The Evolution of the Taiwanese Smart City Industry

Thesis in the field of regional development

for a PhD Degree

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Declaration page

I, Lin-Fang Hsu confirm that the work presented in my thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

The boom in smart city studies from the early 2000s resulted in a bifurcated understanding of smart cities, leading to divergent definitions of the technologies used. Despite fluctuating interest across regions, these practices have persisted, even without the ‘smart city’ label. Empirically, this thesis addresses the gap in existing literature, which lacks studies on the aspect of technology production, by exploring its definition, industry evolution outcomes, policies, and processes. This study utilises evolutionary economic geography and contributes to the theory by addressing three key limitations: 1) the lack of an exogenous perspective on ‘radical innovation,’ 2) the limited explanation of the state’s role, and 3) the obscurity of actor-structure interactions.

A mixed-method approach is employed to study the Taiwanese case, where local firms have extensively developed smart city technologies since the 2000s, supported by state industrial policies. The data includes: 1) a patent database from keyword collection and patent selection, 2) policy reports and government/industry documents, and 3) semi-structured interviews with government and industry experts.

The findings show, firstly, that diversification is inherent to smart city innovation, contrasting with the specialisation of traditional ICT production, thus creating exogenous elements that drive transformation in local industries. These structural changes are reflected in the emergence of software sectors, the rise of collaborative networks between large and small firms, and research institutions, as well as a locational shift in clusters. Secondly, the developmental state’s legacy plays a significant role in industry evolution, though with limitations. While government-business networks and innovation protection mechanisms are pragmatic, they often overlook individual industry needs. Finally, new industrial systems have emerged as non-tech companies join the ICT sector. Over time, innovation activities that deliver integrated solutions have brought about structural changes within Taiwanese ICT industries, demonstrating the impact of smart city innovation on regional development.

Impact statement

This research contributes to revealing transformations in the industrial landscape generated by smart city development. This is an undervalued aspect in regional development studies, which focuses mainly on technology use. In fact, the activities innovating in and producing smart city technologies have injected critical elements propelling evolution for regional industries. Understanding the emerging sectors for developing technologies applied to smart cities is crucial for academia, government, and industries.

Academic impacts are expected to be empirical, methodological and theoretical. The thesis empirically explores the evolution of a new industry in Taiwan, the experiences of which would be a valuable reference for countries aiming to facilitate relevant sectors to grow and coordinate smart city development with local technological capabilities. Then, the study develops an innovative methodology to define smart city technology based on patent analysis, which lays the foundation for the next study of smart city technology and industry in other countries. We can collect and compare worldwide smart city innovation in varied contexts for cross reference as more cases are explored. Lastly, by filling the exogenous understanding gaps in the theory of evolutionary economic geography (EEG), this research enables EEG scholars to enter into a new phase of exploring exogenous innovation and regional evolution.

Parts of this study have been presented at events to increase its impact. The methodology of this study and the results of smart city policy and patent analysis (empirical) have been presented at leading international conferences and workshops under the themes of economic geography, regional study, East Asian geography and smart city in New York (online), Cork, Dublin, South Korea, Taipei, Turin, Florence and London, including the 2022 Association of American Geographers (AAG) Annual Meeting, the 6th Global Conference on Economic Geography (GCEG), the 2022 East Asian Regional Conference in Alternative Geography (EARCAG), the 2024 Regional Studies Association (RSA) Annual Conference, the Humanising the Smart City Workshop, etc.

The thesis will be used to publish four journal articles, including 1) a critique of smart city literature, 2) methodology-based research and its analysis results, 3) an empirical study of a state’s industrial policies and 4) comparative research between East Asian countries’ smart city policies.

Furthermore, the theoretical foundation and methodology developed by this research can be used to explore exogenous-element-driven technological innovation and regional development, e.g. electric vehicle (EV) battery batteries, renewable energy technologies, digital nomad, etc.

The benefits outside academia have been made to policy-making through informal consultancy for a research organisation, the Connected Cities Catapult. The author shared research findings relevant to the mechanism of industrial policy-making and -implementation and the overview of industrial actors in local high-tech industries with this organisation for its UK-Taiwan collaboration initiative to develop city innovation strategies. The analysis of the technology development trajectory can be summarised into an industry overview to disseminate to industrial actors and think tank researchers who participated in this study for their reference when developing future innovation or collaboration initiatives.

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Chapter 1: Introduction

This thesis explores the production activities related to smart city innovation by examining the emergence of the smart city industry in Taiwan, supported by the state's industrial policies, through the lens of regional development.

1.1 Research Background

Key Forces Driving Smart City Development Globally

Since the mid-2000s, high-tech companies worldwide have sought new market opportunities for city technology applications, particularly following IBM's promotion of the *Smarter Planet initiative* in 2008 (Palmisano, 2008). IBM and other big tech firms popularised the concept of the smart city and marketed their technological solutions to city governments globally, leading to a surge in production activities for smart city innovation. Alongside industry efforts, the public sector has played a significant role in driving smart city innovation (see Figure 1). Although governments in different regions adopt various attitudes and approaches towards smart city development, their involvement in such projects is almost inevitable. For example, North American city governments have strongly supported big tech corporations by involving them in procurement processes (Hollands, 2008; Palmisano, 2008; Zukin, 2020; Carr and Hesse, 2022); East Asian states have actively promoted the development of smart-city-related sectors (Hu and Zheng, 2021; Joo, 2023); local authorities in Western European countries have coordinated small-scale initiatives (Mora, Reid and Angelidou, 2019); state-owned corporations have spearheaded city development in the Middle East (Hollands, 2015; Angelidou, 2017); and nations in the Global South have implemented urban infrastructure improvement policies (Das, 2020; Guma and Monstadt, 2021; Park and Yoo, 2023) (see Table 1). Among these global trends, East Asian cases stand out for their vibrant technology production, driven by collective efforts of industries and governments through industrial policies.

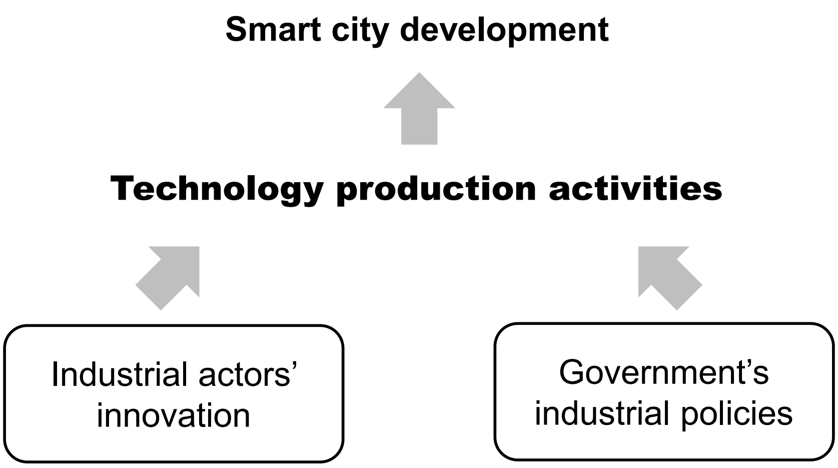


Figure 1 Key forces driving effective technology production for smart city development

(Source: author's own compilation)

Table 1 Global trends of smart city development

Global regions	Governments' efforts	Production activities carried out by
North America	City governments' procurement	Big tech corporations
East Asia	States' industrial policies	Local tech industries
West Europe	Local authorities' coordination	Local small companies
Middle East	State-owned corporations	International tech firms
Global South	National governments' plans for infrastructure improvement	International tech firms

(Source: author's own compilation)

Evolving Focuses in Smart City Literature

With the increasing practices and aspirations surrounding smart cities, the concept has garnered burgeoning academic attention. The notion of the smart city emerged within a cluster of urban discourses related to innovation and technology (Sonn and Park, 2023), including the *creative city* (Florida, 2002), *ubiquitous city* (Greenfield, 2010), *network city* (Castells, 2010), *connected city* (Neal, 2013) and *technopole* (Castells and Hall, 1994), among others. With these technology-favoured tendencies, the debates on whether 'using' technology can make cities smarter became trendy in published research after 2010 (Mora, Bolici and Deakin, 2017), which has subsequently dominated foci throughout evolving frameworks developed by smart city scholars. The literature has shifted from focusing primarily on technology to placing greater emphasis on human-centred concerns (Kummitha and Crutzen, 2017; Kitchin, Cardullo and Feliciantonio, 2019), and from aspiring to widely embrace technology (Nam and Pardo, 2011) to critiquing the issues it has triggered (Galdon-Clavell, 2013; Hollands, 2015; Vanolo, 2016; Lim, Edelenbos and Gianoli, 2019a).

