern economic development, which would take the form of innovation-rich manufacturing industries (Wrigley 1988; Pomeranz 2000; Landes 2003). By contrast, Australian economic development in the nineteenth and twentieth centuries has focused on successful resource-based industries whose exports have facilitated high rates of economic growth, elevated living standards, and investment in modern economic infrastructure (McLean 2013; Dyster &

Meredith 2013). The primary industries, in fact, proved to be important locations of technological advances (Schedvin 1987; Ville & Wicken 2013).

Unfortunately, historical research on the relationship between innovation and economic development in Australia has been quite limited and mostly focused on the colonial period. Several broad studies of innovation have discussed the role of knowledge transfers from the UK and Continental Europe (Inkster 1990; Todd 1995; Raby 1996). McLean (2013, pp. 108-12) pointed to rural sources of productivity growth particularly through innovations in stock breeding, greater use of agricultural machinery, and improved farm management. Magee (1996; 1998; 1999) has undertaken more extensive analysis of pre-Federation Victoria. Deploying patents data, he notes that Australian inventions in the nineteenth century were spread widely across the colonial economy including agriculture, dairying machinery, construction and general mining equipment, carriage and coaching making, and household products; areas 'which, in general, did not require the same degree of formal scientific or technological know-how' (Magee 1998; 2015 p. 123). His work reveals that innovative activity was overwhelmingly the preserve of individuals, usually men, rather than firms (2015, p. 14). They included many engineers but also a broad range of occupations such as farmers, teachers and shopkeepers (2015, pp. 135-6). In seeking to understand more about innovation and economic development in Australia, Magee (1996) also added to the literature by investigating the relationship between patents and economic growth in colonial Victoria. He focussed on the determinants of patent activity, which he concluded were largely the result of demand factors (GDP, population) and supply factors (engineers, growth in manufacturing).

We seek to extend Magee's work by examining the relationship between innovation and economic development into 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 and influences, and whose sources of inventive activity are much less well understood (Dyster & Meredith 2013). Madsen has argued that while resource abundance mostly enabled Australia to grow through increased inputs in the nineteenth century, it could only sustain expansion after Federation by productivity advances achieved 'through innovations, investment in education, and the import of knowledge' (Madsen 2015, p. 51). Banerjee (2012) similarly supports the role of innovation for economic growth in Australia by arguing that patenting intensity (patents per capita) has been a significant determinant of productivity growth since 1870. Others, though, have pointed to the deficiencies of the domestic innovation system in Australia and its over-reliance on patented offshore technology (Mellor 1958; Stubbs 1968; Schedvin 1987).

A new database of patents recently made available by IP Australia permits the first detailed empirical analysis into the role of innovation in the Australian economy throughout the twentieth century. In particular, we will examine innovation's interaction with output, at both the national and sectoral level, together with its relationship to other key facets of development including urbanisation, the growth of multinational enterprise, and key public policy initiatives. Patent data as a proxy for innovation has been used extensively in other countries to sharpen quantitative analysis of innovation, particularly by looking at the determinants of patenting activity. Interest has again focussed on the larger industrial nations, which have generated the bulk of global patents including Germany (Streb et al 2006; Burhop 2010), Britain (Dutton, 1984), USA (Lamoreaux & Sokoloff 2001), and several comparative approaches (Inkster 2003; Khan 2013; Streb 2016). There have been recent calls for more quantitative research on innovation across a broader geographical range of nations (Streb 2016; Beatty et al. 2017; Andersson & La Mela, 2020). Some of the patents literature has also investigated the nature and direction of causality between innovation and growth, as we shall see below. Patents data also facilitates a closer look at how this relationship plays out among individual sectors or particular drivers of an economy's development.

In the next section we look at the potential mechanisms connecting innovation and economic development in Australia. This is followed by a brief outline of the patenting system. The data and methodology we adopt are then explained. Our results are presented and discussed, finishing with some overall conclusions and suggested future directions.

Innovation and economic development in Australia

In the course of the twentieth century, the Australian economy grew rapidly, diversified, but also stumbled in the face of two world wars and the interwar slump before regaining its path of expansion (McLean 2013, p. 19; Madsen 2015, p. 31). The sectoral distribution of economic activity fluctuated with the growth of manufacturing behind tariff walls in the middle decades before the re-emergence of primary industries in the later decades, but with a far broader set of products than in the nineteenth century (Madsen 2015,p. 40; Ville & Wicken 2013, p. 1352). Big business, both domestic and foreign, was becoming increasingly important to the Australian economy, more so than in many other nations (Fleming et al, 2004, pp. 17, 18, 29). The Australian economy drew more and more on the inward transfer of international technology, particularly in newly emerging industries such as automobiles and information technology. Urbanisation became more marked with the continued growth of the capital cities; the share of total population living in the five main cities (Sydney, Melbourne, Brisbane, Adelaide and Perth) rose sharply from 36 per cent to 63 per cent in the century after 1911. (Frost 2015, p. 249). Cycles of industry polices have also been a feature of Australia in the twentieth century, particularly tariffs to protect infant manufacturing industries up until about the 1970s and the growth of competition policies and other forms of microeconomic reform in the final decades of the century (Wilson 2015; Borland 2015). In agriculture, price stabilisation schemes, input subsidies, tax incentives, and support for marketing and R&D provided assistance although average nominal assistance was consistently and significantly lower than for manufacturing (Borland 2015, p. 428; Butlin, Dixon and Lloyd 2015, pp. 578-80).

