The Long-run Effect of Innovations on Economic Growth

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Paper Prepared for the IARIW-UNSW Conference
on Productivity: Measurement, Drivers and Trends

Sydney, Australia, November 26-27, 2013

Session 2B: R&D and Innovation

Time: Tuesday, November 26, 12:00-12:30

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August 22, 2013

Abstract

This study uses patent and trademark statistics as innovation measures to examine the long-run relationship between innovation and output in countries with a long-established system of intellectual property rights (IPR). The findings provide evidence that innovation may no longer play a positive role in driving economic growth in some countries. Post-World War II evidence for countries with extensive measured innovation (the US, Germany and the UK) shows innovation had non-positive effects on economic growth. However, a positive role for innovation was retained in Japan, France and Australia. Long-run output elasticities with respect to innovation among these countries ranged from 0 to 65 per cent pre-World War II and -74 to 82 per cent post-World War II. Using two different innovation measures, the sign and statistical significance of the innovation's long-run effect on economic growth across countries are quite similar.

Keywords: Innovation, Economic growth, IPR, Patents, Trademarks

JEL Classification Code: O31, O32, O34, O40

*I would like to thank Kevin Fox for comments and suggestions and participants in the 42nd Australian Conference of Economists for their discussions. Errors and omissions are my own.

1 Introduction

New growth theory emphasises the importance of innovation in stimulating economic growth along with other drivers, such as physical and human capital. There is little question that innovation played a remarkable role in driving economic growth for over half a century from the start of the second industrial revolution commencing in the 1870s, and led to a profound improvement in the standard of living in many countries.

However, the strong economic growth stimulated by the innovation that occurred during this period has been difficult to repeat in recent decades. The era of achieving fundamental changes in living standards may be over, and the usefulness of new inventions may have diminished compared with great inventions of the past(Gordon, 2012b). The concern that innovation may have stopped driving growth is drawing increasing attention (particularly in the US), but there is a lack of empirical evidence to support this (The Economist, 2013).

Measuring the quantity of innovation activity undertaken at a national level is believed to be a difficult task, and there is no perfect innovation measure. Along with support and criticism, research and development (R&D) data and patent statistics are widely used in economic studies as innovation proxies. Compared to patents, trademark statistics typically measure minor innovations and capture a wider range of innovation activity across sectors and firms, but very few attempts have been made to use trademarks as a measure of innovation in existing studies.

The literature using patent data as the innovation measure has consistently found a strong positive role for innovation. For instance, an Australian study by Crosby (2000) and a Taiwanese study by Yang (2006) both found a positive role for innovation as a long-run output driver. These results tend to disagree with the views of an increasing number of pessimists. In fact, the major share of innovation that is measured by patents filed in Australia originates from the most technologically advanced countries. Since it is highly dependent on foreign technology inflows, Australia (or Taiwan) may not be a good representative for the experience of major technology exporting countries, such as the US. To obtain a broader view of innovation's role, it is necessary to study these major economies that have larger quantities of patents. In addition, by considering the many potential shortcomings of using patent data as innovation indicators, using trademarks as an alternative could provide alternative insights.

This study uses patent and trademark statistics as innovation proxies and examines the long-run effect of innovation on economic growth in six countries with long-established intellectual property rights (IPR) systems, which have the longest time series of IPR statistics: the US, Japan, Germany, the United Kingdom (UK), France and Australia. The results show that the contribution of innovation to economic growth varies significantly across countries, and generally changes in the post-World War II (WWII) years. For some of the most technologically advanced countries, such as the US and Germany, innovation's role decreased over periods, with a non-positive role for innovation on growth found in the second half of the twentieth century. For Japan, France and Australia, the results showed that innovation retained a positive role and had a significant effect on economic growth, particularly in the post-WWII era.

The study is structured as follows: Section 2 discusses the benefits and problems of using different innovation measures, followed by a brief discussion of literature that used patents as an innovation measure. Section 3 presents the model used to estimate the long-run relationships between innovation and growth in six countries. Section 4 describes the IPR statistics and gross domestic product (GDP) data. Section 5 contains the empirical results and Section 6 provides a conclusion.

2 Background

2.1 Measures of innovation

The endogenous growth theory pioneered by Romer (1986) and Lucas (1988) emphasises innovation as a primary driving force of economic growth. However, the empirical implementation of new growth models has been difficult, partly because there is no perfect innovation measure. R&D data, whether R&D expenditure or R&D-related employment, have been most frequently used to measure innovation; see for example Griliches (1990) and Coe and Helpman (1995). However, R&D data have several shortcomings. They measure the innovation input, not the output (i.e. not all R&D will be transformed into innovations); R&D has a lagged effect on the innovation; they cover a relatively short period, it is thus difficult to conduct a time-series analysis involving long lags.

Patent statistics have many advantages over R&D data as an innovation measure. Patent statistics provide innovation output measures. Patent data contain rich information in regarding its inventors, citations and technical fields; They are available for many countries and for long periods, in some cases dating back to the late 1800s.

In the earliest work demonstrating the feasibility of using patent data as an innovation indicator, Schmookler (1966) claimed that patent statistics provided an index for the quantity of inventions created in different technology sectors and at different times. By examining patent data and R&D data, he found high correlations between patent statistics, R&D expenditure and the employment involved in R&D. Inspired by Schmookler (1966), researchers have since often used patent statistics as an innovation proxy in studies related to the economics of innovation. Some early studies include those by Pavith (1982), Archibugi (1992), Patel and Pavith (1995) and Griliches (1990), which have all shown the usefulness of patents as innovation indicators.

Although patent statistics have enjoyed broad coverage in the economics literature, there are some potential issues involved in using patents as an innovation measure (Greenhalgh and Rogers (2010), pp 60-61).First, restricted by patent legislation, only certain types of inventions from a limited number of sectors can be patented.[1] Second, depending on the type and value of an invention, many firms prefer secrecy over patenting. Third, because of the cost involved in patent enforcement, it is infeasible for small firms to use patents. Therefore, patent data are less representative of differing firm sizes. Fourth, some patents are used as a purely anti-competitive strategy. Finally, the strictness of the patent system varies across different countries and over time.

As another important type of IPR, trademarks can be a feasible innovation measure (Greenhalgh and Rogers, 2010). Given the limitations of patent data, it is surprising how little trademarks are used to measure innovation.Unlike patents, which are dominated by a few sectors, trademarks are used in a more extensive range of sectors. In addition, trademarks do not require tests for 'novelty and non-obviousness' and usually involve innovations less significant than those with patents, including new varieties of existing goods. Due to the relatively low cost of application and maintenance, the majority of small firms and those newly entering the market with access to limited resources are much more likely to use trademarks.

[1]As a result, patent applications are concentrated in the manufacturing and extractive industries. The finance industry rarely uses any patents, because the financial service provided by the finance industry is rarely fits into any patent classifications.