Research Gaps: Definition Ambiguity and Limited Production-Side Discussions

Over the past two decades, the proliferation and diversification of smart city studies (Komninos and Mora, 2018) have made the field more comprehensive but increasingly fragmented (Mora, Bolici and Deakin, 2017; Mora, Reid and Angelidou, 2019). Consequently, some fundamental elements—such as a precise definition of a smart city—remain without consensus (Mora, Bolici and Deakin, 2017).

The most widely accepted definition posits that smart city technologies are grounded in information and communication technology (ICT). However, this broad understanding fails to capture the distinctive characteristics of this specific technology set. Some studies, in their attempts to define smart city technologies, adopt either narrow or overly broad perspectives. For instance, computer science and engineering research often focuses on specific techniques such as low-rank adaptation (LoRa) (Sandoval, Garcia-Sanchez, and Garcia-Haro, 2019), 5G (Jiang, 2021), edge computing, blockchain, artificial intelligence (AI), and software-defined networking (Jo *et al.*, 2019). Conversely, social science approaches categorise broader areas, such as the Internet of Things (IoT) (Caragliu and Del Bo 2019), or rely on ICT as an all-encompassing category (Mora, Reid and Angelidou, 2019). These approaches often result in imprecise definitions. This imprecision can lead to the inclusion of irrelevant techniques, contributing to ambiguity in defining smart city technologies and their related industries within existing social science literature.

In addition, the innovation of smart city technologies remains an underexplored area within social science. Existing studies have paid limited attention to how these technologies are ‘produced.’ Even regional development literature, one of the primary sources explaining technological innovation and industry development, has offered limited discussion on the emerging sectors relevant to smart city innovation and technology production. Studying the production side of smart city innovation is critical, as the changes brought about by these technologies in regional development occur not only during their ‘use’ but also during their ‘production.’ Innovation activities in the production of smart city technologies have the potential to significantly transform regional industries (Sonn, 2021), as reflected in changes to the sectoral composition (Lambooy, 2010). Conversely, innovation activities are shaped by the unique capabilities of each region (Martin and Sunley, 2010), underscoring the importance of understanding the production side to fully grasp the interrelationship between smart city technology innovation and regional development.

Given the ambiguous definition and the lack of research on the production perspective of smart cities, it remains unclear whether new technologies have been specifically invented for smart city development or technologies developed for other purposes are merely applied to smart city. Moreover, while technological innovation is often driven by industries, governments’ industrial policies also play a critical role in shaping the direction of technology production for smart city development—a factor that is undervalued in existing smart city literature. In summary, there is limited research examining the production process of smart city technologies, including how these technologies evolve from existing innovations, who produces them, where their production takes place, and how industrial policies influence these innovations.

1.2 Smart City Innovation in Taiwan

Case Selection

Taiwan is selected as the case study for this smart city industry research because of its local industries’ ability to produce a comprehensive array of smart city technologies. Among countries capable of innovating across a wide spectrum of ICT patents—such as the US, Japan, South Korea, Taiwan, and China (Prato and Nepelski, 2014; 經濟部智慧財產局, 2021; OECD, 2025)—Taiwanese industries and the government have collaborated in a relatively coherent manner. Consequently, their long-term efforts have significantly contributed to measurable progress in local industries and facilitated their evolution, making Taiwan a suitable case for this study (see Chapter 4 for details).

Emergence of Smart City Innovation in Taiwan: An Overview

In the early 2000s, Taiwan’s ICT industry sought to upgrade its technological capabilities in response to manufacturing relocation pressures from China (Chen and Wen, 2013). The potential smart city market prompted tech companies to prioritise innovations specifically targeting smart city development. By the mid-2010s, Taiwan's industrial policies aligned with the global smart city trend, utilising government resources to further promote smart city innovation within local industries (Wu, 2020). Through the combined efforts of firms and government policies, smart city innovation in Taiwan has evolved with the goal of establishing a unique sector that represents a shift from the traditional trajectory of Taiwanese ICT industries. Given this empirical context, the emergence and evolution of the smart city industry can be explored from two aspects: the production activities of industrial actors and the government's industrial policies.

While Taiwan's smart city industry initially emerged from the expansion of its ICT sector, it has evolved over the past two decades into a new industry extending beyond traditional ICT, driven by external influences from the imported smart city concept. Taiwan has long been renowned for its ICT production, with its first science park established in the early 1980s. By 2018, the value-added share of the ICT sector accounted for 16.7% of Taiwan's total gross domestic product (GDP), the highest figure in the world (Mas *et al.*, 2021). This solid foundation in ICT industries has enabled the production of smart city technologies.

Leveraging this strength, both the government and industry in Taiwan view promoting smart city development as an opportunity to drive technological innovation (Wu, 2020). Specifically, the central government aims to use smart city technologies to transform local industries from being hardware-centric to becoming comprehensive producers. Consequently, the country approaches smart city development from the perspective of technology creation rather than simply applying existing technologies. To achieve this, a series of industrial policies have been implemented by government authorities at both central and local levels.

City governments are the primary clients of Taiwan's domestic smart city firms. The country is divided into twenty-two administrative divisions, comprising six Special Municipalities, thirteen Counties, and three Cities (see Table 2). Special Municipalities have larger populations and greater revenue compared to Counties and Cities. Each division is governed by its local city government. Consequently, the progress and accomplishments of smart city development across these administrative divisions (hereafter termed 'cities') vary due to differences in local government priorities and resources allocated to city development policies.

Under the national smart city policy, the central government set a goal to implement smart city projects in at least nineteen cities with state support (IDB, MOEA, 2017). Between 2017 and 2020, the Taiwanese government allocated a special budget of six billion TWD to fund high-tech firms developing smart city technologies (IDB, MOEA, 2017). By the end of 2020, 295 smart city projects featuring innovative concepts had been realised through collaboration between high-tech firms and local governments (IDB, MOEA, 2020). Taiwan's experience highlights a strong connection between smart city development and its local ICT industries.