Many of these emerging features of the Australian economy in the twentieth century had the potential to influence or respond to the nature and location of innovation. Large American manufacturing companies reached Australian shores by the 1920s, often products of the new industries of the Second Industrial Revolution, and were developing internal R&D capabilities within corporate research departments (Chandler 1990). European and Japanese multinationals, such as Phillips and Mitsubishi, began to follow suit by the middle decades of the century. While much of this inventive activity took place in their home nation, firms often transferred their new technologies to the host countries in which they invested including Australia (Wilkins & Hill 2011; Conlon & Perkins 2001; Van Der Eng 2018). Rising tariffs that lowered import competition could result in a reduced incentive for domestic firms to invest in innovation and a lower level of patent activity. By contrast, greater import competition might reduce firm level profits resulting in fewer resources to pursue innovation (Autor, et al 2020; Bloom, et al 2016). In a similar fashion, government schemes that provided incentives to agriculture had the potential both to encourage or discourage innovation. Urbanisation offered a large concentrated market that might act as an incentive to innovators. Population might drive the demand for new patents or increase the supply of potential patentees. On the other hand, slower population growth might facilitate greater investment in human capital through enhanced educational and related resources. Increased migrant skill levels and rising participation in higher education, particularly in the later decades, raised the stocks of human capital in twentieth-century Australia (Hatton & Withers 2015, 355-60). Finally, the shifting sectoral focus of the Australian economy is worth investigating in relation to innovation. In other nations a shift to manufacturing production is often associated with higher levels of innovation but in Australia, where we have evidence of technological advances in primary industries, the picture seems much less clear.

The nature of the Australian innovation system was also changing. By the final years of the nineteenth century a longer-term trend had begun towards a greater role for organisations, including foreign companies and public sector bodies, while the nature of new technologies drew more upon scientific knowledge than practical experience. Magee draws attention to the growing prominence of corporate patent applications, particularly by foreign companies, by the final decades before Federation (1998, p. 233; 1999, pp. 344-5). Science policy and public research institutions began appearing on the horizon by the start of the twentieth century (Inkster 1985). The Advisory Council of Science and Industry – 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 (Schedvin 1987).

The patenting system

Prior to Federation, there was no unified patent system in Australia. Each colony drew on UK legislation but operated independently (Magee 1996). 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 jurisdiction. Therefore, many patentees protected their invention in the two largest markets, 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 (Lamoreaux & Sokoloff 1999; Lamoreaux & Sokoloff 2001; 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, pp. 145-6).

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 (Lamoreaux & Sokoloff 2003; Magee 2015). 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, pp. 82-5). Existing State patents were recognised under the new regime, and they could be transferred immediately to the Commonwealth Register or re-registered on expiry (Wing 1996, p. 49). 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 and Methodology

In order to analyse the relationship between innovation and economic development in twentieth-century Australia, we deploy a dataset of patent applications from the beginning of the Commonwealth Patent Office in 1904 that has recently become available online - 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 provides information about the technology and its field of classification along with details of those who filed these IP rights, which enables analysis across a range of research questions (Mita-Khan et.al. 2016). Very few economic historians have used this database. IPGOD categorises patents according to the World Intellectual Property Organisation's International Patent Classification (IPC) eight major technology sectors or IPC classes, disaggregated into 22 subclasses (and further disaggregated within subclasses).[1]

In order to compare with the colonial period and 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, 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, pp. 37-8; Khan 2013, p. 48).

While there is an extensive international literature analysing patent data, it is worth remembering some of the shortcomings of patents as a proxy for invention and innovation (Streb 2016; Griliches 1998; Magee 1996; Pavitt 1985). Differences in laws between jurisdictions can influence the propensity of inventors to patent their discovery. Indeed, Moser

[1] https://www.wipo.int/classifications/ipc/en/

(2013, p. 40) has thrown doubt on the utility of such legislation concluding that, 'historical evidence suggests that in countries with patent laws, the majority of innovations occur outside of the patent system'. 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 believed it would be difficult to imitate. The propensity to patent also varies across industries (Moser 2012). Innovative activity in service industries sometimes goes unrecorded as patents. 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 a smaller set of data - those that survived for more than ten years (Streb et al 2006; Degner and Streb 2013). Others, however, have thrown light on the validity of such renewal of patent rights given the costs involved and the inability of investors to judge the long-term value of their invention (MacLeod et al 2003).

The costs and benefits of patenting have varied across jurisdictions, which influences the propensity to apply for protection. Our study therefore 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 by foreign entities to seek patent protection in Australia could be subject to a range of additional considerations that may limit the rate of registration compared with the domestic patentee (Bertin & Wyatt 1988). However, 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, p. 44). Despite these possible shortcomings, patents provide very rich quantitative and qualitative data and point to the likely degree of inventive behaviour of a society and in which sectors it has focussed those endeavours.

The sources of our data on variables potentially connected causally to patents – real GDP, private capital formation, urbanisation, population, sectoral output, industry assistance and FDI – have been taken from a range of primary and secondary sources indicated in Appendix 1. Sectoral output is taken from Butlin, Dixon and Lloyd (2015), who provide sectoral breakdowns of real gross domestic product by agriculture, manufacturing and mining from 1860 to 2010, with the exception of 1940 to 1948. As a result, our study does not examine patenting by the services sector. In order to identify sector-specific patents we used the IPC technology class definitions most closely associated with three sectors – agriculture; manufacturing; and mining. For pre-Federation patent data we drew on Magee (2000) and matched the Magee industry patent applications to the three sectoral patent application series. The Magee data covers the period 1860–1903, and the IPGOD data covers the period 1920–2010 (1920 is the first year in which IP Australia has assigned an IPC technology class to a patent application). Unfortunately, IPC technology classes do not easily map onto industries or economic sectors. Therefore, we matched each patent application with an IPC technology class to one of the three sectors (agriculture, manufacturing and mining) using the following rules. For agriculture, we defined all agricultural patent applications as those patents registered under IPC technology class 01 (Agriculture). For manufacturing, we define all manufacturing patent applications as those patents registered under IPC technology classes 02 Foodstuffs Tobacco, 03 Personal/domestic articles, 06 Shaping, 07 Printing, 13 Textiles or flexible materials, 14 Paper, 17 Engines or Pumps, 18 Engineering (in general), 19 Lighting, Heating, and 22 Electricity. For mining, we defined all mining patent applications as those patents registered under IPC technology classes 05 Separating, Mixing, 10 Chemistry, 11 Metallurgy, 16 Earth or rock drilling, 20 Weapons, Blasting, and 21 Physics. All other patent applications which fall under other IPC technology classes (five in total) are defined as Other and are not included in the sectoral analysis.[2]