2.2 The role of innovation (measured by patents)

The literature using patents as an innovation measure consistently identified a positive long-run role of innovation in driving economic growth, although there are different views and findings for the short-run role. Schmookler (1966) believed that there would be a positive long-run relationship between these two variables, whereas in the short-run they were likely to be negatively related. By contrast, Devinney (1994) implicitly showed a short-run positive correlation between patents and GDP growth by examining the associations between changes in these two factors. An Australian study by Crosby (2000) focused on the long-run relationship between innovation (measured by patents) and GDP growth, and found evidence of innovation's positive effect on labour productivity and economic growth. Crosby's results tended to support the negative short-run relationships, as argued by Schmookler (1966). A more recent study by Yang (2006) analysed Taiwanese patent data using a similar model and found positive effects of innovation on GDP in both the short run and long run. Both the latter studies considered small open economies with a large share of innovations represented by patents owned by foreign entities.[2]

However, a small but increasing number of economists, particularly in the US, are not as optimistic about the strength of innovation's current role. A recent study by Gordon (2012a) concerned that there has been a drop in the usefulness of inventions in recent decades compared with the remarkable set of inventions during the second industrial revolution and their extensions. Gordon (2012b) argued that new technologies often fail to improve people's living standard in a cost-effective way.[3] He also found support for his view using the fact that the rate of US life expectancy improvement since the 1950s declined by two thirds compared with that of the earlier half century. On the other hand, economic growth in major developed economies that were challenged by unstable macroeconomic conditions such as two oil price shocks in the 1970s and 1980s and several financial crises in more recent decades, has stagnated since the 1970s. It is thus sensible to question whether there is still a positive association between innovation and economic growth in these countries. In this study, both patent and trademark statistics are used as innovation measures, with Fisher and Seater (1993)'s long-run neutrality (LRN) model used to identify the long-run relationship between

[2]For example, over 85 per cent of patent applications in Australia, on average, are owned by technology leaders, including the US, Japan and major European countries, the UK, France and Germany.

[3]For example, the recently invented protonbeam treatment for prostate cancer is more expensive, but does not promise better results than radiation therapy.

innovation and economic growth in six of the major countries of using IPR.

3 Methodology

3.1 The LRN model

This study's empirical model closely follows the concept of the LRN model proposed by Fisher and Seater (1993) and employed by Crosby (2000), which is based on a system of autoregressive models.[4] By assuming a log-linear system of two variables (i.e. the innovation measure and real GDP), the vector autoregressive (VAR) model is formulated as follows:

$$\theta(L)\Delta IP_t = \phi(L)\Delta y_t + \epsilon_t^1, \quad (1)$$

$$\gamma(L)\Delta y_t = \eta(L)\Delta IP_t + \epsilon_t^2, \quad (2)$$

where L is the lag operator, Δ is the first difference operator, and IP_t and y_t represent the innovation measure (i.e. patent or trademark statistics) and real GDP in year t (both in logarithms), respectively. ϵ_t^1 and ϵ_t^2 are error terms, and the vector $(\epsilon_t^1, \epsilon_t^2)'$ is assumed to be independently and identically distributed with zero mean and covariance Σ. The long-run effect of innovations on economic growth is measured using the long-run derivative (LRD) defined by Fisher and Seater (1993) as,

$$LRD_{y,IP} = \lim_{j\to\infty} \frac{\partial y_{t+j}/\partial\epsilon_t^1}{\partial IP_{t+j}/\partial\epsilon_t^1}, \quad (3)$$

provided that the denominator $\partial IP_{t+j}/\partial\epsilon_t^1 \neq 0$. This requires that the disturbance for innovation ϵ_t^1 permanently affects the innovation level and the innovation variable is characterised by $I(1)$. Intuitively, $LRD_{y,IP}$ in Equation (3) expresses the permanent effect of innovation disturbances on economic growth relative to that of innovation disturbance on the innovation level, and $LRD_{y,IP}$ represents the long-run elasticity of economic growth with respect to innovations.

Following Fisher and Seater (1993), it is assumed that: (1) $Cov(\epsilon_t^1, \epsilon_t^2) = 0$ and (2) IP_t is exogenous, $LRD_{y,IP}$ can be the estimated using $\lim_{k\to\infty}\beta_k$ from an ordinary least square (OLS) regression,

$$y_t - y_{t-k-1} = \alpha_k + \beta_k\,(IP_t - IP_{t-k-1}) + e_{kt}. \quad (4)$$

[4] The model was originally designed to test the long-run relationship between economic growth and money supply.

That is, $LRD_{y,IP}$ can be approximated by the estimates of β_k for a large enough value of k.

The concern of a reduced role of innovation in driving economic growth and the fluctuation of the patent and trademark series (shown in Section 4) both suggest that the long-run relationship between innovations and economic growth may contain structural breaks and are significantly influenced by the two world wars. Taking these effects into account, a war dummy, a structural break dummy $D_t(\tau)$, and interaction terms of these two dummies and the term $(IP_t - IP_{t-k-1})$ are included in Equation (4), where τ is the date of the structural break.[5] The unknown break date is determined using the Quandt likelihood ratio (QLR) statistic with 15% trimming (see Stock and Watson (2003), pp. 468-471).[6]

The validity of Equation (4) in estimating the $LRD_{y,IP}$ is based on two conditions. First, the lag length k should be infinite, which is impractical given the limited number of observations in time-series data. As k increases, the degrees of freedom decrease, such that the maximum k should be as large as is feasible given the data length (Crosby, 2000). Fisher and Seater (1993) chose a maximum k of 30 years as the long-run representation, and this choice was followed by Crosby (2000) and Yang (2006). A long-run representation of 30 years is also followed in this study.[7] Second, variables in Equation (4) need to contain stochastic trends or to be characterised as $I(1)$ in order for innovation shocks to have permanent effects on economic growth, and this enables the evaluation of the long-run relationship between innovation and economic growth using the $LRD_{y,IP}$.[8]

Finally, for each of the two innovation measures, Equation (4) was regressed (with dummy variables and interaction terms) for each k and for each country. The coefficient estimate $\hat{\beta}_{30}$ represents the long-run relationship between innovations and economic growth, and the plots of the $\hat{\beta}_k$ and the corresponding 95 per cent confidence intervals against k provide information on the pattern of innovation's effects on economic growth as the innovation ages.

[5] $D_t(\tau) = 0$ if $t \leq \tau$ and $D_t(\tau) = 1$ if $t > \tau$.

[6] The F-statistic for $D_t(\tau)$ and the interaction term was computed for all break dates in the central 70 per cent of the sample. The τ corresponding to the largest F-statistic was the selected break date. Note that similar break dates are found by the QLR statistic using different lag lengths k. For simplicity, the break date found for the maximum k was applied to all other lag lengths.

[7] However, β_k was estimated for a larger lag length of up to 40 years, as it may take an even longer period than the assumed maximum lag length before the innovation's role diminishes.

[8] If both variables in Equation (4) are stationary ($I(0)$), y_t will eventually return to a deterministic trend after a shock, in which case the shock to IP_t has no effect on y_t in the long run (Crosby, 2000). This property of the variables can be tested using the augmented Dickey-Fuller (ADF) test.

3.2 Missing data

Another problem associated with IPR series is missing observations. This is probably because of the effects of wars and the incompatibility of standards between national IP offices and the WIPO. If the missing data-generating process does not share the parameters in Equation (4), simply excluding missing observations from the estimation (known as listwise deletion [LD]) will not cause biases in coefficient estimates in Equation 4 (see Greene (2012)). The LD approach usually performs better than many alternatives, including the dummy variable adjustment approach and various simple data-imputation strategies that usually induce biases (Allison, 2002). However, it tends to lose some efficiencies due to excluded information. An approach that could improve the efficiency without sacrificing the statistical property of unbiasedness is the use of multiple imputation (MI) (See Rubin (1987) and Allison (2002)).

To obtain stable estimates, MI involves repeating the procedure of imputing missing data and estimating Equation (4) using imputed data for the missing observations.[9] Due to the randomisation, a different imputed value for the missing observation and thus the coefficient estimate $\hat{\beta}_k$ was obtained each time these steps were performed. To stabilise the estimation result, the imputation and estimation procedures were repeated and the coefficient estimate produced each time were averaged. Fifty imputations ($M = 50$) were carried out for each IPR-country pair that contained missing observations, which is sufficiently large to minimise the sampling error caused by MI (see Rubin (1987) and van Buuren et al. (1999)).

