Resistant, Path Creation, or Resilient? An Empirical Study of 87 Innovative Cities Worldwide

Chan-Yuan Wong and I-Kim Wang

This study proposes rigorous concepts of resilient, resistant, and path-creation behaviors for urban patenting and innovation studies. The study examines the responses of cities with different regional innovation system (RIS) characteristics when facing a crisis. The concepts allowed us to identify resilient cities based on crisis responses and RIS characteristics. Our study identified cities exhibiting resilient behaviors, such as Taipei and San Jose, demonstrating the ability to recover from a crisis in terms of patenting and sustain high levels of performance in localized learning. For cities with resistant behaviors, such as London, we observed that their momentum for patenting decreased, although they were endowed with RIS performance comparable to the resilient cities. Cities such as Shenzhen exhibit path-creation behaviors, demonstrating the ability to transform and achieve performances on par with the resilient cities. Unformed RIS cities demonstrate low patenting activities and have yet to configure a base for technological activities. The concept and formulated quantitative process to distinguish cities performing in patenting lay new ground for studies on urban economic resilience.

Keywords: Resilient, Patenting Cities, Cluster Analysis, Taipei, London, Shenzhen

JEL Classification: O34; R10

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I. Introduction

Resilient cities (or industrial regions) are a subject of great interest in urban economics and regional studies. Many scholars have been interested to understand what makes a city resilient to crises. They sought to examine how economic shocks (*e.g.*, financial crises) affect a local economy and eventually defined "resiliency" in terms of recovery from the time of uncertainty (see all chapters in Ferreira, 2018). Wong *et al.* (2022) reviewed how cities recover and propagate their technological venturing momentum and reinforce their patenting capacities following adverse economic events. Some studies elucidating resiliency in terms of upgrading aimed to shed light on how local firms upgrade to avoid their industrial value being migrated away (Xiao *et al.*, 2018; Wong *et al.*, 2021). Then, Boschma (2015) particularly emphasized the points on industrial diversification and adaptability as they enable local firms to search for niches in the global production value chain.

As economic geographers increasingly delved into the studies on industrial upgrading from urban and regional perspectives, they questioned how a city can become technologically competent and resilient. They maintained that resilience is vague and perplexing (Sweeney *et al.*, 2020)—particularly when scholars are mistakenly conflating resistant[1] cities with resilient ones. Markusen (2003) elaborated that the lack of conceptual coherence and vague conceptualization is not an uncommon issue in urban and regional-economic studies. In some cases, cities (regions) were first viewed as resilient, but then, this assumption was questioned after an episode of falling apart or gradual industrial decline from a crisis. In other cases, cities acknowledged as resilient cases eventually turned out to be vulnerable.

Following the examination of the city patenting resilience exercise reported by Wong *et al.* (2022), the present study seeks to ensue

[1] This is referring to cities that resist to diversify their core industries but take the risk of falling into outright failure during a time of crisis.

regional resiliency studies by providing a (more) rigorous concept of resilience for urban patenting and innovation studies. We aim to provide a more holistic concept compared with other studies, which we captured in our reading of the relevant literature. We used patenting data to build empirical substantiation to validate our concept and view. The data are instrumental in deriving indexes and in distinguishing between cities that manifest resilient behaviors and those that are resisting—generally denoted as cities that failed to adapt or transform to lay new industrial growth paths. This study will contribute to urban economics and innovation studies in terms of a better understanding of the resilient concept and empirical evidence that supports it.

II. Literature Review

Adopting the evolutionary view to examine the industrial dynamics of a region is not uncommon in regional studies (*e.g.*, Asheim *et al.*, 2011; Boschma, 2015). The conceptual aspects of systemic and endogenous change enabled many scholars to map what made a region capable of commanding industrial technologies and adaptable to its economic environment. Several studies examined the regional policies (*e.g.*, Cooke, 2001; Sohn *et al.*, 2016) of regions dynamically capable of industrial development. They sought to draw development lessons and general principles that had laid an industrial foundation useful to propagate productive activities for a long period of time. A regional innovation system (RIS) is a framework to examine the structural dynamics of a regional productive system in propagating innovation, including guiding regional stakeholders to learn the functional roles in promoting innovative activities common in regional policy–related studies (Cooke, 2001). These studies highlighted the importance of systemic failure identification and understanding of institutional inertia that discourages local innovation from deriving and obtaining a meaningful and impactful policy process. A region needs persistent commitment in developing local capabilities to derive technological innovations—and, therefore, the ability to gain from new productive industrial activities. Such capabilities are crucial for locals to search out niches in the global production value chain and (re)configure new industries. Regions with unformed RIS witnessed inconsistent pursuits to develop their capabilities. These regions are unlikely to prioritize technological learning as their wealth is derived from non-productive means, and their (superficial) commitment to industrial upgrading would be unhandled (completely)—particularly when they face uncertainty, such as a devastating economic crisis.

Lee (2013) adopted the evolutionary view to assess how developing economies catch up with technologically advanced nations. He observed that to catch up, the developing economies need to acquire productive routines and gradually commit to learning new technologies. As the economies advance, they leapfrog the technological dominance of advanced nations by adopting emerging technologies to produce state-of-the-art technologies. They also configure new industries and lead new industrial standards as their derived technologies gain dominance in the market. The emergence of technological leapfrogging is particularly prominent when an economy (or industry) seeks to take advantage of a crisis, that is, when certain productions are curtailed, and the advanced technologies (assets) to construct such productions are in low demand. Such an economy aspires to outperform the forerunners and seeks the dominance of a certain industry—it would acquire ownership of advanced technologies at a favorable price and utilize them to improve productivity or introduce state-of-the-art technologies at a low cost (Lee and Ki, 2017, p. 372). The regions of such an economy that are endowed to perform new growth or "path creation" would be aggressive as the crisis presents a window of opportunity for local firms to upgrade. In other words, local firms and other regional entities (public research institutions, local government, *etc.*) would coordinate and organize a routine that can take stock and allow aggressive technological learning while the rest of the world shrinks back from expanding their industries. Kim and Lee (2022) demonstrated the commitment to learning and technological catching up from a regional perspective. The study presented the case of Shenzhen of China, and the process toward achieving a developed region is germane.