Table 2 Administrative divisions of Taiwan

Administrative division	**Name of city**	**Population (2023)**	**Revenue (million TWD) (2023)**
Special Municipality	Kaohsiung	2,737,941	164,326.40
	New Taipei	4,041,120	188,543.40
	Keelung	2,845,909	157,206.50
	Tainan	1,859,946	111,027.90
	Taipei	2,511,886	205,199.00
	Taoyuan	2,317,445	128,550.60
Country	Changhua	1,239,048	58,029.09
	Chiayi	484,560	36,743.39
	Hsinchu	589,289	33,194.32
	Hualien	317,489	29,409.93
	Kinmen	144,149	12,792.64
	Lienchiang	14,039	5,391.27
	Miaoli	534,575	30,951.20
	Nantou	477,094	33,138.88
	Penghu	107,739	12,883.15
	Pingtung	794,997	55,303.89
	Taitung	211,544	24,348.37
	Yilan	449,890	29,620.48
	Yunlin	659,468	43,848.45
City	Chiayi	263,584	18,304.49
	Hsinchu	456,475	26,261.45

Administrative division	Name of city	Population (2023)	Revenue (million TWD) (2023)
	Keelung	362,255	24,368.35

(Source: Office of the President Republic of China (Taiwan), 2024; National Statistics, 2024)

Technology Industry Development in Taiwan

The foundation of Taiwan's ICT industries was established between 1960 and 1980 (Kenney, Breznitz and Murphree, 2013). During this period, foreign electronics companies made their first investments in ICT manufacturing in the country. The most significant investment was Philip's establishment of the first picture tube manufacturing factory in 1970, which symbolised the beginning of Taiwan's electronics industry gaining technological capabilities from multinational corporations (Van Der Putten, 2004; Kenney, Breznitz and Murphree, 2013). At the time, most local technology firms operated as original equipment manufacturers (OEMs).

In the 1970s, with the ambition to upgrade the local electronics industry, the Taiwanese government prepared to foster local tech firms to develop integrated circuits (IC). Thus, the Industrial Technology Research Institute (ITRI), a public research institute, was founded in 1973 with the support of the Ministry of Economic Affairs (MOEA). ITRI developed specific government-identified technologies and nourished research groups preparing for spin-offs. Soon after, in 1980, the Hsinchu Science Park was founded, which was a milestone in the Taiwanese ICT industry. Since its establishment, the country's high-tech sectors have taken shapes, including IC, computers and peripherals, telecommunications, optoelectronics, precision machinery, and biotechnology (Lee and Yang, 2000). A few world-leading semiconductor foundries, like Taiwan Semiconductor Manufacturing Company (TSMC) and United Microelectronics Corporation (UMC), were spin-offs of ITRI and the earliest companies in the Hsinchu Science Park. Meanwhile, local original design manufacturers (ODMs) emerged in the mid-1980s. Local Taiwanese firms' technological capabilities then fast accumulated from the 1990s onwards through interactions with key international high-tech firms. At that time, consumers and users in the Asia-Pacific region gained greater significance to the global IT industry's innovation processes: as a result, advanced technologies were again transferred from international high-tech firms to local ones (Hsu, 2014).

This unique history laid the foundation for technology innovation and creation originating from East Asia. Within this context, Taiwan's smart city industry evolved, driven by two key catalysts that spurred its later vigorous development. The first emerged from the pressure of technological capability upgrading under the climate of industry relocation. Since the 2000s, China has become the primary offshore production site for the Taiwanese ICT industry (Chen and Wen, 2013), shrinking local clusters of high-tech manufacturing. The firms remaining in the cluster had to seek a new way to survive. Despite the offshore relocation trends, most high-tech firms' R&D functions remained in Taiwan (Chen and Wen, 2013), which fortunately went on to nurture the development of smart city technologies. Secondly, the smart city concept was rising during a period of manufacturing decline and thus has been considered a new target for Taiwanese ICT firms to shift their production. High-tech firms were eager to take advantage of their established capabilities to access this new market, even though the smart city concept was unfamiliar.

Industrial development and state policy in Taiwan have been inseparable due to the developmental legacy left in Taiwan (Wade, 2018). This development pattern contributes to significant economic and industrial advancement, and this success can be attributed to institutional endowments (Carroll and Jarvis, 2017). It should be also noted that the legacy of state-led economic development from earlier decades have a significant impact on smart city-related industrial policies.

Transforming ICT: Taiwan's Industrial Policies and the Rise of Smart City Innovation

After 2000, the Taiwanese government made significant efforts to upgrade its ICT sectors, facilitating the transformation of local OEMs and ODMs into service- and solution-oriented high-tech firms. Among the relevant industrial policies, the earliest initiative to directly identify smart city development as a catalyst for ICT upgrades was proposed in 2014. That year, the Executive Yuan launched the '4G Smart Broadband City Application Scheme' (4G Scheme) ('4G 智慧寬頻應用城市補助計畫'), which was implemented the following year.

With continuous government backing, Taiwan's smart city industry grew steadily in the 2010s and flourished especially after 2016, when the Taiwanese government introduced a pivotal policy: the 'Digital Nation & Innovative Economic Development Program' (DIGI+ Program) ('數位國家・創新經濟發展方案'). This programme aimed to transform Taiwan into a 'Digital Nation and Smart Island' and has since served as the backbone of Taiwan's smart city strategic development (Wu, 2020). Building on this foundation, an overarching policy—the 'Program for Promoting Six Core Strategic Industries' ('「五加二產業創新計畫」六大核心戰略產業')—was implemented to realise the goals of the DIGI+ Program. This programme integrates and advances six key industries, aiming to transform traditional manufacturing through value-added business models (Wu, 2020). Under this policy framework, the 'Smart City Taiwan' (智慧城鄉) policy serves as an umbrella strategy, enabling diverse innovative technologies to address domestic demand. By 2020, local high-tech firms had delivered more than two hundred smart city projects.

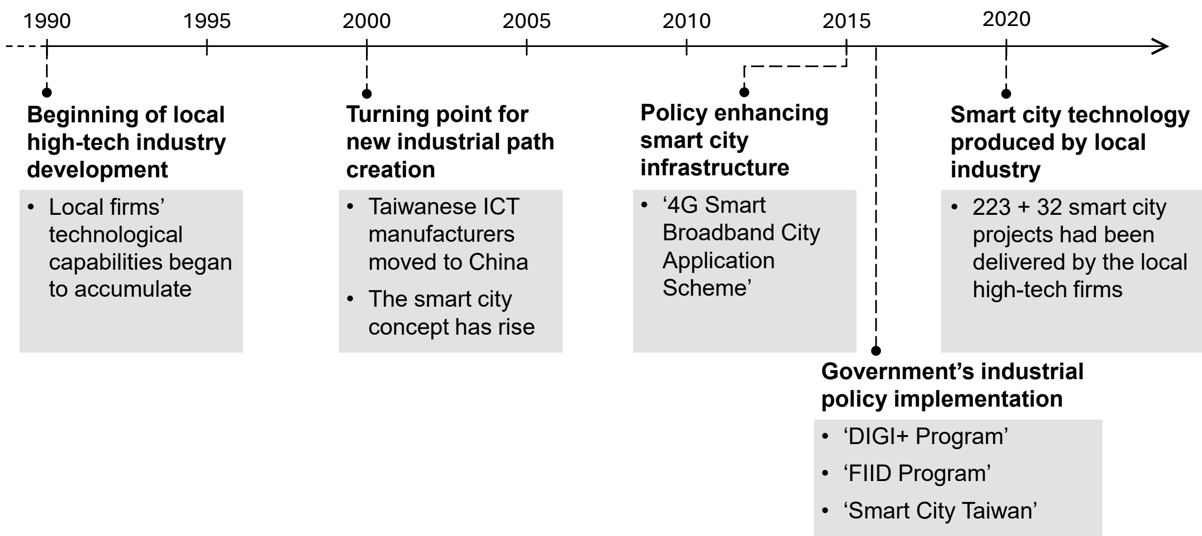


Figure 2 Timeline of events relevant to the development of Taiwan's smart city industry

(Source: author's own compilation)

During the same period, parallel initiatives were undertaken by industries. The smart city concept was introduced to Taiwan in the 2000s and gained traction after IBM launched the *Smarter Planet* initiative in 2008 (Palmisano, 2008). By the late 2010s, the local industry had gradually developed the capacity to independently execute smart city projects. In response to requests from influential local industrial actors, the Taipei Computer Association, with government support, began hosting the annual Smart City Summit and Expo (SCSE) in Taipei in 2014.