4 Data

This study uses real GDP data as the measure of economic growth and IPR data (the number of patent or trademark applications each year) as the innovation measure for the analysis.[10] The real GDP data shown in Figure 1 combines the observations of Organisation for Economic Co-

[9]Any IPR series with missing observations was linearly regressed on the GDP of the same country, the IPR series in countries without missing data and having a large share of IPR ownership in other countries (effectively the US and UK), and a time trend to obtain the predicted series, $\tilde{IP}_t$ and the standard deviation of the error term $\tilde{\sigma}$ of the regression. Missing observations were replaced by imputed values computed by assigning a random disturbance to the $\tilde{IP}_t$. i.e. $IP_t = \tilde{IP}_t + \tilde{\sigma} r_t$, where r_t is a random number between 0 and 1.

[10]IPR applications rather than IPR grants are used because the former reflect the innovative activity in a year, whereas the latter are often restricted by the examination capacity of the IP office that varies over time (Crosby, 2000).

operation and Development (OECD) data and Maddison historical data (see Maddison (2010)). The observations since 1960 (inclusive) are available from the OECD (online) database and are measured in 2005 US$. However, a longer length of GDP data is needed to match the IPR series of over 100 years in length. Maddison historical data contains GDP measures dating back to 1820; these earlier observations from Maddison (2010) are spliced together with OECD data using the overlapping observation for 1960.[11] GDP series in these countries consistently follow a rather similar and upward linear trend, and growth is relatively more stable as compared with the IPR series shown below. Unsurprisingly, as can be seen from Figure 1, the world wars clearly had a significantly negative effect on economic growth, especially for countries extensively involved in World War II, such as Germany, Japan and France.

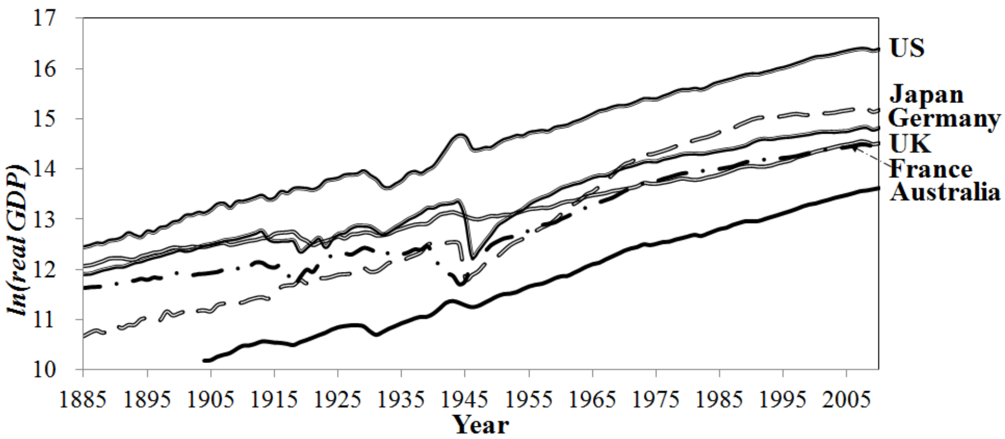


Figure 1: GDP (in Logarithms) of Leading Countries using IPR.

Figures 2 and 3 show trends in the number of new patent and trademark applications, respectively, in six major countries of using IPR dating back to the mid 1880s. The missing data are replaced by imputed values produced using the method described in Section 3. Imputed data are indicated by plotting using dots. The annual patent and trademark series are available from the World Intellectual Property Organization (WIPO) online database. These statistics are patents or trademarks filed in the national intellectual property (IP) office of each country, except for the patent statistics of France, Germany and the United Kingdom (UK) since 1978, which are combined using the WIPO's patent statistics and the number of patents filed separately in the European Patent Office (EPO).[12] As shown in Figure 2, the number of patents in these countries generally increases and

[11]Maddison data share many similarities with OECD data for the period 1960-2008, with a correlation of over 99% between these two GDP series for each country studied.

[12]Since the EPO was founded in 1978, inventors who filed patent applications only through the regional IP offices,

fluctuates over time. Particularly, the patent statistics in Japan clearly follow a different trend than other countries studied, being much steeper.

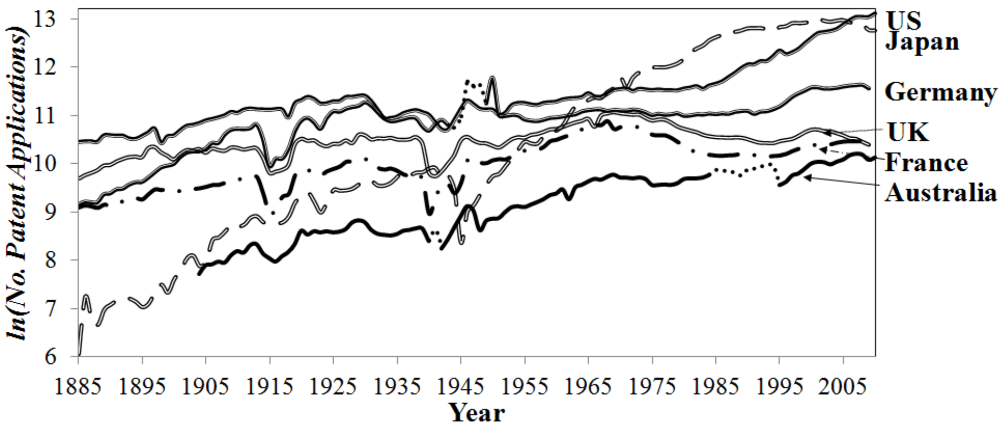


Figure 2: Patent Statistics (in Logarithms) of Leading Countries using IPR .

Both world wars had a significantly negative effect on innovation activities and thus on patent statistics; European countries in particular experienced the most severe declines. By contrast, patent numbers in the US and Australia were less adversely affected by the wars. After experiencing little change during World War I (when Japan was on the side of the Allies), patent numbers in Japan underwent a sharp fall during World War II.

The patenting activity of countries that were seriously affected by World War II instantly recovered and increased rapidly after the war. However, the growth of patent statistics in European countries stagnated from the 1970s. In particular, a decline in patent numbers was observed in the UK and France throughout the 1970s and 1980s, which indicates a possible weakening of innovation activity in these two countries.[13] On the other hand, this reduction in the patent numbers of European countries could have been caused by institutional change. Since the founding of EPO, an increasing share of new patent applicants was redistributed from national patent offices to the EPO. This tends to reduce the chance of repetitive applications of the same patent and therefore decreases the patent number in many countries, especially European countries.

By contrast, patent numbers in the US rose rapidly in the mid 1980s and have maintained the momentum thereafter. There are debates about the functionality of the US patent system given this

were able to file patents either through regional offices or the EPO. Some advantages of choosing the EPO are avoiding the complications caused by different languages and patent systems across countries, and reducing the effort required to make separate applications to each designated country.

[13]This view is supported by declining R&D intensities (i.e R&D expenditure as a percentage of GDP) in the UK during this period; and its R&D intensities are low compared with the US (OECD, 2010).

dramatic increase in the patent statistics (Hall, 2005; Jaffe and Lerner, 2004; Boldrin and Levine, 2013).[14] Similarly, Germany also saw a significant patent increase in the 1990s, although it slowed down after 2000.

