# 行政院國家科學委員會專題研究計畫　成果報告

## 研發、專利和知識外溢(II-II)

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# 成 果 報 告 目 錄

# 一、摘要

## 1.1 中文摘要

本研究計畫已圓滿持執行完畢，有一篇論文“Persistency and technology of innovative activities: A cross-country comparative analysis”已完成並於2005年7月份在加州舊金山舉行的美西經濟學會會議中發表，已投稿 Applied Economics Letters 審稿中。

## 1.2 英文摘要

On the basis of this research projects, one paper on “Persistency and technology of innovative activities: A cross-country comparative analysis” was presented in the Annual Conference of Western Economic Association at San Francisco, California, USA, July 2005. This paper has been submitted to Applied Economics Letter for publication.

# 二、報告內容

## 2.1 會議論文一篇

# A dynamic analysis of innovative persistence and technology diversity

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## Abstract

This paper analyzes firms' dynamic behaviors of patent persistence and technology proximity in innovation activities for U.S., Japan, S. Korea and Taiwan during 1990-2003. We find evidences that the firms in both advanced countries and latecomer countries have a strong persistence to remain in certain states of patenting, in terms of intensity and direction. On average, the persistency of Japanese firms in sustaining their innovative activities is stronger than U.S. firms, while South Korean firms are more tenacious than the Taiwanese counterparts.

**Keywords:** Patent; Persistence; Technology proximity; Transition probability

**Editorial area:** Technology and innovation

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### Introduction

The innovative pattern could be described by two properties: persistence and diversity. In prior studies regarding firms' innovative activities, the focus has been either on the innovative output, such as the number of patent received or the number of new products introduced, or on the determinants of those outputs (Brouwer and Kleinknecht, 1999). However, a relevant issue in gauging a firm's or a nation's competitiveness is whether such innovative momentum could be sustained; another pertinent issue is to unveil the direction of such innovation efforts. This paper takes patents as the innovative output, and analyzes their patterns at the firm level across two advanced economies (US and Japan) and two technology latecomers (South Korea and Taiwan). The patent counts of Taiwan and South Korea have respectively ranked fourth and eighth worldwide for consecutive years since 2001. Such remarkable rise of patent performance, though still trails behind US and Japan, has nevertheless bypassed several other more advanced economies. It is therefore of interest to conduct a cross-country comparison for their patenting properties. We attempt to address two issues: 1) whether innovative momentum has been sustained, 2) whether firms continue to innovate in the same or different technology fronts over time.

# Innovative persistence

Persistence could be observed through the comparison of patent performance of the current period with that of the next period. Malerba and Orsenigo (1999) find that innovation persistence vary systematically across countries. Cefis and Orsenigo (2001) use Markov chain approach to analyze the dynamic pattern of patenting persistence for 1232 US firms and 1297 Japanese firms during 1978-1993. They find that both great innovators and non-innovators have a strong tendency to remain in their state, and this bimodality phenomenon-- a strong tendency for firms to remain in the polar states, either being persistent innovator or being a one-time only innovator -- is stronger in Japan than in U.S.A. We adopt Cefis and Orsenigo's approach (2001), but improve the analysis in two aspects. First, we use a more updated and completed sample that includes 52,959 American firms and 8,444 Japanese firms during 1990-2003 to examine the general applicability of the prior findings. Instead of taking 5-year cross section variation over random sampling, we account for year-to-year variation and cover the entire sample population. Second, we add the latecomers such as Taiwan and S. Korea into the sample to allow us to compare the difference in dynamic persistence across different types of countries.

What attribute to innovative persistence? Malerba, Orsenigo and Peretto (1997) suggest that the determinants of innovative persistence include: firm's technical competence and organizational competence (firm-specific factors), the accumulation and opportunity of the particular field of technology (technology-specific factors), as well as the feedback from the markets (market-specific factors). For example, a firm could persistently score high in innovative output if resources are continuously invested in RD facilities or the organization is structured to be munificent to innovative activities. Additionally, the accumulated stock of RD skills would allow a firm to leverage the existing knowledge and know-how, to recognize new problems and opportunities, and to create new product or process (Cohen & Levinthal, 1989). The rationale of the market determinant is based on Schumpeter's argument that successful creation would yield economic rent to the innovator, and by investing in further RD with the profit, the innovator could sustain to produce innovative output. This is the "success-breeds-success" process described by Nelson & Winter (1982).