Following the first expo, the Taiwan Smart City Solutions Alliance was established under the Taipei Computer Association. The founding members included five companies—IBM’s Taiwan branch, Tatung Company, Chunghwa Telecom, ASUS Cloud, and Advantech—and two government agencies: the ITRI and the Institute for Information Industry (Taiwan Smart City Solutions Alliance, 2024). The alliance was created to locally promote the smart city concept in Taiwan by fostering the engagement of key industrial actors. In its early years, the chairmanship of the alliance rotated among the founding members from industries (Taiwan Smart City Solutions Alliance, 2024). Later, it was taken over by leaders from a more diverse range of companies, including system integrators, security system services, and motorbike manufacturers. By 2022, the number of exhibitors had grown from 100 in 2014 to 450. Over the years, these events have served as a platform for Taiwanese firms to actively promote their smart city technologies and explore business and collaboration opportunities.

The composition of the alliance’s founding members reflects that, in addition to traditional ICT high-tech manufacturers, telecom companies have also been actively involved since the expo’s inception. Meanwhile, changes in its chairmanship demonstrate the growing significance of system integrators and even some non-tech companies in the Taiwanese smart city industry. Additionally, IBM’s participation in this local promotion underscores, to some extent, the diffusion of US innovation to Taiwan and highlights the role of external forces.

Along with industrial policies and the emergence of increasingly diverse actors in smart city innovation, new production activities were expected to transform traditional Taiwanese ICT industries. For instance, at the 2018 SCSE, Acer showcased its smart parking system for the first time, with its visual recognition system as the main selling point—distinct from the company’s traditional PC manufacturing expertise. Similarly, Taoyuan’s smart lamppost system, which won the Innovation Award at the 2019 SCSE, highlighted a new form of collaboration in the ICT industry, led by a telecom company with participation from electronics manufacturers. Additionally, many city governments hoped to leverage their smart city development to attract relevant companies and form new industry clusters. Overall, the rise of these new activities was anticipated to reshape the industrial landscape, driving changes in technological innovation, key industrial actors, and the locations of ICT sectors. To understand the extent to which such anticipation has been realised in driving technological, organisational, and locational transformations within Taiwanese ICT sectors, it is essential to study smart city development from the perspective of production activities.

As stated, this research aims to explore the production side of smart cities. In this context, Taiwan's smart city development, closely tied to local production activities and the state's industrial policies, serves as a suitable case for this study. On one hand, the legacy of the developmental state, which continues to influence the industry, may shape the evolutionary pathway of the smart city sector, with government industrial policies actively facilitating its growth. On the other hand, dynamic local ICT industries, combined with the participation of new actors, have the potential to drive innovation by creating novel technology combinations, introducing innovative solutions, and diverging from traditional ICT practices.

Smart City Technology Production: Discrepancies Between Literature and Empirical Insights

In the existing literature, the concept of a smart city reflects aspirations to 'use' technology to enhance economic performance, energy efficiency, social well-being, and governance effectiveness (Mora, Reid and Angelidou, 2019). As previously discussed, while interpretations of technologies used in smart cities vary, much of the dominant literature directly links smart city technologies to ICT (Caragliu, Del Bo, and Nijkamp, 2011). In Taiwan, smart city innovation has been regarded as an extension of the existing capabilities of its ICT sector. However, although these perspectives appear consistent, an examination of the 'production' activities related to smart city technologies reveals that their scope extends beyond the traditional ICT products of Taiwanese tech firms, which primarily focus on manufacturing consumer electronics, and even beyond ICT-enabled products like motorbikes. This highlights the imprecision in defining this technology set.

Under the 'Smart City Taiwan' policy, the government has identified technological applications for local industries to develop and use in smart cities, spanning various domains such as transportation, energy, safety, and more. While this aligns with the uses of technology discussed in smart city literature, the production activities associated with these applications are reflected in the participation of more diversified industrial actors in smart city innovation compared to traditional ICT sectors in Taiwan. Furthermore, as the smart city concept was invented externally—meaning that Taiwanese tech firms adopted the idea from overseas companies—its associated innovations did not originate from local capabilities. Technological solutions for smart cities, as interpreted by IBM, are based on the integration of multiple systems and data (Buijsen *et al.*, 2011). In line with this guidance, industrial actors specialising in system integration and software techniques—extending beyond the technological capabilities of local ICT manufacturers—have gained significance in Taiwan's smart city industry. These new elements may catalyse radical innovation—distinct from incremental improvements to existing capabilities—within Taiwan's high-tech sectors, driving the structural changes in local industry composition that this research aims to examine.

Lastly, governments serve as the primary clients for smart city companies, emphasising the critical role of industrial policies in driving smart city innovation. Consequently, the evolution of this emerging industry is heavily influenced by government policies on urban development and industrial strategies, coordinated by the state at multiple levels. Accordingly, industrial policies represent an important aspect of studying production activities related to smart city innovation.

In order to address the research gaps in existing smart city literature, this study aims to identify the technologies invented for smart city development and examine the production activities of emerging industrial sectors, as well as the industrial policies supporting their growth.

1.3 Evolutionary Theoretical Framework

Studying Smart City Technology Production through Regional Development Literature

The research gap—a lack of understanding of the production side of smart city technology innovation—can be effectively addressed by drawing on regional development literature, where technological innovation has been a central focus. Among the various theories in regional development, evolutionary economic geography (EEG) emerges as the most effective framework for explaining the production aspect of smart cities. Although EEG has certain limitations that warrant consideration, other theories and approaches in contemporary economic geography and regional development face even greater challenges. For example, New Economic Geography (Krugman, 1998; Fujita and Krugman, 2004) tends to oversimplify spatial effects into distance decay and struggles to integrate cultural, political, and social dimensions of regional development. Global value chain and global production network approaches primarily focus on interactions between multinational corporations and regions, leaving little scope for examining the role of public policy.

The development of regional industries is closely linked to innovation, which drives technological, organisational, and territorial transformations, propelling industry evolution (Storper, 1997). Smart city innovation and regional development interact dynamically, each shaping the other's evolutionary path. EEG offers a comprehensive framework for understanding how regional industries evolve through technological innovation (Boschma and Martin, 2010). Therefore, this study adopts EEG as the theoretical foundation to analyse how smart city innovation-related production activities drive changes in the industrial landscape and to examine the role of government-led industrial policies in supporting these regional transformations.

However, as previously stated, smart city technology production in Taiwan is characterised by two main features: it extends beyond local technological capabilities and is heavily driven by industrial policies. These production activities, fuelled by radical innovation, have the potential to bring significant changes to the industrial environment in regions pursuing this emerging market opportunity. Specifically, smart city innovation, which deviates from traditional industrial development paths and is coupled with government intervention in its emergence, can transform the industrial structure. Under these circumstances, the theory of EEG faces significant limitations in explaining this type of innovation. Overcoming such limitations and enhancing explanatory power of EEG on smart city is the theoretical contribution of this thesis.

EEG's Limitations

First, in the EEG arguments, regions' innovation and industry development are explained through the exploration of a region's endogenous elements, like firms' activities within it (Kogler, 2015; Schumpeter, 1934; 1942). As a result, regional evolution driven by exogenous factors—such as smart city innovation that extends beyond local capabilities (Pike, Rodriguez-Pose, and Tomaney, 2017)—is difficult to explain using EEG. Second, despite the rich discussions of institutions in EEG

(Boschma and Frenken, 2006; Hassink, Klaerding and Marques, 2014), the institutional environment and power dynamics shaped by the state's industrial policies cannot be understood as a generic setting, borrowed from the concepts of institutional economic geography (IEG), geographical political economy (GPE) and relational economic geography (REG) to EEG. The theory has not clarified the state's distinct role beyond organised institutions, which may drive structural changes in regional industries—namely, transformations in sectoral composition (Lambooy, 2010)—through industrial policies (Dawley, 2014).