Japan's patenting activities were among the lowest in the late nineteenth century among all countries studied, at 5-10% of that of major Western economies. However, patent numbers in Japan experienced a spectacular rise throughout the twentieth century, overtaking that of major European economies after World War II and remaining the largest in the world after outstripping the US in the 1970s.[15]

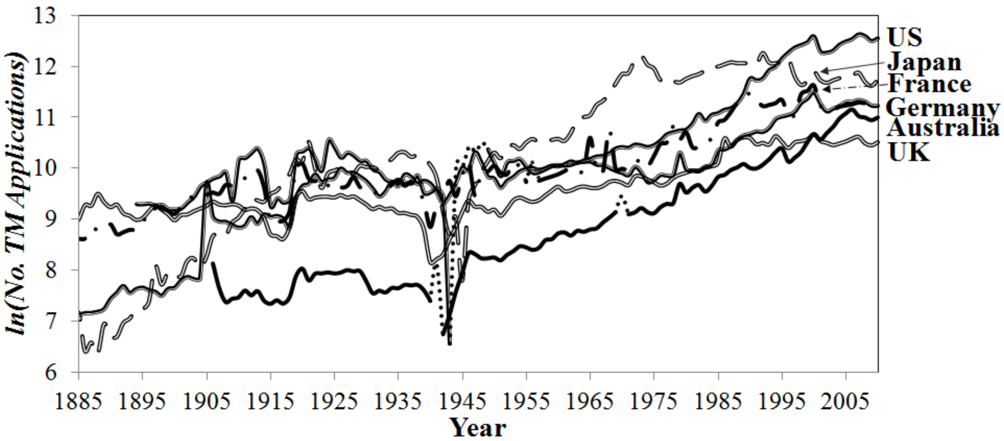


Figure 3: Trademark Statistics (in Logarithms) of Leading Countries using IPR.

Figure 3 shows the trademark statistics for the six OECD countries studied. These trademark series are generally more volatile than those of patents. Trademarks measure innovations differently from patents by representing minor innovations and new varieties of existing products. Therefore, trademark numbers are in a line with the fluctuating level of market activities and respond more instantly and sensitively to economic conditions, rather than the relatively more stable growth of patents.

As shown in Figure 3, trends of trademark series differ between the post-World War II period and the prior period, indicating some structural breaks between these two periods. Prior to World War

[14]This is supported by the rising R&D intensity figure in the US during recent decades, indicating a large rise in innovation activities OECD (2010).

[15]One reason for the high patent numbers in Japan in recent decades is that Japanese patents became less significant than those of other countries after the late 1980s after some changes in the Japanese patent system. There is a view that each US patent is roughly equivalent to three Japanese patents, as the Japanese patent system differs from others by splitting a patent application into multiple stages (Greenhalgh and Rogers, 2010; Sakakibara and Branstetter, 1999).

II, trademark series of most countries studied (except the US and Japan) followed a relatively flat trend. Despite these two countries having the largest number of trademarks in the world in recent decades, their trademark numbers in the late 1800s were only a fraction of the major European countries'. After a rapid tenfold rise for a few decades during the early twentieth century, the numbers reached a similar level to those of major European counterparts between the two world wars.

The trademark statistics for most countries suffered the sharpest drop during the wars, and the decline was relatively more severe than that of patents. They fell by 50-60% for major European economies soon after the outbreak of World War I. However, the effect of World War II seemed to be more catastrophic. In particular, countries on the losing side of the war saw a dramatic drop of over 90 per cent in the trademarks. The number in Australia was also to some extent affected by wars and dropped slightly, likely because of its dependence on European economies. In contrast, the trademark number in the US was less adversely affected by the two wars and maintained steady growth. Trademark statistics of countries experiencing large declines during World War II quickly regained their pre-World War II levels after the war.

The post-World War II growth of trademark numbers in Japan was distinct from the other countries studied. Japanese trademarks grew sharply after World War II and gained the leading position in the early 1950s, whereas only modest growth was observed for other countries during the same period. The top position (of Japanese trademark numbers) was retained for over four decades before being surpassed by the US in the mid 1990s. Throughout the 1980s and 1990s, most countries studied showed strong increases in trademark numbers. This was followed by a sudden correction in the year 2000.

Finally, all variables have been tested for stochastic trends using the Augmented Dicky Fuller (ADF) test. The ADF test statistics show that all three variables contain stochastic trends, and thus the long-run relationship between innovations and economic growth is testable using the LRN test.

5 Results

The results using each innovation measure (patents or trademarks) are reported in Tables 1 and 2, respectively. The plot of coefficient estimates $\hat{\beta}_k$ and the corresponding 95 per cent confidence intervals against k for each IPR-country pair is presented in Figures 4 to 15.

Country		Break date	Before break	After break	Chow test
Australia	(LD)	1947	-0.0223	0.2398 ***	30.98
	(MI)		-0.0223	0.2077 ***	31.98
France		1972	0.6549 ***	0.6574 ***	89.52
Germany	(LD)	1958	-0.0150	-0.5979 ***	44.40
	(MI)		-0.1140 *	-0.7399 ***	24.93
Japan		1941	-0.0388	0.8150 ***	340.33
UK		1948	0.1170 **	-0.0825 ***	143.23
USA		1940	0.5870 ***	-0.0456	26.75

Note: $***$, $**$ and $*$ represent statistically significant at 1%, 5% and 10% levels, respectively.

Table 1: Long-run Elasticities of Output with respect to Innovations (measured by Patents).

Country		Break date	Before break	After break	Chow test
Australia	(LD)	1947	-0.0283	0.1317***	11.03
	(MI)		-0.0277	0.1321***	15.19
France	(LD)	1947	-0.0631	0.1574*	58.91
	(MI)		-0.0631	0.1686**	59.73
Germany	(LD)	1960	-0.0512*	-0.2346***	68.27
	(MI)		-0.1642*	-0.2998***	43.21
Japan		1975	0.1483***	0.6991***	86.34
UK		1948	0.0356	0.0921***	118.26
USA		1943	0.2405***	-0.0485**	39.11

Note: $***$, $**$ and $*$ represent statistically significant at 1%, 5% and 10% levels, respectively.

Table 2: Long-run Elasticities of Output with respect to Innovations (measured by Trademarks).

Shown in column 2 of each table, the break date of structural changes for innovation's long-run role in driving economic growth as determined by QLR statistics varies across countries and innovation measures used. For most IPR-country pairs, this was found to be close to World War II, except for the patents-France and trademarks-Japan cases that occurred during the 1970s, during the period known as the first 'oil shock'. Given the determined break date, the Chow test-statistic (Chow, 1960) for the structural break of the long-run relationship between innovations and economic growth (column 5) for each IPR-country pair rejects the null hypotheses of no structural changes at the 1% significance level.[16]

Results achieved using both the LD and MI approaches are reported for patent and trademark series

[16] Chow test is simply a F test. Also, the F-statistic testing the joint significance of war dummies and their interactions with $IP_t - IP_{t-k-1}$ is sufficiently large to reject the null hypotheses at the 1% significance level for all cases, which confirms the influential effect of wars on the effects of innovation on economic growth.

with missing data. These two estimation strategies offer similar sign and statistical significance of coefficient estimates, particularly when the number of missing observations is small. However, when the MI was used the set of coefficient estimates obtained was slightly smaller in absolute value and plots of coefficient estimates $\hat{\beta}_k$ were generally less volatile, as can be seen from Figures 4, 7, 11, 13 and 14.

The long-run elasticity of output with respect to innovations ranges from 0 to 0.65 in the period before the structural break and -0.74 to 0.82 in the period after when using patents as an innovation measure, and it is in a range of 0 to 0.24 and -0.30 to 0.70 respectively for the two periods when trademarks are used as an innovation measure. These are discussed in sections 5.1 and 5.2.[17] Each subsection broadly describes the unique features of the results by using the innovation measure before categorising countries studied into different scenarios depending on whether the innovation's role in driving economic growth has decreased. This is followed by providing some explanations for the case of the decreasing and non-positive role of innovation in the post-World War II period in Section 5.3.

5.1 Innovation measure: patents

More broadly, as shown in Figures 4 to 9, the plot of $\hat{\beta}_k$ in each country shows a distinct shape for periods before and after the break date. For each country, one of the two periods, the $\hat{\beta}_k$ plot follows either a flat trend or a downward-sloping trajectory, and the $\hat{\beta}_k$ for any k is statistically insignificant at any conventional levels, indicating no evidence of the influence of innovation on economic growth in the short or long-run. By contrast, in the other period when innovations appear to play an effective role in driving economic growth, a trapezoidal or inverted-V shape is observed for the $\hat{\beta}_k$ plot.