Patent applicants are able to identify a primary technology class and (as far as we can ascertain) as many secondary technology classes as they wish when they apply for their patent. Where a patent application in the IPGOD database identified a primary technology class, we used that IPC class and matched it to one of the three sectors. In cases where there was no primary technology class assigned to a patent application but there was a single secondary technology class, we used the secondary technology class (the "lack" of a primary class was most common for patent applications prior to the 1970s). Finally, in cases where there was no primary technology class assigned but more than one secondary technology class, we recorded each secondary technology class as a separate technology for the patent as it is not possible to determine which IPC technology class would be the primary. In these cases, therefore, it might be possible for a patent application to be assigned to more than one sector (up to a maximum of three sectors) when the IPC technology classes were different. For example, a patent could be assigned 01 Agriculture and 22 Electricity, in which case it would be counted in two series – once as an agricultural patent and once as a manufacturing patent. On average 5.4 per cent of patents had two or more secondary technology classes listed, with almost all these patents listing two IPC technology classes.[3] When a patent had more than one secondary technology class but the different technology classes resulted in it being assigned to the same sector, we

[2] The excluded IPC technology classes are: 04 Health, life saving, amusement; 08 Transporting; 09 Microstructural technology, nanotechnology; 12 Combinatorial technology; and 15 Building.

[3] We treat each sectoral patent dataset separately in our quantitative analysis. Therefore, that fact that a single patent might appear in two data series does not confound our results.

counted the patent once (for example, a patent with two secondary technology classes 16 Earth or rock drilling and 20 Weapons, Blasting would be counted once as a mining patent).

Our time series analysis follows in the tradition of studies that have examined the time series causal relationship between patents and economic and industry development.[4] Most notably, cliometric time series studies in Australia and New Zealand economic history were pioneered by Greasley and Oxley, examining the contours of Australian GDP (Greasley and Oxley 1997) and the relationship between patents and economic growth in New Zealand (Greasley and Oxley 2010a). Of most relevance to this study is their work (with co-authors) on innovation and patenting activity in New Zealand in the nineteenth and early twentieth centuries. Their approach uses a cointegration regression framework, including examination of the time series and stationarity properties of patent and output series and estimations of Granger causality using vector autoregression models (VAR) (details of these empirical methods applied to economic history can be found in Greasley and Oxley 2010b).

Greasley and Oxley (2010a) found that patents Granger caused New Zealand output and real GDP between 1860 and 1939, although in some cases there was evidence of bidirectional causality. By contrast, Gibbons and Oxley (2021), using a shorter time period, found that economic growth more commonly led (Granger caused) patenting. Greasley and Oxley (2010a) also interrogated several aspects of the relationship between patents and output more closely at the sectoral and product levels. Focussing on the resource industries, they found that in most cases patenting led output including in the all-important cheese, butter and gold industries. In

[4] See, for example, Greasley and Oxley (2007) on the Industrial Revolution in Britain between 1780 and 1851; Streb, Wallusch and Yin (2007) on knowledge spill-over effects between new chemical firms and older textile firms in Germany in the second half of the nineteenth century; and Greasley and Oxley (2010a), Williams and Oxley (2016), and Gibbons and Oxley (2021) on patenting and output in New Zealand in the nineteenth and early twentieth centuries.

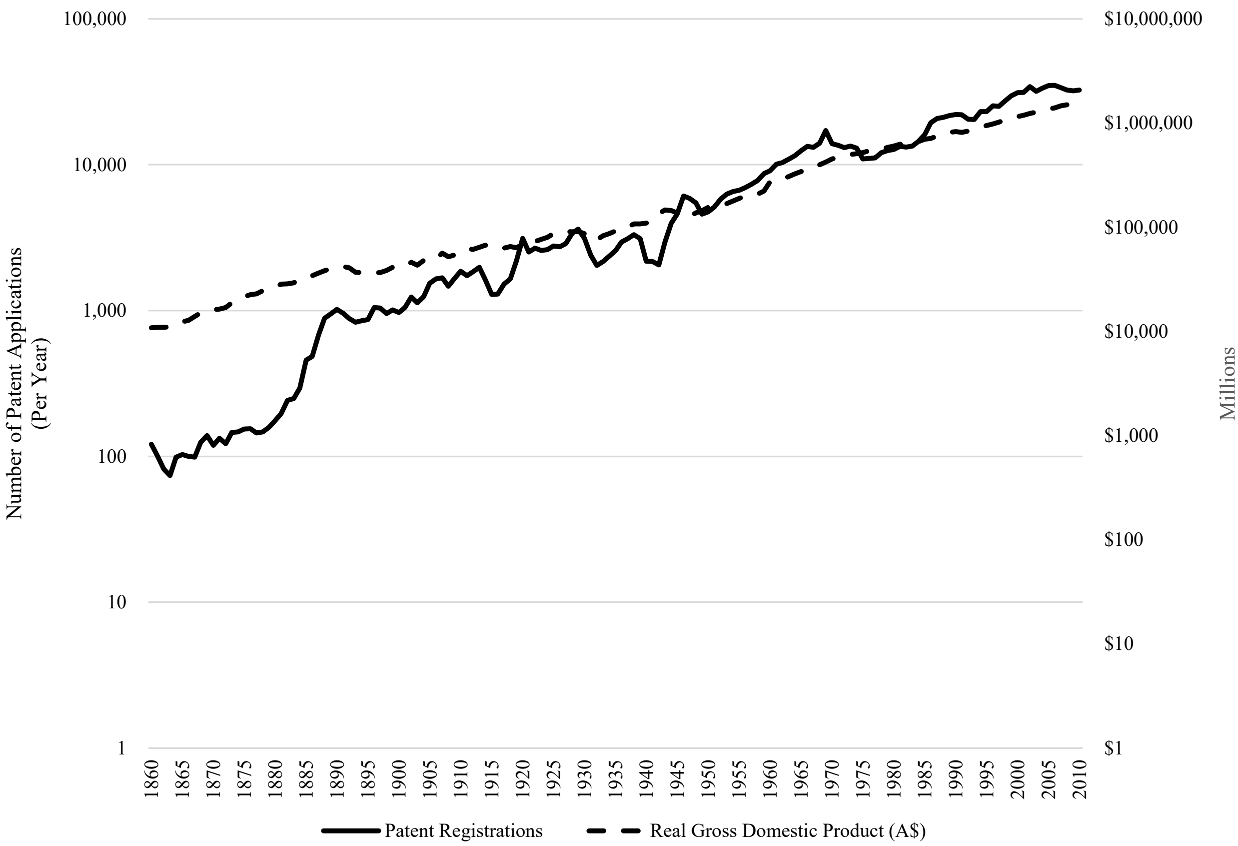
a minority of cases there was a bidirectional relationship but for meat and wool Granger causality flowed from output to patents. Williams and Oxley (2016) found that the geographic concentration of agricultural patents was Granger causally related, in both directions, to agricultural output. Our study adopts a similar methodology by considering causality in a cointegration regression model at the aggregate level and for three sectors – agriculture, manufacturing and mining.