The evolutionary view is also found useful in understanding the concept of regional resilience. Boschma (2015) related resilience to the ability of a region to accommodate shocks in a time of crisis and pursue new skills of related varieties. A region that has routinized technological localization[2] and is endowed with a wide range of

[2] Technology localisation is understood as the ability of a region with local industrial knowledge to generate new knowledge.

related industries enables local entities to gain from inter-industry learning and new combinations. Such learning is termed "adaptation," whereas coping with external shocks and adapting toward unrelated knowledge/industrial domains is "adaptability" (p. 739). Cities such as Seoul of South Korea and Taipei of Taiwan (Wong *et al.*, 2020) inherited technological competencies in semiconductor industries and demonstrated adaptation capabilities in their patterns of technological localization. The cities shared many characteristics with Silicon Valley of the US in driving regional technological activities.

Sweeney *et al.* (2020) examined regional economies that had faced shocks and disruptions owing to crises but did not demonstrate characteristics of resilient regions. Notwithstanding that they may be endowed with certain specialized industrial activities, they are trapped—as their current industries do not allow new industries to branch out. The regions tend to lock in to a trajectory of decline. They attempt to cope and endure when they encounter a crisis—given that, unlike resilient regions, they lack the ability to perform "adaptation" or create new growth paths for their economies. Their transient coping and responding mechanisms are viewed as "resistant," and their recovery from a crisis resumes a trajectory of industrial maturing (if not decline). Sweeney *et al.* (2020) used Canada's automotive industry since 2000 as a case study to demonstrate their points about resistance. Indeed, many old cities in the developed world share resistant characteristics as they are trapped within old industrial routines (Boschma *et al.*, 2015; Xiao *et al.*, 2018) that inherently constrain regions from performing technological adaptation.

Menzel and Fornahl (2009) elaborated on industrial cluster life cycles and how local firms localize learning and influence technological convergence. They stylized the stages of cluster development and elucidated how clusters that are reaching the declining stage instead achieve recovery through adaptation and transformation for a new growth trajectory. Propis and Bailey (2021) explored endogenous transformative paths from a technological innovation capabilities point of view. Their case of the auto production system in Bavaria and Baden-Württemberg underlines many resistant characteristics in the studies of resistant regions. The region had laid a localized learning routine to develop its auto technologies. The locked-in routine made local firms reluctant to learn technologies of electric mobility and autonomous driving. Moreover, they shunned related technological niches developed outside the region that could have been blended with their own. The firms in the region ultimately lagged behind in patenting new technologies and are facing an eroding market share among Germany's premium brands.

Many in the literature (whether on resilient or resistant regions) hold some sense of regional development reality as the insights are drawn from elaborate case studies. However, those qualitatively derived insights from selective case studies are elusive on whether the regional characteristics can be systematically quantified and captured—which would allow regional industrial dynamics examination and determine if a region is resilient or resistant when it faces a crisis. Moreover, Menzel and Fornahl's (2009) view on the cluster life cycle is demonstrated without the aspect of shock in the course of cluster development. Many previous studies disregarded using quantitative measures to examine resilient and resistant regions. Hence, our study seeks to lay an approach through RIS indexes that are useful in two ways. First, this process is to generally categorize the technologically related responses of a region during the time when it faces a crisis. Second, the approach would demonstrate if a region is resisting or performing adaptation to sustain certain technological advantages. We will also determine if a region is consistently transforming for new growth path creation or inherits unformed RIS and struggles to perform technological activities.

III. Conceptual Guide

This study sought to examine the different responses made by regions with different RIS and patenting performances during times of shock (crisis). For this study, we used the 2008 Global Financial Crisis as the shocking incident impacting a world that was committed to patenting activities. The crisis is germane to our study as it caused a global downturn in financial activities and pulled many high-tech firms away from committing to technological ventures. We seek to distinguish which regions adapt to recover and then remain competitive; which regions persist in transcending in patenting to capture the window of opportunity for path creation; which regions resist resuming pre-existing gradual decline; and which regions remain unformed in RIS and probably retreat from patenting in the time of crisis. Figure 1 shows the projection of each group trajectory. The chart consists of two axes: one denoting patent counts and the other denoting composite RIS-related indexes (labeled as RIS8; see explanation in the following sub-section).

It is believed that resilient and resistant regions obtained functional RIS in dwelling for innovative activities. They are likely to have experienced the process of industrialization (Asheim *et al.*, 2011) and gained considerably advanced productive activities over at least a decade in driving the local economy. What distinguishes them are their responses during a crisis. There are regions capable of sustaining their high level of RIS and remaining competitive technologically. These regions host productive and technologically advanced firms, and together with these firms, the regions configure new niches in the global production value chain. There are also regions with high RIS endowments, which lost their momentum to compete as their economies develop. Some cities in the US and Europe are good cases in point (Boschma *et al.*, 2015; Xiao *et al.*, 2018). They were once competitive and their footprints in the technological market were prominent. However, as the regions matured, they settled into a productive routine that is only functional within their respective closed-loop regional networks and resisted adapting or transforming in accordance with the global environment. Their rich endowment (and resource slack) may enable them to recover from a shock. However, they would likely re-adopt to their old routines and resume their pre-crisis decline in terms of leading new technologies. The unwillingness to adapt or transform has caused