Lastly, EEG argues that a region's structure determines how industrial actors innovate to produce smart city technology. In the context of this research, agents (or actors) are defined as firms participating in production activities for smart city innovation, and the industrial structure is composed of networks that connect these firms to selection environments. However, radical innovation in smart city technology does not emerge from the local industry structure, nor does it follow the ordinary path. In this context, the structure does not predominantly play a shaping role but is, to some extent, passively reshaped by the actions of industrial actors engaged in radical innovation activities. The existing understanding of the actor-structure interrelationship in EEG cannot explain the process of regional transformations caused by this type of radical innovation. While EEG scholars agree that the evolutionary process is driven by interactions between the industrial structure and actors (Lambooy, 2002; Martin and Sunley, 2007), the specifics of this process—particularly how industrial actors transform the structure—remain unclear in the existing EEG literature.

In short, EEG has three main limitations in explaining the regional industry evolution caused by smart city innovation: 1) the lack of an exogenous perspective on 'radical innovation,' 2) the limited explanation of the state's role, and 3) the obscurity of actor-structure interactions.

Theoretical Framework Based on EEG

To address these limitations, I developed a new framework grounded in EEG to explore the production of smart city technologies. This theoretical adaptation encompasses three key endeavours. First, this framework integrates concepts from the window of locational opportunity (WLO) and developmental state literature, while also incorporating elements of structuration theory from sociology into EEG. This integration enhances the understanding of how exogenous forces, beyond local capabilities, drive regional industry evolution into a new phase. The main argument of the WLO, introduced by Scott and Storper (1987), specifies a type of innovation that does not originate from local industries but still brings about transformations within the local industrial environment. This concept, explaining new industry development, complements the endogenous perspective of EEG, enabling the theory to account for changes driven by non-local radical innovation—transcending mere efficiency improvements—in the evolution of regional industries. By combining the WLO with Storper's (1997) holy trinity—technology, organisation, and territory—this research proposes a new structure for EEG to explain regional evolution driven by smart city innovation.

Secondly, this research brings the descriptions of a developmental state to EEG theory. The understanding of institutional endowments embedded in regional industry structure in the developmental state literature (Wade, 1990) can be used in EEG to help the theory clarify the state's intervention in industry evolution through various policy approaches in some countries (Wade, 2018). The generic explanations of institutions and power relations in existing EEG literature are not able to represent the intricate industry development model inherited from the developmental state governments. Besides, the uniqueness of the smart city industry, for which the governments have been the main clients, gives more room for the state to leverage public resources through institutional measures to influence industry development.

Thirdly, I incorporate the concept of actor-structure duality from Giddens' (1984) structuration theory into EEG. Integrating this approach can significantly enhance EEG by addressing its limited explanation of the countervailing forces of actors' actions that can proactively reshape industrial structures over time. This theoretical improvement enables a better understanding of smart city innovation-driven regional evolution, moving beyond the constraints of structural determinism. Within this framework, clarifying which actions by industrial actors are critical to initiating structural transformations in a region's industrial environment is challenging. Giddens' (1984) theoretical framework elucidates the concepts of actors and structures, how they draw on each other, and, crucially, the mechanisms of social change. In his approach, the proactive role of actors is as significant as the effects of structures. By integrating structuration theory into EEG, this research reveals how smart city innovations, enacted by industrial actors, transform regional industrial structures and drive their evolution.

1.4 Research Questions

Contextualised in regional development literature, the objective of this research is to explore how production activities related to smart city innovation drive structural changes in regional industries, as well as how industrial policies enable their emergence. Using the theoretical framework outlined above, the study examines the outcomes and processes of regional transformations driven by the production activities of smart city technologies across three dimensions: technology (how), organisation (who), and location (where) (see 1.1). Additionally, it investigates the role of state industrial policies in facilitating these transformations.

Accordingly, this research develops two research questions to explore production activities (research questions 1 and 3) and one to examine industrial policies (research question 2). The first question examines the significance of radical innovation in the evolution of regional industries, focusing on the outcomes of new industry emergence. The second question investigates the state's role in industrial evolution through its industrial policies. Finally, the third question seeks to clarify the evolution process shaped by interactions between industrial structures and actors. The sequence of research questions follows the theoretical rationale. Research Question 1 (RQ1) focuses on innovation as the driving force of evolution, serving as a critical initial element in the evolutionary process. Research Question 2 (RQ2) explores the role of the state and its industrial policies—embodied as institutions that can significantly influence the industrial structure and serve as critical determinants of regional evolution. After addressing these two relatively independent elements, Research Question 3 (RQ3) examines debates within EEG regarding the process of change, particularly highlighting the proactive role of actors, which constitutes a fundamental aspect of evolutionary dynamics.

Drawing on the EEG-based theoretical framework, the three research questions and corresponding hypotheses for this study are outlined below.

- RQ1: Does smart city innovation represent a structural change within Taiwan's ICT sectors?

    - Hypothesis 1 (H1): There were triple transformations, and thus it was radical break from the path of incremental progress in Taiwan’s ICT sectors
- RQ2: Did the state play an important role in such structural change?
    - Hypothesis 2 (H2): Policy mechanisms and government-business relations within a developmental state have fostered innovation and contributed to improvements in the ICT industry.
- RQ3: Did individual actors’ choices and actions cause a structural change of Taiwan’s ICT sectors?
    - Hypothesis 3 (H3): The triple transformations driven by industrial actors have reshaped part of the original structure of Taiwan’s ICT sector.

Chapters 5, 6 and 7 present analyses and provide theoretical explanations to answer three research questions.

1.5 Methodology

This research adopts a single case study mixed-method approach focusing on Taiwan, examining changes in patents and industrial actors’ actions as well as smart city innovation-related industrial policies. The timeframe of this research is from 2001 to 2020, which was the time its local ICT industries endeavouring to upgrade and smart city innovation has been taken as one of primary goals.

To address the three research questions, this study collects and analyses both quantitative and qualitative data (see Figure 3). However, before examining the production activities of this specific technology set, the study must first establish a definition of smart city technologies that is more specific than ICT, providing a foundation for identifying what qualifies as smart city technologies.

Prior to data collection, the literature review defines smart city technologies operationally, drawing not only from existing research but also from guidelines provided by governments and industries. The analysis of radical innovation (RQ1) primarily relies on quantitative data, specifically smart city and ICT patents. In contrast, RQ2 (the state’s role) and RQ3 (actor-structure interactions) are examined using qualitative data, including policy documents and in-depth interviews. Specifically, RQ2 was explored through both policy documents and interview data, while RQ3 was explored solely through interview data.