Results

Figure 1 indicates the growth trend of patent applications in Australia in the century and a half from 1860 by combining Magee's data for colonial Victoria with ours for Australia from 1904. We graph patent applications against real GDP using a logarithmic scale to better show trends over time. Annual patent applications increased for most of the period and outpaced the growth of real GDP for many periods. It is also evident that the patent series is slightly more volatile than GDP, with several periods where annual patent applications decreased.

Figure 1

Patent Applications and Real Gross Domestic Product in Australia, 1860 – 2010



Source: Magee (2000); IPGOD. Logarithmic scales

We wish to understand how patent applications might be related to the aggregate macroeconomic variables discussed in the earlier section. We use two data sets: a long run dataset from 1860 to 2010 which includes patents (total, agricultural, manufacturing and mining), real GDP, sectoral output, population, and private capital formation; and a shorter data set from 1947 to 2010 to examine in more detail the variables listed above as well as the urbanisation rate, industry assistance (to agriculture and manufacturing), and FDI (real FDI, FDI from the UK or the US, and FDI into the agriculture, manufacturing and mining sectors).

First, we report Augmented Dickey-Fuller (ADF) tests for each variable to examine whether the respective series are non-stationary (see Table 1). If the ADF tests are not significant, then the series have non-stationary trends or are integrated order 1 (that is, I(1); Greasley and Oxley 2007; 2010).

Table 1

Unit Root Tests

Variable	Levels Z-statistic	First Difference Z-statistic
1860-2010		
Patents	2.231	-12.042***
Patent per capital	2.065	-12.099***
Agriculture patents	0.043	-15.703***
Mining patents	1.622	-9.887***
Manufacturing patents	0.513	-10.902***
Real GDP	20.199	-4.006***
Agriculture output	-2.503	-16.456***
Mining output	2.889	-11.426***
Manufacturing output	1.070	-12.575***
Private capital formation	3.971	-6.662***
Population	3.671	-16.834***
Urbanisation	-1.563	-13.805***
1947-2010		
Average industry assistance to agriculture	-3.696***	-11.683***
Average industry assistance to manufacturing	-1.253	-10.068***
Real FDI	2.976	-9.095***
UK FDI	0.482	-8.367***
US FDI	-0.392	-12.310***
Agriculture FDI	-1.299	-7.582***
Mining FDI	7.906	-2.029
Manufacturing FDI	-1.067	-12.279***

Notes:
* Significant at the 10 per cent level, ** 5 per cent level and *** 1 per cent level respectively.

The ADF tests for levels indicate that all series (with the exception of average industry assistance to agriculture) have a non-stationary trend. Therefore, to ensure that we have stationary series for our time series regressions we use the first difference for each variable. ADF tests on the first difference for each variable are significant at the 1 per cent level, with the exception of mining FDI (where we use the second difference).

Innovation and Real GDP

The first set of results show the time series relationship between patent applications and real GDP, population, private capital formation at the macro-level, using a VAR model estimated on data between 1860 and 2010. The VAR models were estimated for patents applications and patent per capita and each macro-level variable. Using the 1947–2010 dataset we also use urbanisation, real FDI, UK FDI and US FDI. Table 2 reports Granger Causality test results for our VAR models, defining Granger Causality as relationships significant at the 5 per cent level.[5] Wald tests statistics are available on request.

[5] Gibbons and Oxley (2021) use a 5 per cent significance level to define Granger causality. By contrast, Williams and Oxley (2016) define Granger causality at the 10 per cent significance level.

Table 2
Patent applications, real GDP and Foreign Direct Investment
(first differences)

Variable	Patents 1860-2010	Patents 1947-2010	Patents per capita 1860-2010	Patents per capita 1947-2010
Real GDP	O	←	O	←
Population	←	←	←	←
Private capital formation	→	←	→	←
Urbanisation		←		←
Real FDI		←→		←→
UK FDI		←		←
US FDI		←→		←→

Notes:
→ indicates unidirectional Granger causality from the column variable to patents/patents per capita, significant at the 5 per cent level
← indicates unidirectional Granger causality from patents/patents per capita to the column variable, significant at the 5 per cent level
←→ indicates bidirectional Granger causality, significant at the 5 per cent level
O indicates no statistical significance

Our long run analysis of 150 years of patent applications reveals two key findings. First, we find no relationship between patents and real GDP for the full period 1860 to 2010, but patents Granger cause real GDP from 1947 to 2010. This is consistent with Greasley and Oxley's (2010a) main findings for New Zealand for the nineteenth and early-twentieth century (to 1939). However, our results contrast with studies finding that real GDP leads patents (Khan & Sokoloff 1993; Schmookler 1966; Magee 1996). As the closest comparators, our results differ from Magee (1996, 2000) findings for the colonial period for Australia and Gibbons and Oxley (2021) for nineteenth-century New Zealand. We note that Magee's work is for the first 40 years of our study and his regression models only tested for a unidirectional relationship from GDP to patents.[6] Our second main finding is that private capital formation Granger causes patents

[6] Magee (1996) does not use time series econometric techniques; instead, a time series/panel data ordinary least squares regression which combines all years to investigate whether there is a positive relationship between GDP and patents. We ran VAR models on the Magee time period for colonial Victoria we found no statistically significant relationship between patent applications and GDP, population or private capital formation.

between 1860 and 2010, which is consistent with Magee's findings on investment in the colonial period. VAR results for the shorter period since 1947, designed to capture FDI data, shows a series of Granger causal relationships between patents and this variable. In particular, there is a bidirectional relationship between patents and total FDI and with American FDI. In addition, patents lead FDI from the UK. We also note that patents lead population for both of the time periods analysed and urbanisation since 1947.