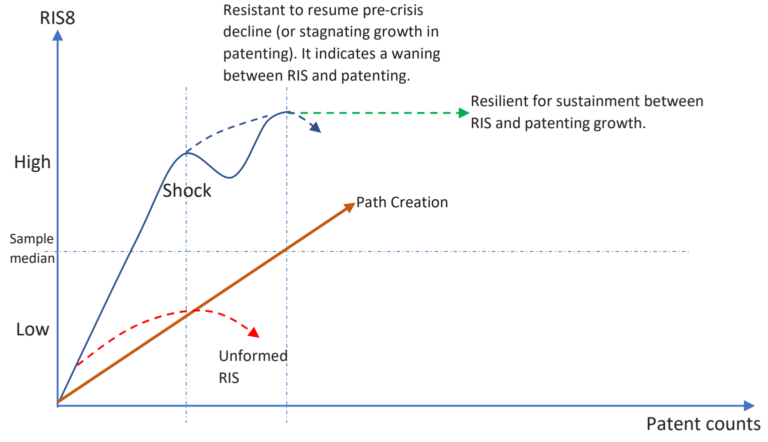


Figure 1
Typology For Resilient, Resistant, Path-Creation, And Low-Ris Regions

them to gain little traction in configuring a new growth path in their technology development trajectories.

Regions manifesting path creation ability would be seen as aggressive. They are consistent in improving their RIS and are driven to achieve technological competitiveness comparable to that of the resilient regions. We will likely observe a steep learning curve from these regions in advancing functional RIS while seeing a probable causal effect on their patenting growth. Regions with unformed RIS, from another aspect, operate under dysfunctional RIS in driving technological activities. The term is used here to designate cities that show little signs of patenting capabilities that can match any of the other three groups. As these regions lack consistent local efforts in driving local technological learning and configuring new growth path creation, they are unlikely to maintain their RIS and patenting activities—with or without a shock.

IV. Data and Patenting Indexes

This study denotes the city as a proxy for the study of a region. A city denotes a common space where technological activities are concentrated in a nation. It is generally endowed with better financial and human resources compared with less industrialized regions and is more able to mobilize them to derive high(er) value-added activities. For this study, we utilized the patenting data[3] and indexes of Wong *et al.* (2020) to examine the RIS performance of 87 cities. See Appendix 1 for RIS indexes. The criteria which are set for city selection for our study are similar to those of Wong *et al.* (2022, p.5). We seek a balance of inclusivity in the selection of cities. We targeted two cities from most nations based on the rank of gross domestic product per capita. Some cities of interest are covered too. As a result, Canada, Germany, India, Italy, Japan, South Korea, and the UK each have three cities, whereas bigger and more productive nations such as the US and China each have a total of five cities in this study.

City patents proxies as the outcome of technological activities driven by RIS. The 87 cities include performing cities in patenting from developed and developing nations. The city patenting data were

[3] We extracted (granted) patenting data from the US Patent and Trademark Office's database.

processed to devise eight indexes that are common in patenting and quantitative-driven innovation studies (Jaffe and Trajtenberg, 2002; Lee, 2013). The eight patenting indexes are as follows:

1. Diversification—how diverse a region is for venturing into different patenting classes.
2. De-concentration—1 minus the concentration index to assess how evenly the regional patents are distributed among local entities.
3. Intra-regions collaboration—the extent of intra-regional inventor distribution.
4. Inter-regions collaboration—the extent of inter-regional inventor distribution.
5. University-industry linkages—co-patenting ratio of firms and universities.
6. Science-based linkages—the significance of non-patent references in patent citations.
7. Localization—the significance of local patents in generating new patents. In this study, it helps us to distinguish whether a region is capable of laying localized learning for patenting activities.
8. Cycle time[4]—the age of the average citations that a region relied upon to produce new patents.

The eight patenting indexes are aggregated to derive a composite index that reflects the extent to which local entities are capable of governing their RIS and commanding the process of deriving new technological activities. The indexes are normalized between 0 and 1. We label this composite index as RIS8.

We deployed cluster analysis to group cities based on the eight patenting indexes as attributes. Our cluster analysis sought to observe which cities were similar to each other during a crisis (2008) and how they configured themselves after the crisis (2010 and 2012) compared with cities originally in the same cluster. The cities which stayed consistent with their attributes remained within the same group during and after the 2009 crisis. The resultant groups and their cities from cluster analysis were then cross-examined with the RIS8 index,

[4] For Cycle Time index, we denote long cycle (8 years or above) time as 1, short cycle (1–7 years) time as 0.5, and 0 as patent without citation.

TABLE 1

INDICATIONS FOR RESILIENT, PATH-CREATION, RESISTANT, AND UNFORMED-RIS CITIES.

	Resilient	Path Creation	Resistant	Unformed RIS
RIS8	High	Rising	High	Low
Localization	High	Rising	High	Low
Patenting in post-crisis period	Rising	Rising	Low	Low
Note	Regions that acquired localized learning and laid RIS for technological activities. Regions can perform adaptation in the time of crisis to recover and to remain competitive in post-crisis period.	Aggressive regions that took advantage of a crisis to construct new niches by transforming routines and leapfrogging the dominant technologies of the forerunners.	Regions that have laid their locked-in localized learning. Their advanced RIS can lead a recovery from a crisis but only to its pre-crisis trajectory of decline. That is, the learning routine has stalled new technological ventures.	Regions that embed dysfunctional RIS and are unable to develop localized learning routines.
Key source of reference	Boschma (2015)	Lee (2013)	Sweeney *et al.* (2020)	Studies about dysfunctional innovation systems, *e.g.*, Godinho et al. (2006) and Intarakumnerd (2018)
Indications in the typology (Figure 1)	High and sustained RIS8; increasing in patent counts in post-crisis period.	Pattern of improvement in RIS8, increasing in patent counts.	High and sustained RIS8; stalling or resuming the pre-crisis gradual decline in patent performance.	Low RIS8, low patent counts.

patenting counts, and localization index. Finally, we labeled the groups based on the proposition criteria we constructed in Table 1.