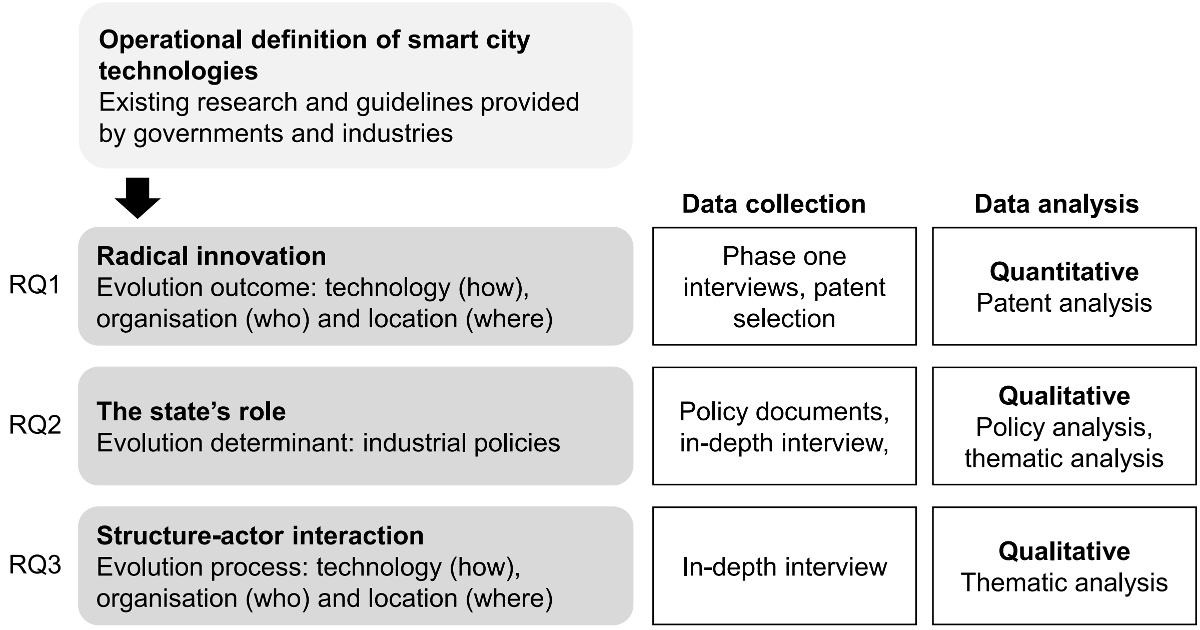


Figure 3 Aspects of the three research questions and their relevance to the methodology

(Source: author's own compilation)

The quantitative database for patent analysis was constructed using technical keywords gathered from the phase one interviews and patent selection process. Interviews with individuals in the smart city industry provided the technical keywords used to describe smart city patents. These keywords were then used to develop a search rule for identifying smart city patents in the database of the United States Patent and Trademark Office (USPTO)[1]. The final dataset built for analysis includes seventeen patent classifications[2], which are defined in this research as smart city technologies. The study analysed the dataset, focusing on cited patent classifications, assignees, and inventors' locations, to examine the triple transformations of technology, organisation, and territory within Taiwan's high-tech sectors. It also explored whether smart city innovation, as an exogenous factor, fosters radical innovation and drives the country's industries to evolve into a new phase.

[1] The USPTO can provide complete data on patent citations and patent inventors' locations. Besides, in this database, the number of foreign patents originating from Taiwan was in fourth place among all foreign countries (USPTO, 2015).

[2] The patent classification used in this research is the international patent classification (IPC) because this is the patent classification system that patents registered in the Taiwan Intellectual Property Office follow.

For the qualitative analysis, the data is based on policy reviews and semi-structured interviews conducted with individuals from the smart city industry and government authorities involved in the creation or implementation of smart city policies. Interviewees were recruited from local firms and both local and central government levels, focusing on participants involved in critical smart city projects supported by national or essential local schemes, such as the capital city's primary smart city initiative. Interviews with industry representatives explored their actions related to technological innovation, cross-firm collaborations, and participation in public programmes. For government agency interviewees, questions aimed to uncover their perspectives on industrial actors, policies, and strategies for facilitating smart city innovation.

By analysing policies using a policy analysis approach and insights from interviews through a thematic analysis approach, I identified key schemes relevant to smart city industry development, representative projects, and critical industrial actors. This information formed the basis for analysing the duality of structure and actors to explain how industrial actors have transformed the industrial environment, as well as the institutional elements influencing industry evolution, which highlight the role of state industrial policies in facilitating the sector's rise.

The policy documents reviewed were primarily issued between 2016 and 2020, as this period marked the formal adoption of smart city development as a national goal for infrastructure and industry advancement. In Taiwan, the Smart City Taiwan policy, issued in 2017, is the most significant industrial policy promoting the development of technology solutions for smart cities within local industries. This research analyses the 'Smart City Taiwan' policy alongside its related industrial and infrastructure policies. Additionally, critical local government plans that support the development of the smart city industry have also been examined.

1.6 Research Contributions

This research makes both empirical and theoretical contributions to smart city studies and regional development literature, particularly in the areas of technology and industry development.

Empirically, this production-focused research complements existing smart city literature by enhancing understanding of these technologies. The fragmented discussions on smart city technologies, often mixing practices with aspirations, can hinder progress in this field (Mora, Bolici and Deakin, 2017). A production-side perspective addresses the ambiguity surrounding the definition of this technology set and its related industries. By examining innovation and production activities for smart city technologies and tracing their products or solutions, this study helps delineate their scope, establish a concrete definition of smart city technologies and industries, and systematically describe this technology set.

To achieve this, I developed a methodology based on interviews and patent analysis. The measure employed in this research draws on collective empirical experiences rather than focusing on specific projects or speculative concepts. As a result, the definition of smart city technologies proposed here reflects a wide range of real-world cases, offering a solid foundation and common ground for future discussions and research on smart cities.

In addition to clarifying the definition of smart city technology, this research maps a comprehensive picture of the smart city industry by examining its production activities, identifying the critical industrial actors involved, and locating these activities geographically. Through this approach, the study uncovers the changes in regional development driven by the production of smart city technologies and, conversely, the regional effects on these technological innovations. To date, there has not been a comprehensive depiction of the smart city industry from a regional development perspective, nor has there been an empirical study that explores its emergence through regional development theories. Applying this theoretical framework to smart city research provides a foundational understanding of the essence of this technology set.

On the other hand, as previously mentioned, my research makes a theoretical contribution to the regional development literature by addressing three limitations of EEG through an enhanced theoretical framework. The first two limitations concern radical innovation and the state, which render the theory incomplete—particularly in explaining the industrial evolution of regions driven by smart city innovation. This type of innovation, being exogenous to local industries and shaped by state industrial policies, falls outside the path-dependence framework of EEG. By integrating insights on non-local innovation and state power from the WLO and developmental state theories, this research strengthens EEG's arguments and addresses these two limitations.

The third approach to enhancing EEG differs from the integration of explanatory elements used to address the first two limitations. The limitation concerning the evolution process reveals a fundamental weakness in EEG, as it struggles to contextually reflect the critical actions of industrial actors in transforming structures. To address this, I draw on structuration theory's concept of the duality of structure to reconstruct EEG's explanation of the evolution process and overcome this limitation.

By incorporating these approaches, my research establishes a new framework that reflects the dynamic interactions between structure and actors in EEG. This enhanced framework offers a more comprehensive understanding of the effects of radical innovation and state intervention on regional industry evolution, thus improving EEG's explanatory value.

1.7 Structure of the Thesis

This thesis is organised into eight chapters. The next two chapters, following the introduction, focus on the theoretical foundations of this research. Chapter 2 presents the literature review, which is divided into two key areas: 1) studies on smart cities, and 2) critical regional development theories related to technology and industrial development—with particular focus on core arguments from EEG theory, especially those concerning innovation, institutions, and actor-structure interactions. Chapter 3 outlines the theoretical framework of this research. It builds on EEG theory while integrating insights from the WLO and the developmental state approaches. Additionally, it incorporates structuration theory from sociology to address the limitations of EEG, particularly regarding its explanation of the evolution process.

After establishing the theoretical foundation, Chapter 4 explains the methodology proposed to qualitatively and quantitatively investigate the emergence of smart city technology and its related industrial sectors. The latter part of the chapter outlines the data exploration process, detailing the construction of datasets through the described methods. The following three chapters present the empirical analyses and findings of this research. Chapter 5 uses patent data to explore whether smart city innovation is radically different from traditional ICT industries in Taiwan, focusing on the three dimensions of regional industries: technological, organisational, and territorial. Chapter 6 analyses policy documents and interviews to examine how the Taiwanese state facilitates the emergence of new sectors through institutional measures implemented as industrial policies. Chapter 7, the final empirical chapter, analyses interview data to reveal the evolution process, interpreted as the accumulation of interactions between the industrial structure and actors, specifying how firms' actions structurally transform the industrial environment. The final chapter concludes by summarising the findings of the empirical chapters and discussing the theoretical implications of this research for EEG.