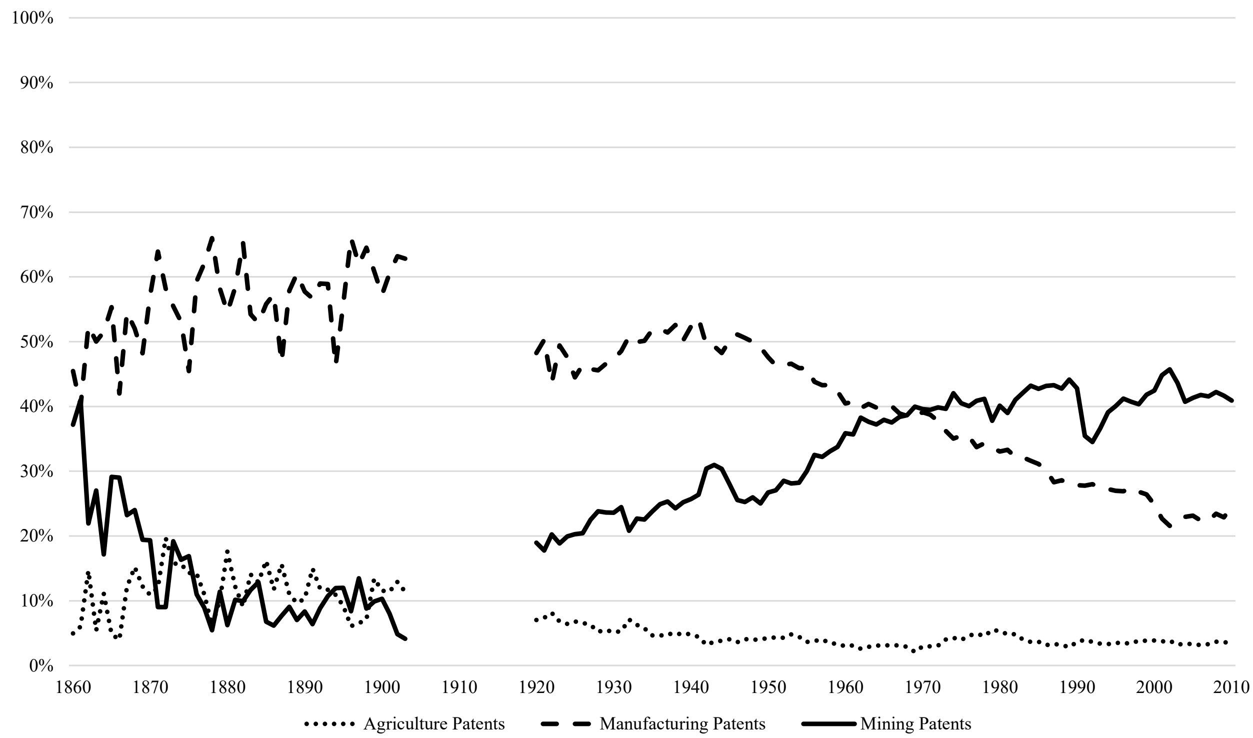
Sectoral Evidence

The above analysis provides a broad view of the important interaction between innovation and economic development in Australia, thereby confirming the research of such authors as Madsen (2010; 2015) and Banerjee (2012). Given the distinctive sectoral configuration of the expanding Australian economy – the continued leadership of mining and agriculture for much of the twentieth century – we have looked more closely at the innovation-development nexus at a more disaggregated sectoral level. In this section, we examine whether sector-related patent applications are associated with sector output and other variables.

Figure 2 shows the composition of patent applications by sector between 1860 and 2010. As discussed above, the series have a break between 1904 and 1920 as 1920 was the first year in which IP Australia has assigned an IPC code to a patent application. Agriculture, manufacturing and mining together comprised on average 78 per cent of total patent applications each year between 1860 and 2010 (an average of 81 per cent 1860-1903, and 77 per cent 1920-2010).

Figure 2

Patent Applications by Sector, 1860 – 2010



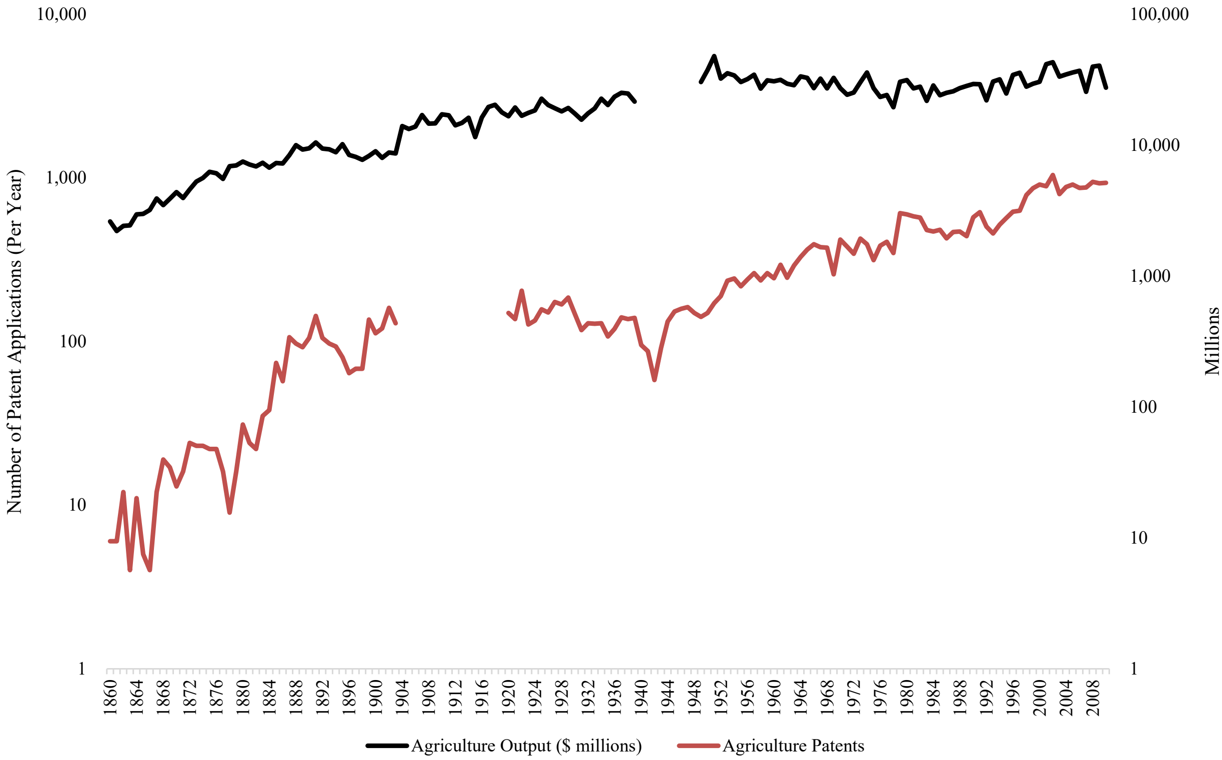
Pre-Federation manufacturing patent applications were the largest group, comprising 50 to 65 per cent of the total between the 1870s and 1890s. From 1920 manufacturing patents' share of total applications declined from 50 to 25 per cent. Mining patents were the second largest group in the 1860s and 1870s, declining in proportion to less than 10 per cent of all patent applications in the 1890s. From 1920 there is an increase in mining patents so that from the 1970s they were the single largest group of patents. Agricultural patents peaked at 20 per cent of all applications in the 1870s, but were less than 10 per cent of all patent applications during the twentieth century.