V. Results and Discussion

We implement a statistical test to ascertain structural breaks in our panel data to verify whether there is a change in patenting trend following the 2008 financial crisis (Ditzen *et al.*, 2021; Karavias *et al.*, 2022). The reason is that the major events in the panel data are likely to impede our ability to draw causality between observed variables. This test is developed and tested to detect the breaks, such as the COVID-19 outbreak. We applied the test to our patent data without informing it of any known breaks in the data. The null hypothesis is no breaks. The test statistics (τ = 33.18, p-value $<$ 0.001) rejects the null, suggesting three structural breaks. The test identifies breaks that occurred in 1999 and 2007–2008. See Appendix 2 for the two dips for the cases of Taipei, London, Shenzhen, and San Jose. These breaks correspond to major economic downturns that occurred during the sampling period.

We completed our journey on this study by compiling RIS indexes of 87 cities. Table 2 reports the performances of selected cities. Cities such as San Jose of Silicon Valley (United States), Taipei of Taiwan, Seoul of South Korea, and London of the United Kingdom are endowed with high RIS8 performance. High RIS-performing city here denotes cities performing at or above the sample median RIS8 value (3.41). Cities such as Dubai of the United Arab Emirates and Mexico City of Mexico are performing below the RIS8 median value. Cities such as Shenzhen of China are somewhat achieving the level of performing cities. As we performed cluster analysis and cross-examined against a longitudinal RIS8 study, we distinguished four groups of cities by what responses they made during the time of the 2008 Global Financial Crisis. Table 3 reports our observations, and Appendix 3 reports the cities' movement in our cluster analysis between 2008 and 2012.

There are resilient cities achieving relatively high RIS8 and demonstrating the ability to localize technological learning (Localization). These cities had the ability to recover from a shock and were able to maintain their competitiveness in terms of the RIS8 value and momentum in patenting for long periods of time. Resistant cities shared similar high RIS8 performance and the ability to lay technological learning. However, they responded to the 2008 crisis with resistant behavior. Their post-crisis momentum for patenting shrank or demonstrated stalled growth in patenting activities. They exhibit strong RIS that is useful to maintain their (accumulated) productive assets.

However, they show an inability to exploit RIS to perform adaptation and regain growth momentum for their technological activities. We observed that many cities from the developed world are grouped under resistant cities in our cluster analysis.

For cities with path creation behavior, they demonstrate a pattern of trending up for RIS8 and patenting counts. They are aggressive in localized learning and show a pattern of catching up to close the RIS performance gap with the performing cities. Meanwhile, cities with unformed RIS achieved relatively low RIS8 and showed virtually no intention for localized learning. They do not have elaborate patenting activities. Appendix 4 compared the performances of selected cities having Taipei and San Jose to represent resilient cities, London as resistant cities, and Shenzhen as path creation cities.

A. Resilient City: The case of Taipei

The case of Taipei for the resilient group is particularly revealing. It has a yearly patenting performance comparable to that of San Jose and also achieved comparable localized learning performance (Table 2). Taipei attained a strong intra-region network for patenting but performed relatively lower in terms of the inter-regional patenting network compared with San Jose.

Figure 2 shows polynomial smooth plots for Taipei's RIS8 and Localization performances. It demonstrated the ability to build patenting activities before the 2008 crisis but witnessed a transient contraction of RIS8 performance between 2002 and 2005 because of the Dot-com bubble in 2000 (Figure 2a). It subsequently recovered, and the 2008 Global Financial Crisis did not affect its sustainment of RIS8 throughout the end of the 2000s and 2010s. As a part of the most significant high-tech cluster of Silicon Valley, San Jose witnessed a decade of slow patenting growth, thereby leading to poorer RIS8 performance after the Dot-com bubble.

Taipei's localization has been consistent (Figure 2c) and is tailed by the momentum for city patenting. Taipei has exhibited a clear pattern of resilient cities in this study. The case of Taipei in this study coincides with the observation of Kim and Lee (2022), highlighting the ability of this early developed city to maintain strong RIS performance and patenting activities.

Table 2

RIS Indexes of Selected Cities, 2012

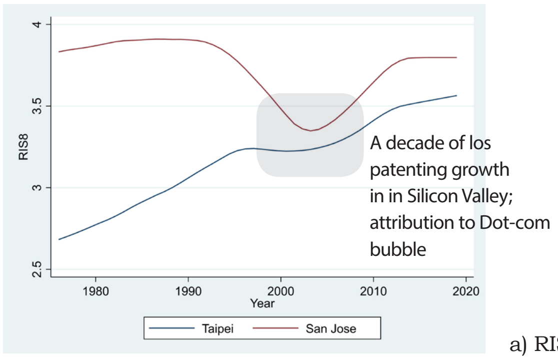
	Group	Patent Count	Patents per million capita	Diversification	De-concentration (1-Concentration)	Intra-regions collaboration	Inter-regions collaboration	Univ-Industry Linkages (U-I)	Science-based linkages	Localization	RIS8
Mexico City	Unformed RIS	18	0.87	0.166	0.71	0.72	0.17	0	0.33	0	3.10
Dubai	Unformed RIS	12	5.7	0	0.819	0.42	0	0	0.66	0	2.90
London	Resistant	359	43.5	0.24	0.97	0.66	0.16	0	0.77	0.03	3.85
Shenzhen	Path creation	1826	171	0.19	0.81	0.93	0.01	0	0.35	0.05	3.35
Seoul	Resilient	3189	319	0.20	0.77	0.59	0.39	0.02	0.47	0.06	3.52
Taipei	Resilient	3490	1342	0.28	0.94	0.8	0.13	0.01	0.21	0.06	3.45
San Jose	Resilient	3384	3547	0.10	0.98	0.46	0.5	0	0.67	0.07	3.79

Note: The cycle time for the selected cities is 8 years or above. They each obtained one for the cycle time index.