The combined effect of the above determinants is not apparent to be measured. This study assumes the economic maturity and technology level is similar among the advanced economies, such as the US and Japan, and among the latecomer economies, such as Taiwan and Korea; therefore, the aforementioned determinants of innovative persistence should be rather similar. Under this assumption, this study first analyze the patent count applied by firms from the US, Japan, Taiwan and Korea during the period of 1990-2003, and then analyze the dynamic behavior of patent application over time to explore whether there is the presence or absence of a persistent pattern.

# Technology Diversity

In addition to the exploration of whether innovative output is persistently produced, another pertinent issue is to unveil whether firms continue to innovate in the same or different technical fronts. Technological diversity refers to the tendency whether the innovative output is closely-related or cross field. In analyzing the technology advantages of the world's top 400 firms, Patel & Pavitt (1997) find these firms have significant numbers of patents across several technical areas. While technology diversification often follows product or market diversification, it is even more dispersed than production activities. It appears firms would have to be specialized in a few areas, and by being capable of integrating different skills and knowledge, they could then improve exist products or introduce new products or services. Therefore, it is necessary to consider additionally the cross-field innovative output when assessing a firm's technical competence. Breschi, Lissoni & Malerba (2003) suggested that firms' technology diversifications are path dependent, as their innovative activities occur in a systematic way. Diversifications are related in technology fields, based on similar scientific principles or common heuristics. Furthermore, the authors proposed a measure of knowledge-relatedness, which is the co-classification codes contained in patent documents. Their findings suggest firms would choose related fields to expand their specialization, because they gradually increase their knowledge coherence by filling systematically all the classes that are related to those they started with. Instead of taking number of technology classes specified on the patents traditionally used in most previous studies (Patel and Pavitt, 1997; Suzuki and Kodama, 2004), Jaffe (1986) developed a measure based on both the number of technology classes specified on the patents and also the proportion of patent shares to evaluate the technology proximity between two countries in a specific year. We modify this static index to explore the evolving pattern of the firm-level technology proximity through the comparison of patent relatedness of the current period with that of the next period. This paper is the first empirical study to explore the dynamic feature of technology proximity.

## Models and Data

The data sets of this study come from the NBER patent database for the data during 1990 to 1999 and the U.S. Patent and Trademark Office (USPTO, hearafter) website for data ranged between 2000 and 2003. After excluding the unassigned patents, this 14-year panel contains 1,022,744 patents granted to companies based in the US, Japan, Taiwan and Korea. Our sample firms, which have received at least one patent in the US during the sample period, include 52,959 US firms, 8,444 Japanese firms, 1,380 Taiwanese firms and 569 Korean firms.

We first identify the count of patent received by the subject firm each year, and based on the Markov chain principle, we assess the dynamic change of patent performance of each firm between each two-year interval. The transition probability of firm changing its patent state from i to j between year t to year t+1, $P_{ij}$, is defined by

$$P_{ij} = P\{X_{t+1} = j \mid X_t = i\} , \qquad (1)$$

We assert there are four states for the number of patent being granted: 1) zero, 2) one, 3) two to five, and 4) six or more. Therefore, the four-state transition probabilities of patenting could be expressed as

$$P = \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ P_{21} & P_{22} & P_{23} & P_{24} \\ P_{31} & P_{32} & P_{33} & P_{34} \\ P_{41} & P_{42} & P_{43} & P_{44} \end{bmatrix}, \quad P_{ij} \geq 0 \text{ and } \sum_{j}^{4} p_{ij} = 1 . \qquad (2)$$

For example, $P_{23}$ denotes to the probability that the subject firm has changed its status of patenting from state II in year t, to state III in year t+1. The diagonal element of the matrix shows the persistency of innovative activities in one specific state. According to Anderson and Goodman (1957), we use maximum likelihood method to estimate the element in the matrix, $\hat{p}_{ij}$, as

$$\hat{p}_{ij} = \sum_{t=1990}^{2003} n_{ijt} \Big/ \left(\sum_{j=1}^{4} \sum_{t=1990}^{2003} n_{ijt}\right), \tag{3}$$

where $n_{ijt}$ represents the frequency associated with the subject firm that has shifted from patenting state i to state j between year t and year t+1 during the period of 1990 to 2003.