Figures 3 - 5 provide the trend of agricultural, manufacturing and mining patents against output in their respective sectors. In each case, patenting grew more quickly than sectoral output.

Agricultural patents grew rapidly in the nineteenth century, were relatively stagnant from the interwar period to the 1960s, then grew rapidly once more. The growth rate of manufacturing patents was fairly consistent throughout the period, Finally, mining patents grew rapidly in the latter two decades of the nineteenth century, stagnated from the 1920s, before rising quickly from the 1950s at a similar rate to sectoral output in the booming mining sector.

Figure 3

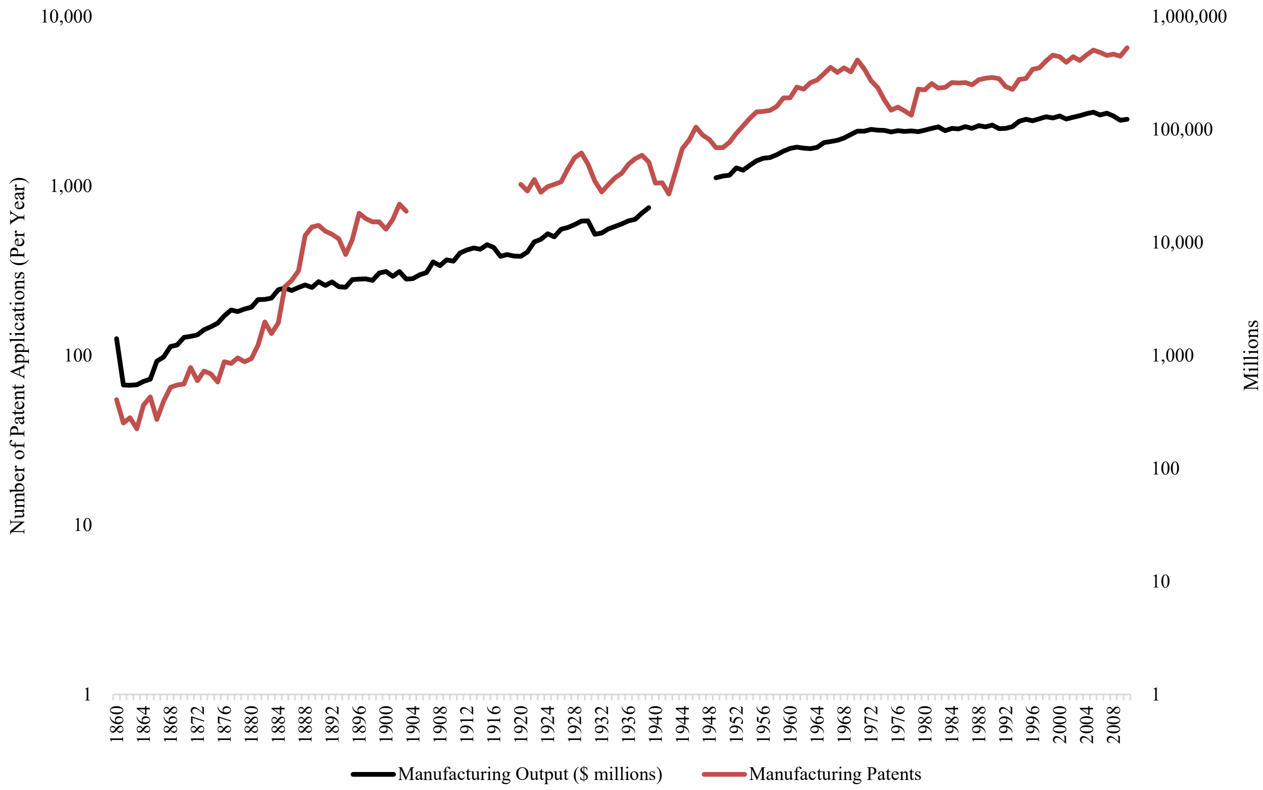
Agriculture Patent Applications and Real Agriculture Output, 1860 – 2010