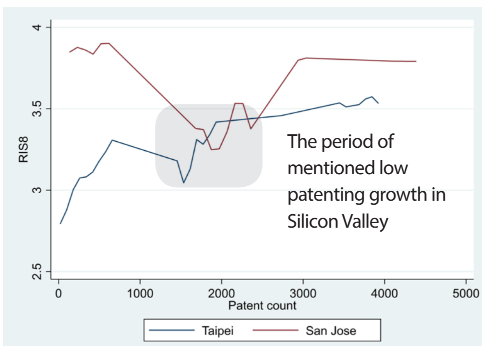
Table 3

Groups, Criteria, and Cities

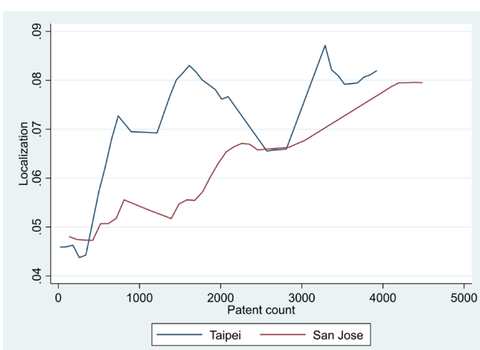
Group	Criteria (meeting as least two of the following)	Cities					
Unformed RIS	Relatively low in RIS8 (below or at the border of median value) Relatively low localization index Relatively low patenting counts	Dubai Mexico City Pretoria Bogotá K. Lumpur		Buenos Aires Santiago Cairo Bucharest Abu Dhabi Luxembourg Suwon		Sao Paulo Johannesburg Kiev Ankara Bangkok Penang Jakarta	
Resistant	Relatively high RIS8 (above or at the border to median value) Relatively high in localization index Relatively low or stalling in yearly patenting counts	Berlin Amsterdam Basel Copenhagen Lyon Suzhou	Milan Hamburg Brussels Auckland Warsaw Manchester Paris	Stuttgart Vienna Helsinki Rome Vancouver Munich Zurich	Singapore StPetersburg Eindhoven Turin Dublin Nagoya Prague	Toronto Shanghai New York Daejeon Tokyo Osaka	Stockholm Hong Kong Tel Aviv Haifa Moscow Los Angeles
Path creation	Rising RIS8 Rising in the localization index Rising in yearly patenting counts	Pune Hangzhou Hsinchu		Shenzhen Bangalore Bucharest		Delhi Ottawa Austin Cairo	
Resilient	Relatively high RIS8 (above median value) Relatively high in localization index Relatively high in yearly patenting counts	Seoul Seattle		Taipei	Beijing San Jose		



a) RIS8 v time



b) RIS8 v patent counts



c) Localization and patent counts

Note: Taipei witnessed a fluctuation of localization performance in the time when it was performing at the low patenting base in the 1970s and 1980s.

Figure 2

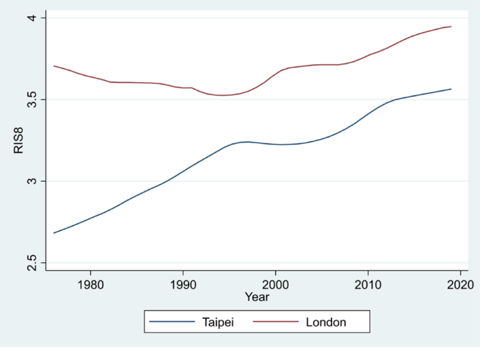
Polynomial Plots for RIS8 and localization: The case of Taipei compared to San Jose

B. Resistant City: The case of London

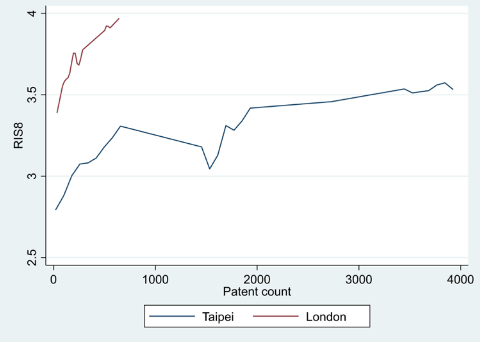
London is denoted here as a case of city resistance. It was once a heralded city for state-of-the-art technologies, and it had championed world trade by commanding the world's manufacturing activities in the 19th century. The servicing sector in London such as banking and finance rose alongside manufacturing. London witnessed a fall in its manufacturing competitiveness—losing out to the developing nations as the world intensified global trading for functional cross-border production value chain in the mid-20th century. London's servicing sector however then triumphed, whereas the city retained high value-added activities such as R&D that propelled some science-based industries (*e.g.*, pharmaceutical and biotechnology).

Figure 3a shows the significant RIS8 of London since the 1970s. The high RIS8 performance is generally sustained throughout the decades between 1976 and 2018. It did witness a brief patenting decline in 1997 and 2005 but swiftly recovered in the following years. However, such performance is not coevolved with that of patenting counts. Although the 2008 Global Financial Crisis did not affect its RIS8 performance, it witnessed comparatively low patenting counts and localized learning (Figure 3b,c) compared with that of Taipei (and San Jose) over the same period of time.