Given a firm has already produced patent output, another issue to explore is how related technologically its patents are over the years. The U.S.PTO assigns each granted patent into one of the $400^{+}$ three-digit patent technological classes. Based on the classification by Hall, et al (2001), we distinguish these patents classes into five groups: (1) Chemical; (2) Electronics, Computer & Communications; (3) Drug & Medical;(4) Mechanical; and (5) Others. These five groups span the technology space. Referring to Jaffe (1986), we develop a measure of technology proximity in the technological space as the distance between the patent distributions of each respective year during the two-year interval for a specific firm k as

$$C_{k,t,t+1} = \sum_{n=1}^{5} f_{k,n,t} \, f_{k,n,t+1} , \tag{4}$$

where the technology proximity of patents pertaining to firm k, i.e. $C_{k,t,t+1}$, is the sum of the product of $f_{k,n,t}$, the share of firm k's patents in year t allocated to group n, and $f_{k,n,t+1}$, the counterpart for year t+1. This index ranges from 0 to 1. If it is high between two years, the subject firm is deemed to produce patents in the related technological space over time, which implies the firm concentrates their R&D efforts in the focal technology fields continuously. On the other hand, for those firms with lower index of technology proximity, technology diversification over time is presumed, since their patents received during the two-year interval spread to different technological categories, so they conduct their innovative activities to other sectors in addition to their original core field.

We further divide $C_{k,t,t+1}$, into three different states: (1) low-level technology proximity of patenting between two years ($0 \leq C_{k,t,t+1} \leq 0.33$);( 2) medium level ($0.33 < C_{k,t,t+1} < 0.66$);and (3) high level ($0.66 \leq C_{k,t,t+1} \leq 1$). We divide $C_{k,t,t+1}$ equally to three states since regression for the C index and the patent count exhibit a normal distribution with the correlation coefficient concentrates in the range of .25--.55. The 1/3 cut-off is therefore applied. The 3-state transition probabilities of technology proximity could be expressed as:

$$P = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \qquad P_{ij} \geq 0 \quad \& \quad \sum_{j}^{3} p_{ij} = 1, \tag{5}$$

with $P_{ij}$ being the probability for firm k to change its status of technology proximity level from state i in the current interval (for example, year t to year t+1) to state j in the subsequent interval (for example, year t+1 to year t+2). Given the model, we could precisely analyze as the firm evolves, whether their innovation efforts would continuously concentrate on few selected fields, or such effort would veer to different directions over time.

## Empirical Analysis

The four-state transition probabilities of patenting on Table 1 show the pattern for innovative persistence. Because the diagonal elements for state I (no patent) and state IV (six or more patents) are relatively high for all of four countries during 1990-2003, both inactive innovators and great innovators have a strong persistence to remain in their states, while persistence is lower in the intermediate states (state II and state III). The remarkable bimodality phenomenon appears not only in advance countries of U.S. and Japan but also the latecomers of Taiwan and S. Korea. However, there are cross-countries differences in the probability of each state. The probability to stay as non-innovator for both US and Japanese firms at the state I is as high as 0.82. As for state IV (six or more patents), the probability for US firms to maintain the same momentum is 0.708, while it is higher (0.795) for the Japanese firms. Regarding to the intermediate states, US firms have a higher probability than the Japanese firms to persistently product one patent (0.18 vs 0.172), yet lower probability to maintain consistently 2-5 patent output (0.332 vs 0.363). These findings are consistent with the study of Cefis and Orsenigo (2001), which is based on a much smaller sample in the earlier period 1978-1993. It demonstrates a long-term tendency that the tenacity of Japanese firms in sustaining their innovative activities is stronger than U.S. firms. In regards to the performance of the latecomers, we find that Taiwanese firms are not as tenacious as the Korean counterparts in sustaining the innovative momentum at state I and state IV, while the former behaves more persistently in state II and state III than the latter.

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Table 1 also demonstrates the inertia of patenting as the transitions tend to be gradual, from one state to the nearest one. In other words, it is much less likely to see a great innovator become abruptly a non-innovator or an occasional innovator becomes suddenly a greater innovator in the subsequent years. Further, from the transitions of state II and state III, it is ubiquitously evident that firms are more likely to recess than improve the innovative momentum. For a firm that produces one patent in the current year, for example, it is more likely to recess to state I (no patent) than to improve to state III (2-5 patents) or even state IV (6 patents) in the following year. However, the likelihoods of improving from state II to state III and from state III to state IV are higher for the Japanese firms than for the US firms; likewise, the probabilities for S. Korean firms are higher than those for Taiwanese firms. In a similar vein, the likelihoods to recess from state II to state I and state III to state II are lower for the Japanese firms than for the US firms. Apparently, Japanese firms (v.s. US firms) and S. Korean firms (v.s. Taiwanese firms) exert a more persistent pattern in their patenting activities over time.