Source: Magee (2000); IPGOD. Logarithmic scales

Figure 4

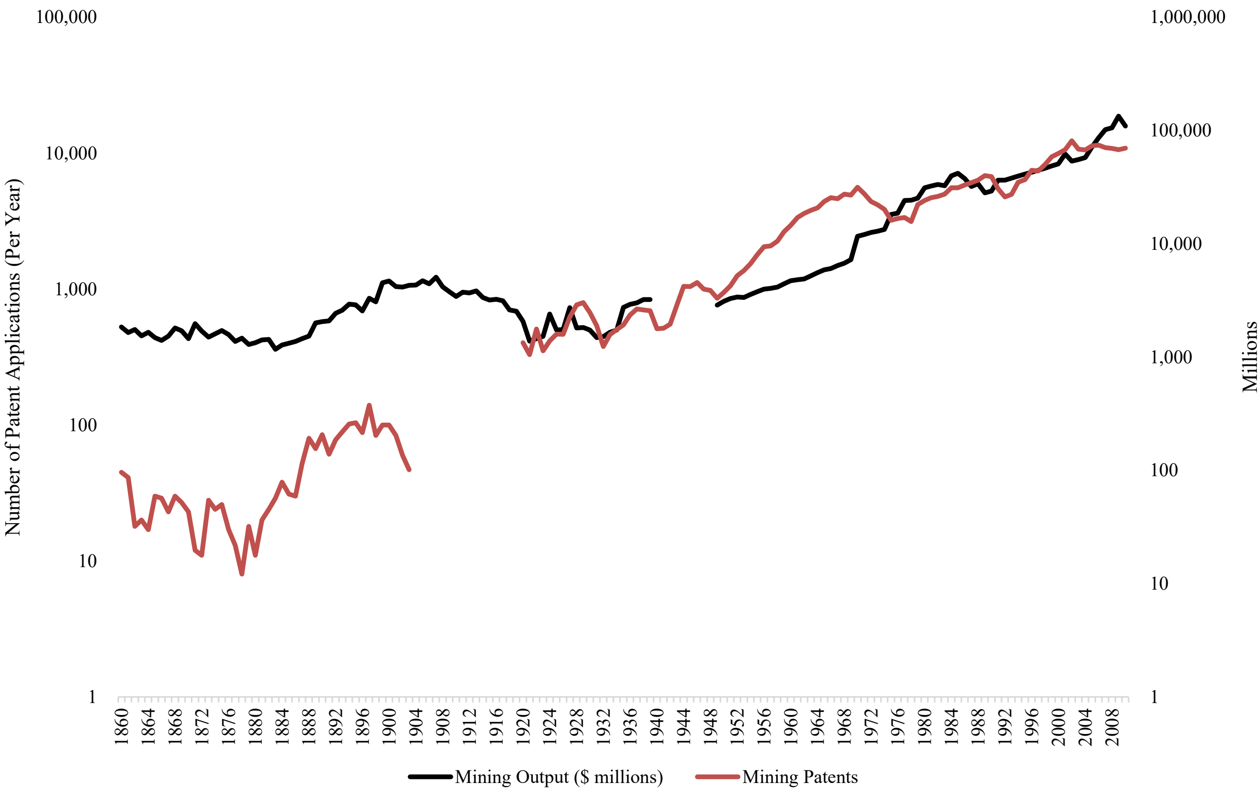
Manufacturing Patent Applications and Real Manufacturing Output, 1860 – 2010



Source: Magee (2000); IPGOD. Logarithmic scales

Figure 5

Mining Patent Applications and Real Mining Output, 1860 – 2010



Source: Magee (2000); IPGOD. Logarithmic scales

Table 3 reports Granger Causality test results for our sector-level VARs, significant at the 5 per cent level. Again, Wald tests statistics are available on request. It provides a rich set of results.

Table 3
Patent applications, sectoral output and Foreign Direct Investment
(first differences)

Variable	Agricultural Patents 1860-2010	Agricultural Patents 1947-2010	Manufacturing Patents 1860-2010	Manufacturing Patents 1947-2010	Mining Patents 1860-2010	Mining Patents 1947-2010
Sectoral output	○	○	○	○	←	←
Population	←	←	←	←	←	←
Private capital formation	←	○	○	○	→	→
Urbanisation		→		○		○
Sectoral FDI		○		○		←
UK FDI		←		←		←
US FDI		→		○		←→
Sectoral industry assistance		○		○		NA

Notes:
→ indicates unidirectional Granger causality from the column variable to patents/patents per capita, significant at the 5 per cent level
← indicates unidirectional Granger causality from patents/patents per capita to the column variable, significant at the 5 per cent level
←→ indicates bidirectional Granger causality, significant at the 5 per cent level
○ indicates no statistical significance

At the sectoral level, we find a series of significant results that are particularly focussed on agriculture and mining. In agriculture, patents had a broad causal impact on population and private capital formation through the whole period and on population after 1947. Contrariwise, urbanisation impacted agricultural patents over the longer period. In mining, patents Granger caused sectoral output and also impacted on population, while private capital formation caused mining patents, all of these relationships occurring over both the longer 1860 to 2010 period and the shorter 1947 to 2010 period. In manufacturing, though, there are fewer relationships – patents led population over both periods. In none of the sectors is there a relationship with industry assistance.

It is in the relationship with FDI from 1947, however, that the range of causal relationships becomes most evident, particularly in agriculture and mining. Agricultural patents Granger caused total UK FDI with total US FDI leading agricultural patents. Mining patents were related to all forms of FDI that we measured: patents Granger caused mining FDI, total UK FDI and total US FDI (bidirectional). Again, manufacturing patents were involved in fewer causal relationships – they led total UK FDI. In general, we find a larger number of statistically significant relationships and a greater tendency for Granger causality to run from patents to other economic variables than was the case for most of the work on New Zealand (Gibbons & Oxley 2021).

Discussion

Overall, therefore, we can see that innovation was associated with several key facets of national economic development in Australia, particularly investment and growth. It seems, therefore, that innovation, as proxied by patents, was a factor driving economic expansion rather than responding to it, while at the same time rising levels of investment may have provided the funds necessary to support heightened inventive activity. That innovation might help to explain economic growth is consistent with the endogenous growth literature but contrasts with some of the historical evidence analysed by other authors, including Magee for colonial Victoria, that find patents as more commonly responding to other economic indicators. One possible explanation of this difference over time in Australia may lie in the idea, discussed earlier, that Australian colonial growth was mainly the product of increased inputs (especially land, labour, and livestock). Therefore, innovation may have constituted ad hoc individual responses to the opportunities and challenges of higher levels of output, particularly in an environment that remained unfamiliar to most settlers. Necessity was the mother of invention. By contrast, post-Federation governments and companies behaved more proactively by utilising their public and private organisational resources and expertise to pursue innovation. However, these are fairly speculative conclusions from results that tell us only a limited amount about the role of innovation for the specific case of Australia.