The case of London to some extent demonstrates many struggles of developed cities in advanced economies (Boschma *et al.*, 2015; Xiao *et al.*, 2018). They are relatively rich owing to their productive assets (*e.g.*, prior patenting routine and productive firms), which were accumulated over many decades. Cities such as London may be viewed by some to have the commanding power in Fintech (*e.g.*, Irrera and Krouse, 2014; Harris, 2021). However, a bigger picture of city patenting tells us that they are witnessing declining capabilities in technological activities. We conjecture two possibilities. First, these resistant cities are trapped in their industrial specializations, which inherit low technological potentials for the cities to perform adaptation when they face an industrial value migration problem (Boschma *et al.*, 2015). Second, they have long abandoned the commitment to drive technological-related competitiveness even before the 2008 Global Financial Crisis and only invest in non-productive sectors that do not populate many technological activities. These cities did recover from the 2008 crisis or else were not affected by it. However, they recovered only back to



a) RIS8 v time



b) RIS8 v patent counts

c) Localization and patent counts

Note: Similar to Taipei, London also witnessed a fluctuation of localization performance when it was performing at a low(er) patenting base between the 1970s and 1990s.

Figure 3

Polynomial plots for RIS8 and localization: The case of London compared with Taipei the pre-crisis patenting decline as their technological industries were becoming irrelevant in the global production value chain.

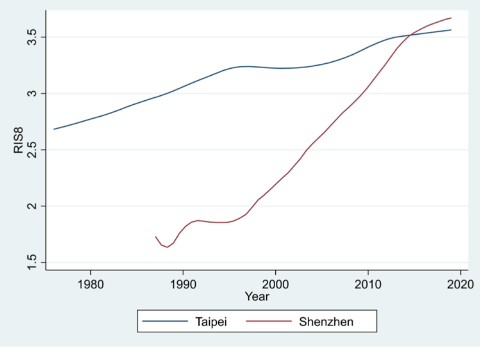
C. Path Creation: The case of Shenzhen

The case of Shenzhen is germane to path-creation cities. It witnessed a fluctuating RIS performance between 1987 and 2000 before a drive to stabilize put it at an aggregate level between 2.4 and 3.0 from 2003 to 2010 (Figure 4a and 4b). The 2008 Global Financial Crisis had little impact on Shenzhen's RIS8 performance. The city seems to have captured the window of opportunity to advance its RIS performance and step-up the efforts to localize learning (Figure 4c). The patenting counts of Shenzhen are coevolving with its RIS8 performance. Shenzhen's performances in RIS8 and patenting counts are closing the gap with that of advanced cities, such as Seoul and Taipei.

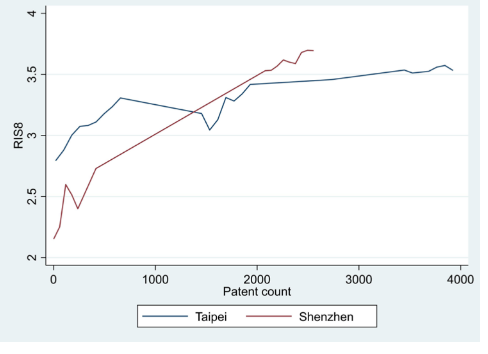
The aggressive industrial catching-up and advanced technological activities in Shenzhen are not uncommon in the literature (Shi and Shi, 2021; Kim and Lee, 2022). Shenzhen in the 1980s was a region endowed with contracted manufacturing activities. Within a period of 20 years, the city had transformed its economic endowment—from one dependent on low-cost imitative-based manufacturing to a vibrant economy driven by high-tech start-ups and high value–added manufacturing for the ICT industry. The city manifested the ability to perform transformation and create a path toward functional RIS to propagate technological activities. Other cities demonstrating similar path creating behavior are Pune (India), Bangalore (India), Dehli (India), Hangzhou (China), Austin (the US), Hsinchu (Taiwan), Ottawa (Canada), Cairo (Egypt), and Bucharest (Romania).

D. Unformed RIS Cities

Unformed RIS cities generally demonstrate some ability to patent but not as much as the performing cities, such as Taipei and Seoul. The cities may have the intention to upgrade and bring forward technological push-based industrial development agendas (*e.g.*, Wong and Salmin, 2016; Wong, 2017; Intrakumnerd, 2018) using state expenditure budgets (*e.g.*, projects to encourage academics in public universities to patent their inventions). The efforts may drive some public research entities to patent but not enough to localize learning and lay a productive routine for patenting activities. It is not enough to



a) RIS8 v time



b) RIS8 v patent counts

c) Localization and patent counts

Figure 4

Polynomial plots for RIS8 and localization: The case of Shenzhen compared with Taipei trigger momentum from the market to "pull" demand for technological-oriented industrial activities.

Mexico City (Table 2), along with cities in developing economies, and some cities in the rich world are grouped under unformed RIS. Generally, the patenting base is low, and therefore, it is not possible to observe the change in patenting counts before and after a shock. The localization is low or virtually non-existent, and the RIS8 performance is below the median. Their economies may have been captured by non-technologically based industrial structures and have yet to configure a routine to transform and populate technological activities.

VII. Conclusion

This study provided a rigorous concept of resilience for urban economics and innovation studies. We formulated a quantitative process to distinguish patent-performing cities into four groups based on their responses during the 2008 Global Financial Crisis. The criteria that qualify a city for a group are set based on RIS8 performance, patenting counts, and localization. This study has solidified the concept of regional resilience and made resiliency more empirical and qualifiable for analysis.

This study distinguished cities into four groups. The group with resilient characteristics exhibits high RIS8 performance and demonstrates adaptation ability to maintain it after a shock. Their RIS8 performance is coevolving with routines to localize learning and their comparatively high patenting activities. Taipei shows such characteristics and obtained patenting performance comparable to that of San Jose and Seoul. The resistant group demonstrates comparable performances in terms of RIS8. However, such performance does not coevolve with patenting activities and localization. Resistant cities performed relatively lower in patenting and ability in localized learning compared with resilient cities. They did show the ability to recover from a shock but only to the level of pre-crisis decline—as their regional industrial value is being migrated away to more competitive regions.