This shape of the $\hat{\beta}_k$ plot demonstrates the effects of innovations on economic growth as innovations age. Both social benefits and costs are attached to innovations and time lags are often inevitable before the effects of any benefits materialise due to the uncertainties involved. Therefore, costs

[17] These results are obtained using OECD and Maddison data on real GDP in US$ terms to ensure the longest data series possible. It is also interesting to see if the results are robust by using real GDP in constant national currencies. When the same analysis is carried out using Australian data directly from the Australian Bureau of Statistics in real Australian dollar terms from 1960 combined with data from Maddock and McLean (1987) from 1947, the elasticity estimates are generally larger than those reported here and similar to those found by Crosby (2000), but the qualitative conclusions are the same and the estimates are not statistically different at the 5% level.

are likely to dominate benefits in the early stage of innovations (or in the short run), when the innovation's role has not yet been fully revealed. However, the effectiveness of innovations gradually improves over time as market share rises, such that benefits outstrip costs in the long run. The negative effect of monopoly rents on the national economy can be another explanation for the shape. Although it has a tendency to reduce the net social benefit in the short run, this negative effect becomes limited in the long run when the innovation is no longer characterised as new and sophisticated. Restricted by the statutory limit enforced by the patent system, the underlying innovation also has a finite lifespan; the role of innovation thus eventually fades away over an even longer run, which explains the phenomenon that $\hat{\beta}_k$ eventually converges to zero after reaching the maximum.

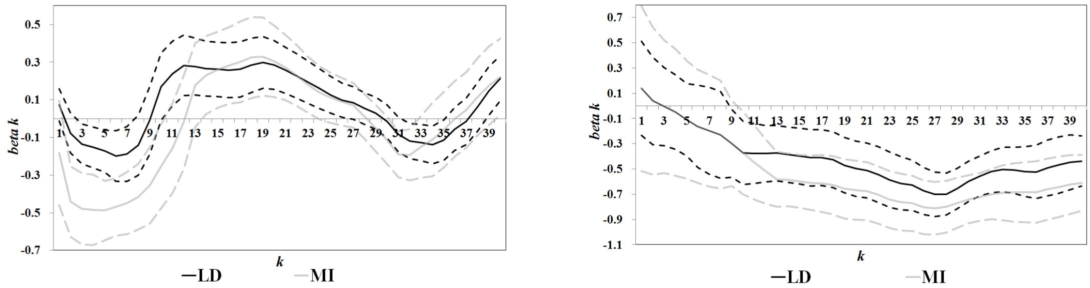
5.1.1 Decrease in the role of innovation: Germany, the UK and the US

The first scenario includes the US, UK and Germany, some of the world largest economies and major technology exporters. Results show that the role of innovation in these three countries decreased to a large extent during the second period (mainly the post-World War II period), when a non-positive relationship between innovations and economic growth was found. Although, positive and statistically significant coefficient estimates of β_k were obtained in the first period (roughly the pre-World War II period) given a sufficiently large k value, which emphasises the strong role played by innovations during the earlier period.

In particular, innovations made an extraordinary contribution to the US economy during the long period before World War II. In the long run, a 1 per cent increase in innovation is associated with a nearly 0.6 per cent increase in real GDP. By comparison, the role of innovation was effective but smaller in the other two countries (the UK and Germany) in the pre-World War II period, and the lifespan of inventions' effects in these countries seems to be much shorter than that of the US.[18] This explains the negative but statistically insignificant $\hat{\beta}_{30}$ reported for Germany in the pre-World War II period in Table 1, where the effect of innovation ceases before k reaches 30 years, the default long-run lag length; a positive $\hat{\beta}_k$ of around 0.3 can be achieved with a slightly smaller k value. Similarly, if a smaller long-run representation of k value was assumed, the output elasticity with respect to innovations $\hat{\beta}_k$ in the UK at its maximum is approximately 0.2 with $k = 24$, twice as

[18]The $\hat{\beta}_k$ peak occurs at a lag length k of around 15-20 and 20-25 for Germany and the UK, respectively.

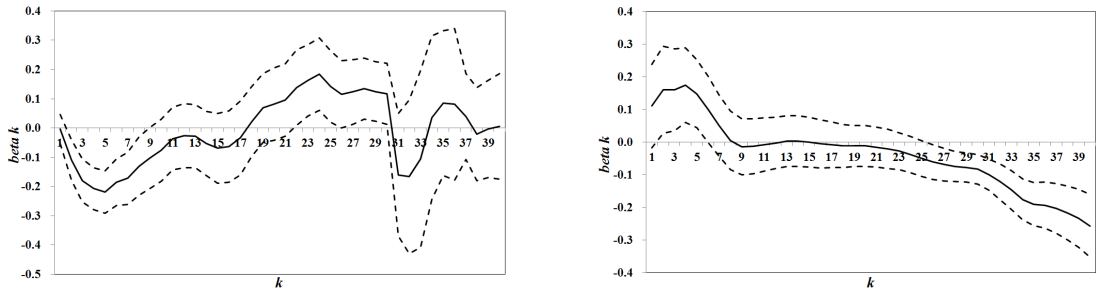
large as that reported in Table 1, with $k = 30$.



(a) Before 1958 (inclusive)

(b) After 1958

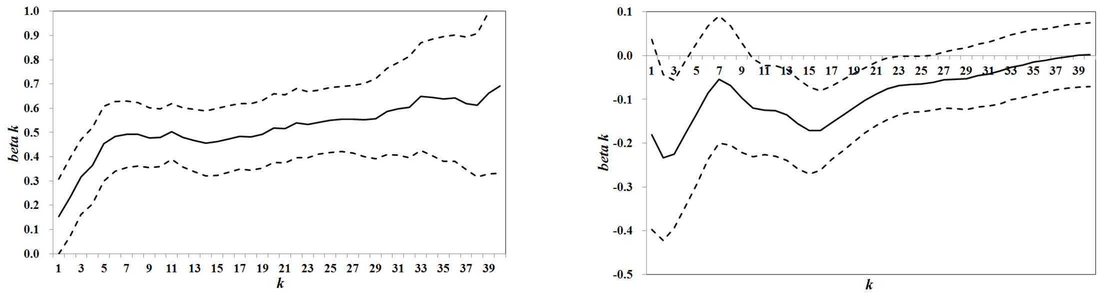
Figure 4: The $\hat{\beta}_k$ plot in the German Case using Patent Statistics as an Innovation Measure.



(a) Before 1948 (inclusive)

(b) After 1948

Figure 5: The $\hat{\beta}_k$ plot in the UK Case using Patent Statistics as an Innovation Measure.



(a) Before 1940 (inclusive)

(b) After 1940

Figure 6: The $\hat{\beta}_k$ plot in the US Case using Patent Statistics as an Innovation Measure.

Surprisingly, a similar role of innovation was not found for these three countries in the second (post-World War II) period: the evidence shows a dramatic decrease in innovation's role in enhancing economic growth. Specifically, a non-positive coefficient estimate $\hat{\beta}_k$ was consistently found in this period with any k values, and $\hat{\beta}_k$ plots (shown in Figure 4b, 5b and 6b) no longer have a trapezoidal shape as they did for the previous period. Instead, the $\hat{\beta}_k$ remains practically and statistically insignificant. In the long run, a negative relationship between innovations and economic growth was consistently obtained for the UK and Germany, whereas the $\hat{\beta}_{30}$ of the US shows a long-run neutral relationship between innovation and economic growth.