Chapter 2: Literature Review

2.1 Introduction

The prevalence of the smart city concept has stimulated radical innovation in industries, driving the evolution of regional production activities. Globally, there is growing anticipation that the widespread application of technologies in cities can help address various urban challenges, such as traffic congestion, air pollution, energy shortages, and crime (Schaffers, Ratti and Komninos, 2012; Hollands, 2015; Lim, Edelenbos and Gianoli, 2019b; Das, 2020). These issues are also extensively discussed in the literature. Technological innovations aimed at addressing these challenges have emerged, forming a specific set of technologies supported by regional industries. In turn, smart city innovation injects new forces that drive regional industrial transformations (Caragliu and Del Bo, 2019), resulting in sectoral changes, an aspect that receives comparatively less attention in the smart city literature.

This chapter aims to explore the relationship between regional transformations and production activities for smart city innovation. The first section reviews existing research on smart cities, identifying a gap in the literature regarding production-side perspectives. The second section examines regional development theories to establish a theoretical framework for analysing the production of smart city technologies and the development of their associated industries.

2.2 Existing Smart City Literature

Most of definitions of the smart city has two elements, efficiency and use of ICT networked infrastructure (Eger, 1997; Komninos, 2006; Hollands, 2008). Definitions hugely vary depending upon authors and context, making the concept inherently ambiguous and subject to interpretation (Mora, Bolici and Deakin, 2017; Mora, Reid and Angelidou, 2019). Review of all works written ever about smart city is not feasible given its size, so this chapter attempts a systematic approach through categorisation of relevant studies. Drawing on the rationale provided in existing literature, this research establishes a framework to categorise different approaches to studying smart cities. Following this framework, I review the critical arguments within each category. In the second part of this section, I focus on a relatively overlooked area in dominant social science approaches to smart city studies: what smart city technologies are and how they are produced in industries from regional development perspectives. My review of relevant literature broadly examines the development of this specific technology set across various research disciplines.

2.2.1 Categorisation of smart city studies

Smart city research has expanded significantly, with scholars approaching the topic from a wide range of perspectives. To address this variety, several studies have proposed frameworks to systematically categorise smart city research and enhance understanding of this complex topic.

In the early 2010s, the concept of a smart city was relatively fluid and often linked to related ideas such as digital city, intelligent city, and creative city (Nam and Pardo, 2011; Willis and Aurigi, 2018). Nam and Pardo (2011) categorised these related concepts by identifying three key components of a smart city: technology, humans, and institutions. While this framework provides a straightforward overview of the topic, the last two components—humans and institutions—are interrelated and challenging to distinguish. Kummitha and Crutzen (2017) simplified these three components into two categories: technology-driven and human-driven approaches. They further integrated these into the 3RC framework: restrictive school, reflective school, rationalistic school, and critical school. This improved framework elucidates the core arguments and perspectives of three primary approaches to smart city research: technology-inclined, human-inclined, and balanced perspectives. Under this framework, technology and humans are not treated as separate entities but as interdependent components, reflecting the duality inherent in smart city development.

Mora, Reid and Angelidou (2019) analysed citations from smart city studies across various research domains. They concluded that these studies generally follow two dominant strands: holistic interpretations of smart city development and explorations of the role of information and communication technology (ICT). Similarly, Lim, Edelenbos and Gianoli (2019) categorised smart city studies based on the observed or hypothesised outcomes of urban development. Their framework includes four categories: observed to be positive, observed to be negative, hypothesised to be positive, and hypothesised to be negative. They found that most existing research emphasises expectations for smart city development rather than empirical findings from real-world cases (Lim, Edelenbos and Gianoli, 2019a).

During the early 2010s, in the initial smart city research on categorisation, the essential components of smart cities, which are technology and people (including institutions), were used as two fundamental categories to distinguish objectives of smart city development in relevant studies (see Table 3). As the smart city concept was realised in more real city development projects, the discussions moved beyond the binary of technology and people. By the late 2010s, two new categories of vision/practice and benefit/shortcoming had emerged (see Table 3), reflecting the changing interests in smart city research. While the smart city concept has constantly evolved throughout the last decade, technology's unique role has always received particular attention. The emphasis on technology applications in cities constitutes the radical difference between smart cities and traditional cities. Despite the varied frameworks reviewed above, they all delineate studies on technology as a specific category.

Table 3 The evolution of categories for understanding smart city studies

Proposed by	**Rationale for categorisation**	**Categorisation framework**
Nam and Pardo (2011)	Smart city components	• Technology • Human • Institution
Kummitha and Crutzen (2017)	Smart city components and mentalities towards smart city development	• Technology-driven and human-driven • Restrictive, reflective, rationalistic and critical
Mora, Reid and Angelidou (2019)	Interpretation of smart city development	• Holistic interpretations of the smart city development • Exploration of ICT's (technology) role
Lim, Edelenbos and Gianoli (2019)	Results of smart city development	• Observed to be positive, • Observed to be negative, • Hypothesised to be positive

Proposed by	Rationale for categorisation	Categorisation framework
		• Hypothesised to be negative

(Source: author's own compilation)

This research aims to explore the production side of smart cities. To do so, it is essential to understand the expectations surrounding smart city development and the application of smart city technologies. Consequently, this research adopts the framework proposed by Mora, Reid and Angelidou (2019) to review relevant studies. Specifically, I follow two categories: 1) smart city aspirations and 2) technology uses and impacts, to examine the smart city literature.

On the one hand, it is important to review what people hope to achieve through the realisation of the smart city concept. On the other hand, it is necessary to understand what changes in cities and regions can be brought about by technology. The first category includes research that seeks to clarify the various aspirations associated with becoming smart cities. The second category focuses on practical issues, specifically the uses of technology and their impacts. The critical arguments within these two categories are reviewed below.

2.2.1.1 Literature on goals of smart city development

In most of the related studies, solving existing urban problems and improving the quality of life for citizens has been regarded as the ultimate goal of building smart cities (Kanter and Litow, 2009; Caragliu, Del Bo and Nijkamp, 2011; Nam and Pardo, 2011; Batty *et al.*, 2012; Albino, Berardi and Dangelico, 2015). Then, smart city studies from different points of view expand on this idea with various approaches, i.e. environmental, social, economic and governance. As a result, smart city developments are generally related to achieving sustainability (Kitchin, 2015; Mora, Reid and Angelidou, 2019), benefiting local communities (Komninos, 2006, 2008), fuelling economic development, improving public service efficiency (Lim, Edelenbos and Gianoli, 2019b), and facilitating citizen engagement (Hollands, 2008, 2015). The debates about smart city developments in relevant research tend to focus on conflicts and contradictions of pursuing different aspirations. For example, Hollands (2015) argues that business interests should not be given priority over citizens' voices when developing smart cities.

2.2.1.2 Literature on the impacts of smart city technology

The discussions of the technology's uses or the impacts in smart city literature have been fragmented into multiple aspects. Batty *et al.* (2012) explore the possibilities of urban planning created by ICT and digital technology. They argue the networked urban environment can realise data-driven measures for policy analysis and planning. With this new approach, we can envisage and shape distinctive forms of social organisation with better resource efficiency, social equality, and quality of living (Batty *et al.*, 2012). In short, it is possible to reshape human activities in cities by implementing smart city development and using smart tools for planning.