We observed that path-creating cities are aggressively catching-up to the performance levels of resilient regions. Their RIS8 and localization advanced significantly, and their patenting activities intensified over the last two decades. They see crises as a window of opportunity to transform and are driven to advance RIS and localize learning for long-term post-crisis regional resilience. Unformed RIS cities, from another aspect, exhibit low RIS8 performance and achieve low patenting activities. They obtain a low patenting base and produce patenting counts way below that of resilient cities. Such a base has yet to kindle the formation of RIS that is instrumental to populating technological activities.

This study contributes to the literature of urban patenting and innovation studies in terms of understanding among notions of adaptation (implying sustainment performance of a resilient city), transformation (denoting a city that is capable of configuring a growth path, particularly in a time of crisis), and resistant (city only recovers to pre-crisis decline). As the aspect of shock is not elaborated explicitly in Menzel and Fornahl's (2009) view on the cluster life cycle, the typology and analysis in this study enable us to better understand the concept of resilience in achieving functional RIS. This research laid new ground for the studies of regional resilience. The study has also made a step toward a comprehensive taxonomy development for city responses in times of uncertainty. This study calls for more research to explore other possible crisis responses and characteristics of the four city groups in future studies.

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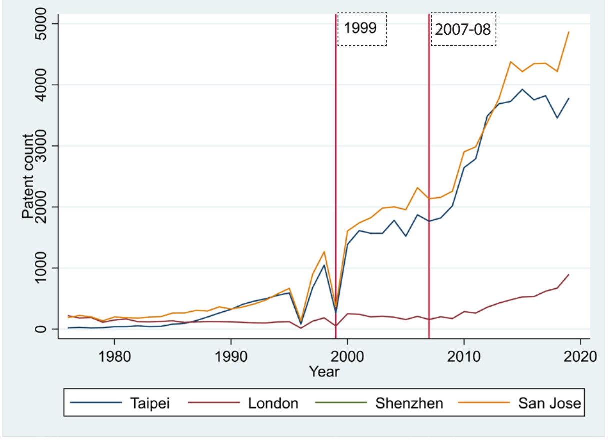
Appendix 1
RIS Indexes

	Localization	De-concentration	Collaboration	Diversification	Cycle time (Backward)	U-I Linkage	Science-based linkage
Equation	$A - B = \frac{n_{xx}}{n_{xt}} - \frac{n_{cxt}}{n_{ct}}$	$1 - HHI$ $= 1 - \sum_{i \in x} \left(\frac{N_{it}}{N_{xt}}\right)^2$	$N_x = I_{1,xc} \cap I_{2,xc}$ $G_x = I_{1,xc} \cap I_{2,c}$	$\left(\frac{N_i}{tech\ class_t}\right) xt$	Granted year of citing patent x – granted year of patent y cited by x	$\frac{N_{u+f}}{N_{xt}}$	$\frac{Nref_{sb}}{N_{xt}}$
Variable explanation	A is the probability of the x region's patent citing its own patent. n_{cxt} is the number of citations of location x's patents by all patents, except for its patents filed in year t. n_{ct} is the number of all citations made by all patents granted in year t, except for location x's patents.	N_{it} is the number of patents granted by assignee i in year t. N_{xt} is the total number of patents granted by region x in year t. Note: We use the top five assignees. We use 1 – HHI to express the decentralization of the concentration.	N_x = inter-regional collaboration G_x = international collaboration Intra-regional collaboration $= 1 - (N_x + G_x)$ I_{xc} – inventor from that region (1, 2) I_c – second inventor outside the region	N_i is the number of technological classes that region x has filed for patents in year t. Technology class t is the total number of three-digit patent classes in the US patent classification system in that particular year.		N_{u+f} is the number of co-patents (derived from co-assignee information) between the university and the company. N_{xt} is the total number of patents granted by location in x in year t.	N_{refsb} is the number of patents that cite (at least) a non-patent reference. N_{xt} is the total number of patents granted by location in x in year t.
RIS8	RIS8 = S_Localization + S_1-HHI + S_IntraCollaboration + S_InterCollaboration + S_Diversification + S_Cycle Time + S_U-I Linkage + S_ Science-based linkage Note: "S_" denotes standardized index						

Source: Adapted from Wong and Lee (2022, pp. 986-988) and Wong *et al.* (2022, p. 6).