The three-state probabilities of patenting on Table 2 describe technology proximity. Again, the diagonal elements are significantly much higher than the non-diagonal elements for all four countries, which implies the firms with either low-level, medium-level or high-level technology proximity have a strong perseverance to maintain their status quo as time evolves. For those firms that produce patents with high-level technology proximity, they will continue to invest efforts in the similar technology areas, yielding high degree of relatedness over time. In contrast, for those firms whose patents show low-level proximity previously, they will keep diversifying their efforts to other technology areas in the next interval. With further diagnosis of the probability of each state, we find across countries the probability to remain in the LOW-LOW state is the highest among the three states for firms in both advanced and latecomer countries. In the advanced countries, the firms tend to have strong tendency to maintain technology diversification (i.e. low-level technology proximity) between two intervals, and this trait might be stemmed from the needs to integrate multi-field technologies to produce new products in many areas over time, as portrayed by Patel & Pavitt (1997). In comparison, latecomer firms also display similarly strong persistence in technology diversification even thou

gh they lack the kind of knowledge accumulation of the former group. Such apparent similarity might be of different nature. As evidence shown in our empirical data, more than 80% of latecomer firms in the LOW-LOW state are electronics-manufacturing-based. The patents of U.S. (637,375 counts granted from U.S. during 1990-2003) and Japan (326,257 counts) were evenly distributed over a broad spectrum of technology fields, while Taiwan (15,838 counts) and S. Korea (23,274 counts) patents concentrated only in IT technologies. The technologies of S. Korea and Taiwan tend to be application-oriented. It is possible that based on few specialized technologies, they improve and expand production processes of one product to many other over time (Ferguson and Morris, 1993).

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## Conclusion

The existing literature addressing innovative persistence and diversity have focused on analyzing technology competence among firms in the advanced economies. This study is the first to compare such technology attributes among and between the advanced and latecomer economies, to examine the general applicability of prior findings. Also, a dynamic model in analyzing technology proximity is adopted in comparing to the prior static approach. Our study provides evidences that firms in both advanced and latecomer countries have a strong persistence to remain in their states of patenting (particularly for non-innovators and great innovators) and the direction of patenting (particularly for firms with low-level technology proximity) over time. The tenacity of Japanese firms in sustaining their innovative activities is stronger than U.S. firms, while S. Korean firms are more persistent than the Taiwanese counterparts. Remarkably, it is more like to recess then to improve the patenting momentum. For those firms that continue to have patent output, cross-field patenting is commonly observed across the four countries, even though the nature of such diversity is different.

While we have a robust empirical support for the finding, it should be noted that the sources and implications of innovative persistence and diversity remain inconclusive and therefore are important issues for future research. As the determinants for persistence are multifold, and the propensity to patent differs by industry (Reitzig, 2003), it is suggested for future cross country comparison, a specific industrial context should be considered. Additionally, how persistence and diversity in patenting affect firms' technological competence and therefore the firm performance requires further delineation. We believe our empirical work has depicted an interesting phenomenon for innovation intensity and direction over time; however, to analyze the causality and implications, further details of firm level data is required, and future research efforts in this area are encouraged.

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Table 1

Four-state transition probabilities of patenting:1990-2003

| ***US*** | I (No patent) | II (1 patent) | III (2-5 patents) | IV (≥6 patents) |
|---|---|---|---|---|
| I (No patent) | 0.820^ | 0.146^^ | 0.033 | 0.001 |
| II (1 patent) | 0.715 | 0.180 | 0.099 | 0.006 |
| III (2-5 patents) | 0.364 | 0.228 | 0.332 | 0.075 |
| IV (≥6 patents) | 0.051 | 0.040 | 0.201 | 0.708 |
| ***Japan*** | I | II | III | IV |
| I | 0.822 | 0.145 | 0.032 | 0.001 |
| II | 0.713 | 0.172 | 0.107 | 0.008 |
| III | 0.316 | 0.208 | 0.363 | 0.112 |
| IV | 0.035 | 0.022 | 0.148 | 0.795 |
| ***S.Korea*** | I | II | III | IV |
| I | 0.789 | 0.171 | 0.037 | 0.003 |
| II | 0.761 | 0.132 | 0.085 | 0.022 |
| III | 0.382 | 0.209 | 0.276 | 0.133 |
| IV | 0.058 | 0.022 | 0.151 | 0.769 |
| ***Taiwan*** | I | II | III | IV |
| I | 0.799 | 0.167 | 0.032 | 0.001 |
| II | 0.772 | 0.142 | 0.078 | 0.009 |
| III | 0.347 | 0.245 | 0.304 | 0.105 |
| IV | 0.053 | 0.024 | 0.184 | 0.739 |

Note：^ denotes the transition probability；^^the probability that the firm changes from zero-patent state in previous year to one- patent state in the following year.