5.1.2 The role of innovation remains (Australia and France) or increases (Japan)

For the countries in the second case, the role of innovations during the first period remained steady or increased in the second period.[19]

In the France case, similar trapezoidal-shaped $\hat{\beta}_k$ plots were observed in both periods. However, the $\hat{\beta}_k$ plot in the first period appeared to shift horizontally over time to the right. This indicates some potential changes in innovation's role in the second period, although the long-run relationships between innovations and economic growth ($\hat{\beta}_{30}$) in the two periods were close. Specifically, the $\hat{\beta}_k$ in the first period is positive for some small k values, but it lasts for a relatively short period. A longer lag length is required before the β_k in the second period becomes positive and statistically significant, but it remains so for a much larger k. This shows that it becomes less likely to benefit from innovation in the short run in the recent period than the period before. This is likely to be partly because of the gradually rising monopoly rents and the dramatic increase in innovation costs to accompany the advanced sophistication of new products. On the other hand, this boost in a product's sophistication probably plays a role in enhancing the lifespan of innovations in the second period, which explains the right shift of the $\hat{\beta}_k$ plot.

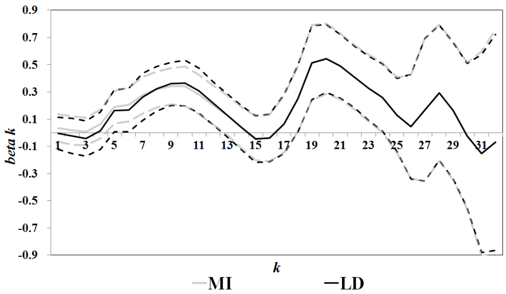
With regards to the long-run output elasticity with respect to innovations, in France in both periods it was close to two thirds - among the highest across all countries studied. As for Australia, the effect of innovations on economic growth prior to World War II was characterised by a relatively short lifespan; it thus failed to obtain a positive estimate when $\hat{\beta}_{30}$ is assumed to be the long-run effect. In fact, there is strong evidence of positive long-run effects of innovations if a slightly shorter lag length is assumed.[20] The $\hat{\beta}_{30}$ of Australia in the post-World War II period shows that the long-run elasticity of output with respect to innovations is about 0.21.[21]

An extraordinary improvement in the contribution of innovations in the post-World War II period was found for Japan. The pre-World War II experience of Japan was unlike that of all other countries

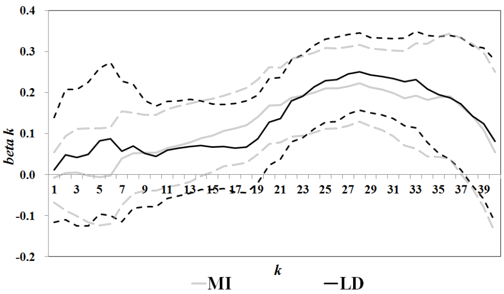
[19] As is shown in column 2 of Table 1, the first period is the period before 1947 (inclusive) in the case of Australia or the period before 1972 in the case of France, and the second period is the period after the corresponding break date.

[20] The elasticity of output with respect to innovations is over 0.5 with a k value of 20 to 25 years.

[21] A slightly larger estimate of 0.24 was obtained using the alternative LD estimation strategy; see Table 1.

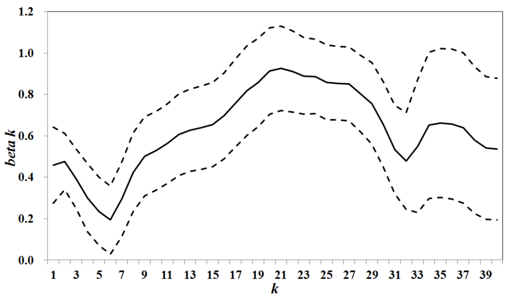


(a) Before 1947 (inclusive)

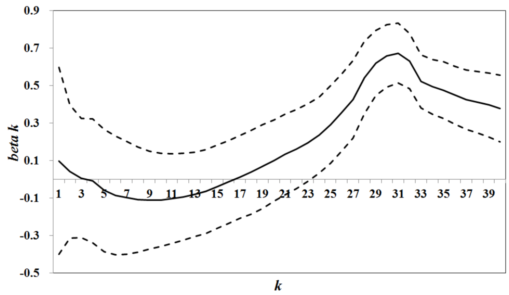


(b) After 1947

Figure 7: The $\hat{\beta}_k$ plot in the Australian Case using Patent Statistics as an Innovation Measure.

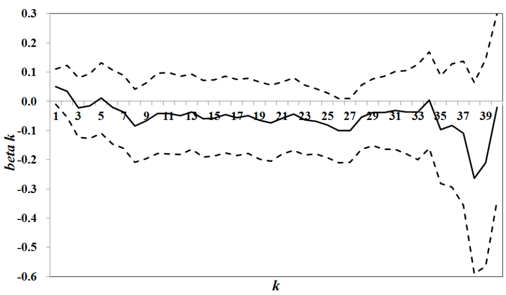


(a) Before 1972 (inclusive)

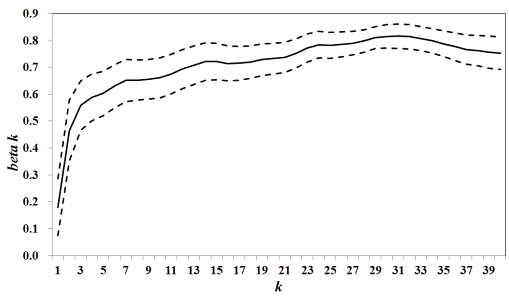


(b) After 1972

Figure 8: The $\hat{\beta}_k$ plot in the French Case using Patent Statistics as an Innovation Measure.



(a) Before 1941 (inclusive)



(b) After 1941

Figure 9: The $\hat{\beta}_k$ plot in the Japanese Case using Patent Statistics as an Innovation Measure.

studied; the $\hat{\beta}_k$ remains statistically insignificant for any k values at even the 10% significance level, which shows evidence of the ineffective role of innovation in Japanese economic growth during that period.

Different evidence was found for the post-World War II period, a positive and statistically significant $\hat{\beta}_k$ was consistently found for any lag length k, indicating innovation's strong effect in driving economic growth in both the short run and long run. For example, a 1% increase in the innovation measure is associated with an approximate 0.82% rise in real GDP in the long run, which is among the highest in the postwar period across all countries studied.

5.2 Innovation measure: trademarks

Explained by their rather distinct functions compared with patents, when trademark statistics are used as an innovation measure, the plot of $\hat{\beta}_k$ (shown in Figures 11 to 15) is characterised by at least two different features. Unlike patents, which are mainly used to protect newly invented ideas, trademarks are used to protect brands and marketing assets and are not attached to any technologies (Sandner and Block, 2011). As a result, a newly registered trademark lacks a consistent history of good quality for sale and contains little economic value. Therefore, a non-positive relationship between trademarks and real GDP is likely to be observed for the relative short run (i.e. when k is small). In addition, trademarks do not have a statutory limit, and their potential economic values increase with age (or in a longer run) as long as trademarks remain active. Thus, as shown in the figures, the $\hat{\beta}_k$ has the tendency to continuously rise as the k value increases.

5.2.1 Decrease in the role of innovation: the US and Germany

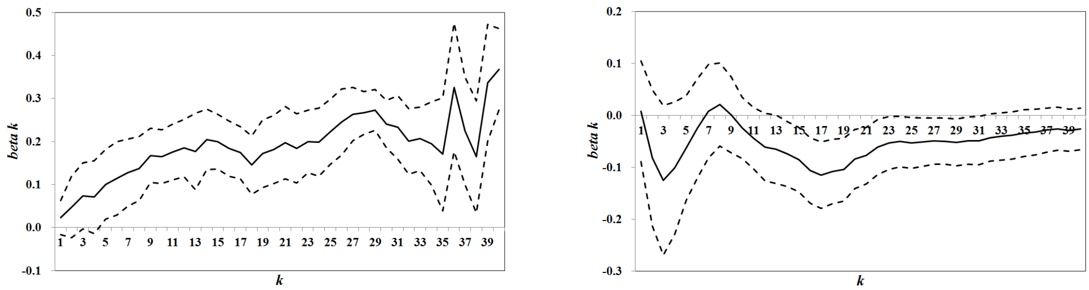
The six countries are grouped into two scenarios, in which innovation's role in output growth either decreases or increases during periods after break dates.