Appendix 2
Patent Counts for the Cases of Taipei, London, Shenzhen, and San Jose

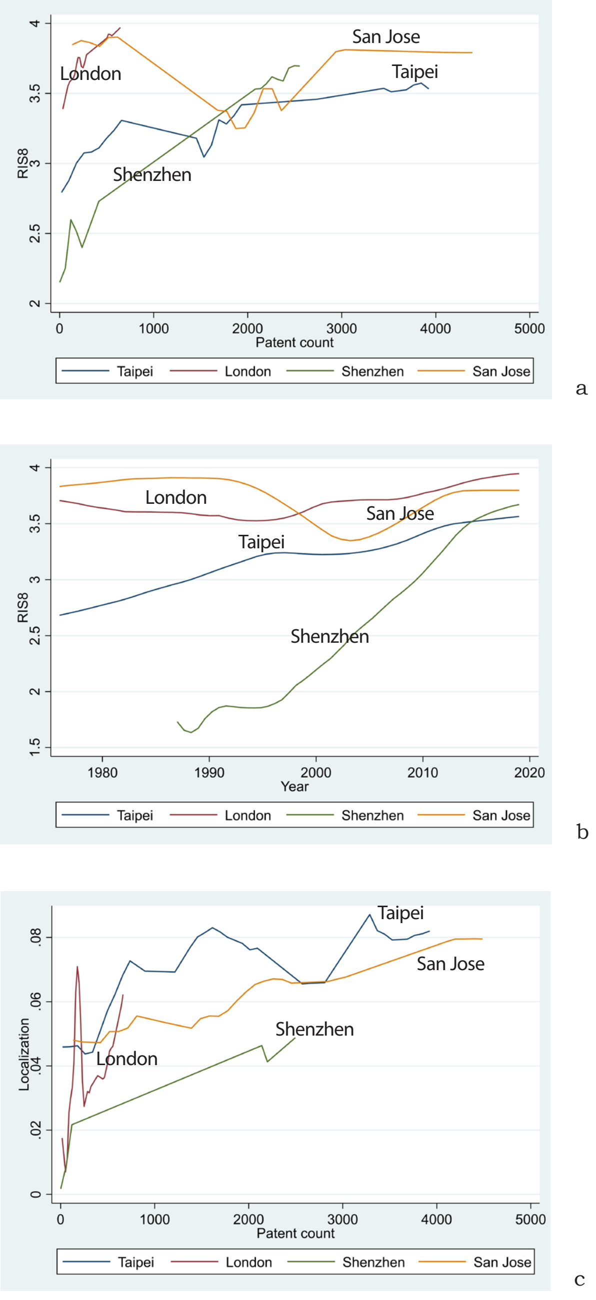
Appendix 3

Cities' Movement in the Cluster Analysis between 2008 and 2012

Group	Cities	
	2008	2012
Unformed RIS	Dubai (1), Mexico City (1), Pretoria (1), Bogota (1), Bogota (2), Kuala Lumpur (1), Buenos Aires (1), Santiago (1), Abu Dhabi (2), Luxembourg (2), Sao Paulo (1), Johannesburg (1), Kiev (1), Suwon (3), Istanbul (1), Ankara (2), Bangkok (1), Penang (3) Jakarta (3)	Dubai (1), Mexico City (1), Pretoria (1), Bogota (1), Bogota (1), Kuala Lumpur (1), Buenos Aires (1), Santiago (1), Abu Dhabi (1), Luxembourg (1), Sao Paulo (1), Johannesburg (1), Kiev (2), Suwon (3), Istanbul (2), Ankara (3), Bangkok (2), Penang (3), Jakarta (2)
Resistant	Berlin (3), Amsterdam (2), Basel (2), Copenhagen (2), Lyon (2), Milan (2), Hamburg (3), Brussels (2), Auckland (2), Warsaw (2), Manchester (2), Paris (3), Stuttgart (3), Vienna (3), Helsinki (3), Rome (3), Vancouver (3), Munich (3), Zurich (3), Singapore (3), St Petersburg (3), Eindhoven (3), Turin (3), Dublin (3), Toronto (3), Shanghai (3), New York (3), Stockholm (3), Hong Kong (2), Tel Aviv (3), Haifa (3), Moscow (3), Los Angeles (3), Daejeon (3), Tokyo (3), Osaka (3), Nagoya (3), Prague (3), Suzhou (3)	Berlin (1), Amsterdam (1), Basel (1), Copenhagen (1), Lyon (1), Milan (1), Hamburg (1), Brussels (1), Auckland (1), Warsaw (1), Manchester (1), Paris (2), Stuttgart (2), Vienna (2), Helsinki (2), Rome (2), Vancouver (2), Munich (2), Zurich (2), Singapore (2), St Petersburg(2), Eindhoven (2), Turin (2), Dublin (2), Toronto (2), Shanghai (2), New York (2), Stockholm (2), Hong Kong (2), Tel Aviv (2), Haifa (2), Moscow (2), Los Angeles (2), Daejeon (2), Tokyo (2), Osaka (2), Nagoya (2), Prague (2), Suzhou (2)
Path creation	Pune (3), Hangzhou (2), Shenzhen (3), Bangalore (3), Delhi (3), Ottawa (3), Austin (3), Hsinchu (3), Cairo (3), Bucharest (2)	Pune (3), Hangzhou (3), Shenzhen (3), Bangalore (3), Delhi (3), Ottawa (3), Austin (3), Hsinchu (3), Cairo (3), Bucharest (3)
Resilient	Seoul (3), Seattle (3), Taipei (3), Beijing (3), San Jose (3)	Seoul (3), Seattle (3), Taipei (3), Beijing (3), San Jose (3)

Notes:

1) Most unformed RIS cities are categorized under group 1. Highlighted cities (in green) under unformed RIS are categorized into groups 2 and 3. They are in unformed RIS because of low RIS8 performance. Suwon (RIS8 = 3.17), Kiev (3.32), Istanbul (3.25), Ankara (3.10), Bangkok (3.24), Penang (3.10), and Jakarta (2.44) were performing under the sample median (3.41) in 2012.
2) For resistant cities, we observed cities that were once advanced in 2008 (in group 3 or 2) were then regressed in 2012 after the financial crisis (in group 2 or 1).
3) Path-creation cities are ones moving from unformed RIS to a somewhat comparable level to that of resilient cities in times of crisis. They are Pune (from 3.10 in 2008 to 3.59 in 2012), Hangzhou (from 3.09 to 3.44), Shenzhen (from 2.44 to 3.35), Bangalore (from 3.29 to 3.51), Delhi (from 2.82 to 3.60), Austin (from 3.09 to 3.73), Hsinchu (from 2.87 to 3.52), Ottawa (3.16 to 3.77), Bucharest (from 2.79 to 3.38), and Cairo (from 2.49 to 3.37). Arguably the case of Cairo may not fit this group as it achieved low localization performance.



APPENDIX 4

RIS AND LOCALIZATION PERFORMANCES OF SELECTED CITIES

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