Table 2

Three-state transition probabilities of technology proximity:1990-2003

| ***US*** | Low | Medium | High |
|---|---|---|---|
| Low | 0.868^ | 0.064^^ | 0.068 |
| Medium | 0.213 | 0.679 | 0.108 |
| High | 0.130 | 0.116 | 0.754 |
| | | | |
| ***Japan*** | Low | Medium | High |
| Low | 0.821 | 0.121 | 0.058 |
| Medium | 0.159 | 0.758 | 0.083 |
| High | 0.103 | 0.203 | 0.693 |
| | | | |
| ***Korea*** | Low | Medium | High |
| Low | 0.832 | 0.183 | 0.066 |
| Medium | 0.138 | 0.742 | 0.062 |
| High | 0.060 | 0.295 | 0.800 |
| | | | |
| ***Taiwan*** | Low | Medium | High |
| Low | 0.900 | 0.044 | 0.057 |
| Medium | 0.164 | 0.687 | 0.149 |
| High | 0.091 | 0.121 | 0.788 |

Note：^denotes the transition probability；^^the probability that the firm changes from the state of low-level technology proximity in previous year to the state of medium-level technology proximity in the following year.

## 2.2 出席國際學術會議報告

### 行政院國家科學委員會補助國內專家學者出席國際學術會議報告

94 年　11 月 25 日

| | | | |
|---|---|---|---|
| 報告人姓名 | 鄭秀玲 | 服務機構及職稱 | 台灣大學經濟系<br>副教授 |
| 會議 時間<br>地點 | 94 年 7 月 4 日至 7 月 8 日<br>美國加州舊金山 | 本會核定<br>補助文號 | 台會合字第 0940033642 號 |
| 會議<br>名稱 | (中文)美西經濟學會第 80 次年會<br>(英文) 80th Annual Conference, Western Economic Association | | |
| 發表<br>論文<br>題目 | 1. Show-Ling Jang, Yang-Ting Tsai, and Jennifer Chen, A dynamic analysis of innovative persistence and technology diversity.(與本計畫直接有關的成果)<br>2. Show-Ling Jang, Ming-Shun Lee, and Jennifer Chen, Technology catch-up and patent citation: The evidence from Taiwan's Flat Panel LCD industry.<br>3. Sonya Wen and Show-Ling Jang, Technological competence and product diversification: The patent study of fables industry. | | |

報告內容：

一、參加會議經過

本人此次與兩位台大國企所博士班學生，陳慧如和文馨瑩,，一起參加會議，共同發表三篇有關我國 LCD 產業，IC 設計產業的創新活動和專利引證行為分析的論文。有機會與其他國家的產經學者共同討論，獲取不少有用的評論。

二、與會心得

此次美西經濟學會有來自 U.C., Berkeley, U.C.L.A., Stanford University 及其他美國西岸的經濟學者，以及太平洋沿岸例如日本，韓國，中國，香港，和新加坡等經濟學家共聚一堂，發表研究論文，是一極為難得的國際學術交流的機會。

三、考察參觀活動(無是項活動者省略)

至 Stanford University 的圖書館收集與研究相關的專利和產業資料。

四、建議

應鼓勵國內年輕學者和博士班學生多參與此類國際性會議。

五、攜回資料名稱及內容

本次會議議程表，內有所有此次發表於年會的論文題目和發表人之 e-mail，日後可與作同一領域的學者聯絡，交換研究心得。

六、其他

無

# 三、計畫成果自評

本研究計畫是二年期研究計畫中的第二年計畫，是有關 R&D, patent and Knowledge spillover 的研究，主持人、相關的研究生及助理已成為國內少數知道如何充分應用美國專利資料庫和相關文獻進行一系列有關產業科技研究的研究團隊。我們的研究也可以幫助政府相關機構擬定政策之參考。