In the first scenario, similar to the first case of patents, two leading economies, the US and Germany, show decreases in the role of innovation in stimulating economic growth in the period after the break date.[22] The results for the US before the break date (shown in Figure 10a) shows that innovations (measured by trademarks) played an important role in driving the growth of real GDP. As indicated by $\hat{\beta}_{30}$ (in Table 2), a one per cent increase in innovation is associated with a 0.24 per cent increase in economic growth in the long-run. After the break, the picture is quite different (Figure 10b), with a $\hat{\beta}_{30}$ of -0.05 (Table 2). As in most other countries, trademarks in the US show a strong increase in the post-World War II period, particularly during the 'dot-com' boom of the late 1990s. However, economic growth during the same period did not quite align with this measure of innovation. This indicates a possible decrease in the role of innovations in driving economic growth, consistent with some evidence of overuse of trademarks in the US relative to their use in the pre-World War II

[22]The break date is 1943 for the US and 1960 for Germany; see Table 2.

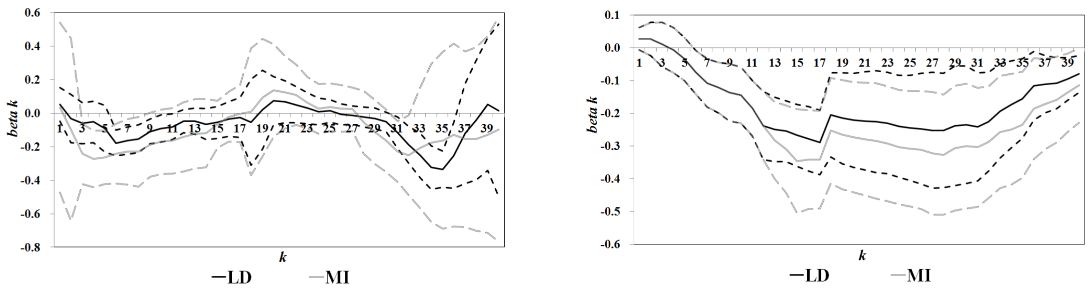
period (Greenhalgh and Rogers, 2010).

The findings for Germany also show evidence of decline in the role of innovations in the period after the break date (1960), and there is consistently no evidence of an anticipated positive role of innovations, whether using patents or trademarks as an innovation measure; see Figure 11. Specifically, the $\hat{\beta}_k$ in the first period is practically and statistically insignificant for any k values, indicating no evidence of any relationships between innovation and real GDP in the short or long-run. In the second period, the $\hat{\beta}_k$ remains negative and statistically significant at the 1% level as the k increases, although it has a tendency to move towards zero after k passes 30.



(a) Before 1943 (inclusive) (b) After 1943

Figure 10: The $\hat{\beta}_k$ plot in the US Case using Trademarks as an Innovation Measure.



(a) Before 1960 (inclusive) (b) After 1960

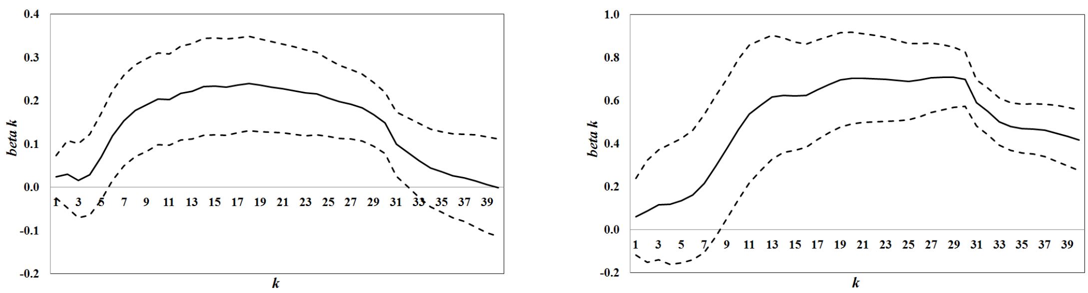
Figure 11: The $\hat{\beta}_k$ plot in the German Case using Trademarks as an Innovation Measure.

5.2.2 Increase in the role of innovation: Other countries

The results for Japan show evidence that the positive role of innovations (measured by trademarks) in boosting the Japanese economy in the period before the break date (1975) becomes even more significant in the period after; see Figure 12. In the first period, the long-run elasticity of output with respect to innovations $\hat{\beta}_{30}$ is found to be about 0.15.[23] Unlike the US, there is some evidence of

[23]The elasticity is slightly larger if a smaller lag length is used since the peak occurs when $k = 18$.

innovation's enhanced role on real GDP in the second period, during which a one per cent increase in the innovation is associated with an approximately 0.70 per cent real GDP rise in the long run, the highest of all periods or countries studied when the innovation is measured using trademarks. Such a large estimated long-run effect of innovations may seem suspect; however, it is comparable with the results found in Section 5.1 using patents as the measure of innovations.

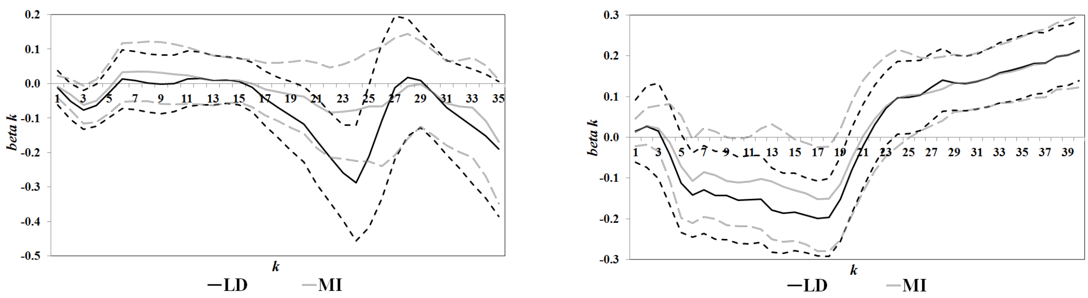


(a) Before 1975 (inclusive)

(b) After 1975

Figure 12: The $\hat{\beta}_k$ plot in the Japanese Case using Trademarks as an Innovation Measure.

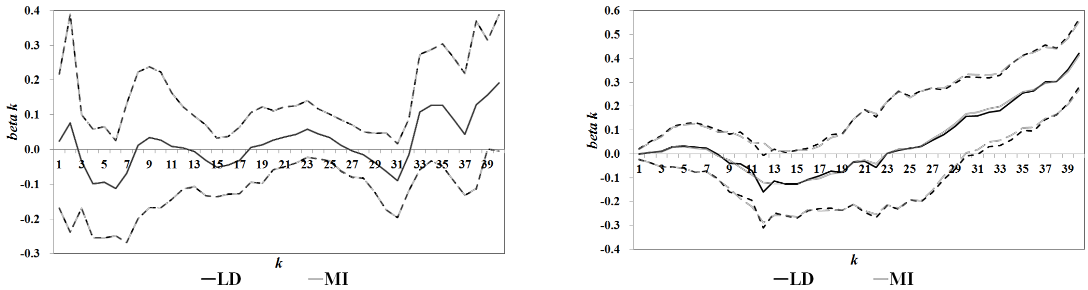
For the remaining three countries (Australia, France and the UK), in the first period the $\hat{\beta}_k$ in these countries remains small and statistically insignificant even for large k values, indicating no role has been played by innovations; see figures 13, 14 and 15. In contrast, more promising evidence for the role of innovations was found for the second period: long-run output elasticities with respect to innovations are statistically significant, ranging from 0.09 to 0.17, although there is no evidence of short-run positive effects.