Instead, the results intimate the need to delve down to a sectoral level perspective to gain a better and more granular understanding of the innovation-development nexus in Australia. Population, urbanisation, capital formation and output by sector were all key measures of economic development in Australia whose relationship with the level of inventive activity, as measured by patenting, largely played out through the resources industries, that is agriculture and mining. Similar to Oxley's conclusions for New Zealand, our results point to a resource-based economy that was not merely fortunate in its rich endowment of natural resources but for whom a strong knowledge base mattered for the success of these industries in the twentieth century as they became more reliant on the application of science. This is also consistent with Madsen's (2015) argument for the interaction of innovation and human capital, the latter abetted by rising educational levels, as driving Australian economic development.

Australia's resource-based industries also looked to the research departments and human capital embedded in large-scale enterprise, both Australian and foreign. As the volume of inward FDI expanded rapidly in the second half of the twentieth century, we find a range of close associations with patenting. Magee (2015, p. 149) has noted, 'Distinct in-house R&D functions in companies and specialist research laboratories staffed by scientifically trained personnel appeared, charged with the task of managing continuous technological progress'. Whether or not foreign multinationals conducted much of their research in Australia, knowledge spillovers clearly occurred across firms (Streb et al 2006).

Mining was the largest source of productivity growth in the second half of the twentieth century (Madsen 2015, pp. 41-2). Its rapid expansion relied heavily on new technology in order to respond to export market opportunities in Japan and the development of new, or the expansion of existing, resources such as bauxite, nickel, and natural gas. In turn, improvements in technology brought additional production streams online that were not previously viable. Foreign global mining companies yielded many important technological breakthroughs. A study of IPGOD patents from 1994 to 2011 reveals the valuable contribution of foreign companies. The great majority of patent applicants - both among mining companies and those providing services to the industry – were foreign entities. While some of these were large global enterprises such as Xstrata or Rio Tinto, many innovators in the METS (Mining, Equipment Technology Services) sector were foreign small scale technology specialists in such fields as drilling, tunnelling, transportation, and information systems (Francis 2015).

There is much less evidence that policy measures had impacted on patenting. This is consistent with the widely held view by the 1970s that tariff protection for Australian firms, as part of a wider suite of regulatory measures, may have helped to protect them from foreign competition but did little to foster entrepreneurial strategies and innovativeness and indeed may have inhibited it (Borland 2015, pp. 420-2). In addition, if much of the innovative activity in manufacturing was imported through multinationals, industry policy may have had little influence on their level of patenting. The investment decisions of multinationals, which did interact with patents, were based on a much wider range of criteria than current industry assistance.

Conclusions

Utilising an extensive and long run national database of patents, this paper has investigated the nature of the relationship between innovation and some of the key measures of economic development in Australia since the colonial period. The international historical literature indicates that the relationship is ambiguous and highly dependent on place. Australia is a valuable country for analysis since it took an unusual pathway to economic modernisation based on natural resource industries rather than manufacturing. We have used time series regression techniques to evaluate the interrelationships between aggregate and sectoral patents and output rather than assume causality runs in a specific direction. As we noted in the previous section, our findings point to innovation as a driver of economic expansion in the twentieth century. This is in contrast to the colonial experience and is perhaps driven by research strategy at the corporate and government levels that became more organised and proactive.

The sectoral focus reveals that the innovation-development nexus is most apparent in the agricultural and mining sectors, reaffirming earlier literature on these sectors' leadership in both growth and innovation in the Australian economy. A key relationship here is between patents and FDI. Australia's increasing dependence on FDI for private capital formation in the later decades of the twentieth century served as an important stimulus for knowledge creation in the key sectors of agriculture and mining. However, not all of the identified relationships between innovation and development can be explored comprehensively in this paper. Our findings produce a basis for a broader agenda for future research on the role of innovation in the Australian economy.

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Appendix 1. Data Sources

Variable	Time Period	Source
Patents	1860-2010	Magee (2000) 1860-1903; IPGOD 1904-2010
Patent per capital	1860-2010	Magee (2000) 1860-1903; IPGOD 1904-2010
Agriculture patents	1860-1903, 1920-2010	Magee (2000) 1860-1903; IPGOD 1920-2010
Mining patents	1860-1903, 1920-2010	Magee (2000) 1860-1903; IPGOD 1920-2010
Manufacturing patents	1860-1903, 1920-2010	Magee (2000) 1860-1903; IPGOD 1920-2010
Real GDP	1860-2010	Butlin, Dixon and Lloyd (2015)
Agriculture output	1860-1939, 1949-2010	Butlin, Dixon and Lloyd (2015)
Mining output	1860-1939, 1949-2010	Butlin, Dixon and Lloyd (2015)
Manufacturing output	1860-1939, 1949-2010	Butlin, Dixon and Lloyd (2015)
Private capital formation	1860-2010	Butlin, Dixon and Lloyd (2015)
Population	1860-2010	Butlin, Dixon and Lloyd (2015)
Urbanisation	1901-2010	Australian Bureau of Statistics
Average industry assistance to agriculture		Butlin, Dixon and Lloyd (2015)
Average industry assistance to manufacturing		Butlin, Dixon and Lloyd (2015)
Real FDI	1947-2010	See note on FDI
UK FDI	1947-2010	
US FDI	1947-2010	
Agriculture FDI	1947-2010	
Mining FDI	1947-2010	
Manufacturing FDI	1947-2010	

Note on FDI estimates.

The Australian Bureau of Statistics and its predecessor the Commonwealth Bureau of Census and Statistics, have assembled and reported annual FDI statistics since 1947-48. The estimation procedures and the titles of publications containing the annual data have changed regularly over time. The FDI calculations used in this paper are part of a current project being conducted by Pierre van der Eng, Claire Wright and Simon Ville measuring the pattern of investment and its relationship with government policy.