(a) Before 1947 (lnclusive)

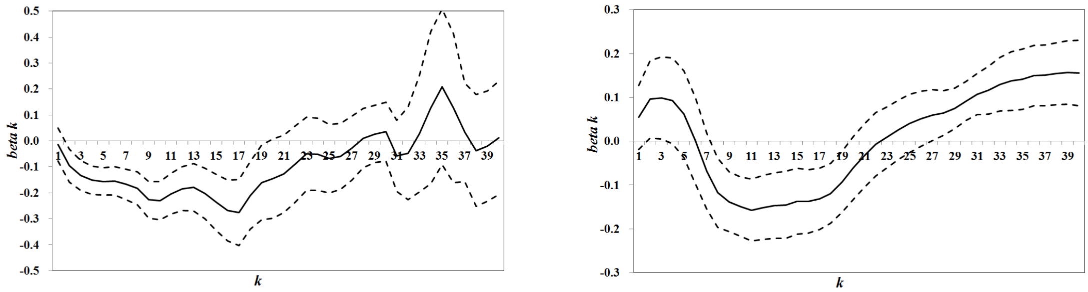
(b) After 1947

Figure 13: The $\hat{\beta}_k$ plot in the Australian Case using Trademarks as an Innovation Measure.



(a) Before 1947 (inclusive) (b) After 1947

Figure 14: The $\hat{\beta}_k$ plot in the French Case using Trademarks as an Innovation Measure.



(a) Before 1948 (inclusive) (b) After 1948

Figure 15: The $\hat{\beta}_k$ plot in the UK Case using Trademarks as an Innovation Measure.

5.3 Discussion

Some possible explanations of a reduced and non-positive role of innovation in driving economic growth found for some countries in the more recent period are discussed below. First, a possible explanation is the declining usefulness of inventions in recent decades compared with those in the past (Gordon, 2012b). Gordon (2012b) argued that most recent inventions are basically diffusions of great inventions of the second industrial revolution (IR), and do not fundamentally change our life and improve living standards to the extent that their ancestors did.

Second, the timing of the knowledge diffusion of inventions taking place in different IRs is to blame. This is a period when the effect of inventions of the second IR gradually weakened after being influential for over half a century, while inventions in the third IR (i.e computers and information technology) starting in the 1990s are still quite young. Their effects on economic growth and living standards have not yet been fully revealed.

Third, the fluctuating macroeconomic condition may be a factor. The oil price shocks in the 1970s, and other economic crisis and their 'macro-consequences' are likely responsible for at least some of the decline of the role of innovation (Griliches, 1988).

Fourth, the combination of globalisation and modern technology could apply downward pressure on innovation's role in the highest income countries, like the US. Due to globalisation, US labour was forced to compete with foreign inexpensive rivals through both outsourcing and imports (Gordon, 2012a). Developing new technology is expensive and risky. For a technologically advanced country like the US, a large share of innovation activities and expenses occur domestically, while an increasing proportion of their production (and services) have relocated overseas since World War II. As a result of this massive offshoring activity, measured domestic economic growth cannot fully capture the innovation's role.

Finally, innovation is usually associated with both negative monopoly rents and positive social returns. There may be considerably more monopoly rents for countries with larger market sizes and more advanced technology, for example, the US and Germany. For a small economy such as Australia, negative monopoly rents tend to be relatively small. Because of the increased sophistication of new products, these rents are likely to be enhanced and remain influential for a longer duration in the postwar period. The stronger and longer lasting monopoly rents over time could potentially impose downward pressure on the net social benefits of innovation, which could to some extent explain the reduced role of innovation over time obtained for the US and Germany.

Caution should be taken when comparing long-run elasticities across periods or countries, as evidence of innovation's changing role may be partly influenced by time inconsistencies and international differences in using IPR statistics as innovation measures, which is mainly due to time and country variations in the strictness of IP systems. The same IPR unit could represent different levels of innovation across countries or over time, which could be associated with different economic values.[24] There have been debates regarding whether there has been a reduction in patent systems' efficiency in recent decades, given there was a significant rise in the number of patents during the 1990s without a comparable rise in economic growth (see Jaffe and Lerner (2004); Hall (2005)). Also, this rise reflects the increased quantities of IPR for intermediate products due to the enhanced sophistication of final production and rising demand for different varieties of similar products to-

[24]Various options were considered for weighting the IPR series to improve cross-country and intertemporal comparability. Unfortunately, the weights typically used in the literature start from the 1960s or later, which is too short a timeframe for this study. For example, the value of patent rights estimated by many studies (see e.g. Schankerman (1998)), or the 'index of patent rights' constructed by Park (2002) are only available for period since 1990.

day; the same number of IPR may represent different innovation levels over time, and therefore their effects on economic growth may have changed. Similarly, distinct patent systems across different countries make innovation levels, and therefore the estimated long-run role of innovation, less comparable.

6 Conclusion

This study extends an Australian study by Crosby (2000) to a wider range of developed countries with a long established IP system. In addition to patents , as used by Crosby, it also uses trademarks as an alternative measure of innovation, which is motivated by trademarks' broader coverage in sectors, firm sizes and less significant innovations. Moreover, the potential structural breaks of innovation's long-run role in driving economic growth are rigourously tested. Furthermore, as an improvement to the conventional treatment, the missing data of IPR statistics were resolved using multiple imputation.

The results vary across countries and generally differ between two time periods divided by their country-specific break dates. In line with the concern of small but increasing number of pessimists, the evidence does not always support a positive role of innovation in stimulating economic growth. When patents were used as an innovation measure, for some major developed economies where the majority of the world's innovation activities originate (the US, UK and Germany), the innovation probably no longer plays a positive role in driving economic growth in Post-World War II period, as it did in the previous period. On the contrary, the innovation's role in stimulating economic growth was found to be strong and positive in Japan and Australia in the more recent period, unlike those findings in the previous period. Further, the results for France show a consistently strong positive long-run relationship between innovation and economic growth in both periods. The long-run elasticity of output with respect to innovation (measured by patents) among these countries ranges between 0 and 0.65 in the period before World War II, and has a wider range between -0.74 and 0.82 in the period after.

When trademarks were used as an innovation measure, the conclusions remained mostly the same, except for the UK. Similar to the patent case, two of the top economies, the US and Germany, show evidence of innovation's less prominent role, and non-positive associations between innovation and long-run output were found in the post-World War II period. In addition, innovation in Japan shows a long history of having a major role in stimulating economic growth and this remained the case in the second period after the mid 1970s. Finally, for France, Australia and the UK, there is evidence of an improved role for innovation; strong positive long-run elasticities were obtained for the second period after their break dates, although similar positive long-run roles were not found in the earlier periods. The long-run elasticity of output with respect to innovation (measured by trademarks) was found to be between 0 and 0.24, and -0.30 and 0.70 respectively for the two periods.

Using a similar approach to that used by Crosby (2000) for Australia and Yang (2006) for Taiwan, but with an additional measure of innovation, this study has found the same conclusions regarding the relationship between innovation and economic growth for Australia, France and Japan. However, differing results are found for the US, UK and Germany. While caveats will necessarily remain for this kind of complex long-run analysis involving multiple countries, through considering a range of countries over a long time period, and with alternative measures of innovation, the results significantly expand the existing sparse empirical literature on the role of innovation in driving growth, an issue of great policy interest and topical relevance.

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