Mora, Reid and Angelidou (2019) highlight that the interconnected urban system is one of the main focuses of smart city research. This system is composed of connected physical objects installed throughout the urban environment, which can be realised by applying two essential technologies: the Internet of Things (IoT) and ubiquitous computing (Weiser *et al.*, 1999). Dirks and Keeling (2009) specify the effects of connected infrastructure with the concepts of instrumentation, interconnection, and intelligence. Through instrumentation, the urban system can collect extensive data via ubiquitous sensors or devices; through interconnection, communications between components contribute to informatisation; through intelligence, the collected information can produce knowledge and solutions (Dirks and Keeling, 2009). Aurigi and Graham (2003) underline the benefits brought by technology to society, contending smart city technologies can help intensify the connections between people and enable various social interactions.

In the majority of smart city studies, nearly all implementations of technologies-based urban development require the use of data. Accordingly, debates about the impact of technology mostly centre around issues concerning data. Galdon-Clavell's (2013) research on smart technologies raises the concern about surveillance. When we uncritically adopt technology applications that accumulate and utilise personal data to produce solutions, citizens' privacy can be undermined (Galdon-Clavell, 2013; Vanolo, 2016). Vanolo (2016) further argues that urban planning or city management relying on data analytics can cause social inequality because of the bias of data interpretation. Data analytics cannot fully reflect the characteristics of places, especially the social and cultural.

According to the reviews above, it is evident that studies in either the smart city aspiration or technology uses/impacts categories generally focus on the discussions of the use side of smart city technology, i.e. what a smart city should be, how we could use smart technologies, and what pitfalls should be avoided concerning technology applications. However, these dominant studies overlook the production side of smart city technologies. Specifically, they rarely address how, by whom, and where smart city technologies are created, or how innovation in these technologies drives industrial change and fosters regional evolution.

2.2.2 Smart city technologies and their related industries

In social science, researchers have explored how smart technologies are used, as it is widely believed that applying these technologies to cities can transform urban life. Whether these changes are positive or negative, they are significant and shape the future of cities and the activities within them. However, this perspective overlooks the fact that changes in regional activities driven by smart city technologies occur not only when people use these technologies but also during their production. Technical changes, grounded in technological innovation—whether driven by R&D or initiated by market needs—are compounded with transformations in production activities and are therefore significant to regional development (Mowery and Rosenberg, 1979; Dosi, 1982; Frenken, 2000; Lambooy, 2002). Consequently, innovation has been recognised as a key component of regional development (Sonn, 2021).

Despite this interrelationship between smart city innovation and regional development, the social scientific understanding of the production of smart city technologies remains limited. The relationship between technology production and regional development is reciprocal: on one hand, technology development transforms regional social and economic activities; on the other hand, technological innovation is shaped by regional capabilities. To comprehensively understand the significance of smart city technologies for urban and regional development, it is crucial to adopt a production-side perspective that reveals the changes brought about by the emergence of the smart city concept.

The production of smart city technologies has mainly been explored in computer science and engineering studies. In this vein of research, the development of a range of technologies that are constituents of interconnected systems has been linked to carrying out the smart city development, e.g. IoT, big data (Liu, 2018; Jo *et al.*, 2019), low-rank adaptation (LoRa) (Sandoval, Garcia-Sanchez and Garcia-Haro, 2019), 5G (Jiang, 2021), edge computing, blockchain, AI, software-defined networking (Jo *et al.*, 2019) and technological applications of the industry 4.0 concept (Lom, Pribyl and Svitek, 2016). However, the development of smart cities can involve a set of different smart technologies. The approaches above inclining toward a particular technique can hardly reflect the complexity of integrating multiple technologies. Among those discussions, their understanding of smart city technology is partial. Besides, none of them discussed how the development of technologies to realise smart city visions interacts with regional innovation activities.

A few studies probe the production of smart city technology, but they define smart city technologies in a relatively loose way. Clark (2020), Kim, Jung and Choi (2016) and Caragliu and Del Bo's (2019) studies are the closest embarking on the studies of smart city technology production from the social science perspective. Clark (2020) articulates the smart city industry as a specific sector with technical and industrial standards in a state of flux.

Kim, Jung, and Choi (2016), based on Korean experience, analysed the input-output of the locally defined smart city industry containing thirty IoT-related sub-sectors. Their research shows that the characteristics of the smart city industry are intermediate between ICT and urban construction industries (Kim, Jung and Choi, 2016). In other words, the local capabilities of ICT and urban construction sectors are pertinent to the development of the smart city industry. While an overview of the smart city industry has been proposed in their research, their definition of the smart city industry has a bias towards IoT technologies. The approach emphasises the construction industry, but the application domains of smart city technologies are beyond this specific sector. Lastly, in Caragliu and Del Bo's (2019) study on the relationship between smart city policy and urban innovation, they analyse patents to reveal smart-city-related innovation in industries. This research directly examines whether smart city development can foster technological innovation in regions. However, in their study, the patent classifications defined as smart city technology are based on the Intellectual Property Office's analytical report on IoT patents. In other words, still this approach does not tackle the imprecision in the definition of smart city technologies and their related industries. Besides, the local effects on tech development have not been studied in this research.

Existing research does not comprehensively examine smart city technologies and their related industries. In the computer science and engineering disciplines, studies on the production of this technology set tend to be overly narrow. Meanwhile, in the social sciences, definitions of smart city technologies are often too vague to accurately reflect their underlying technological innovations. Consequently, the production activities of smart city technologies cannot be fully captured through the understanding of smart cities presented in existing literature. This research gap limits our ability to explain the changes in urban and regional development driven by smart city innovation. Although some studies attempt to explore the relationship between smart city technological innovation and regional development, several key questions remain insufficiently addressed: What technologies are being innovated and produced to meet the specific needs of smart city development? Who is producing these technologies? What social, cultural, political, and economic factors determine or influence their production? How do regional industries transform to produce these technologies? Where does this production take place? These questions are critical to understanding local and regional development. Therefore, insights from literature grounded in regional development theories can provide valuable perspectives to address them.

2.2.3 The definition of smart city technology

For this research, it is crucial to first clarify the definition of smart city technology. Existing smart city literature has not unified or specified the definitions of smart city, smart city technology, or the smart city industry (Albino, Berardi and Dangelico, 2015). A review of the existing literature on smart city definitions suggests that ICT (Eger, 1997; Komninos, 2006; Hollands, 2008) serves as the primary clue for identifying smart city technologies. However, it remains difficult to determine whether a specific technology (or patent) belongs to smart city technologies, as not all ICTs are applicable to smart cities. The ambiguity surrounding the definition of smart city technology also makes it challenging to delineate the scope of the smart city industry. This, in turn, complicates the analysis of whether and how regional high-tech industries evolve into a new phase capable of producing smart city technologies.

My research addresses the issue of defining smart city technologies by first examining their application domains as outlined in policy documents from governments and industries. The term ‘smart city’ encompasses a wide range of technology sets, and how these technologies are developed depends significantly on their application areas. In Taiwan, the focus of this research, the ‘Smart City Taiwan’ policy[3] lists various application areas, including ‘smart transportation,’ ‘smart safety,’ ‘smart energy,’ ‘smart business,’ ‘smart logistics,’ ‘smart agriculture,’ ‘smart tourism,’ ‘smart education,’ and ‘smart healthcare’ (IDB, MOEA, 2017). It is evident that the Taiwanese government aims to include as many application areas as possible, regardless of their direct relevance to smart city development. This strategy aligns with the policy’s first-phase goal of enabling most ICT manufacturers in Taiwan’s high-tech industries to develop or produce software technologies. Consequently, not all application areas listed under the ‘Smart City Taiwan’ policy are directly pertinent to smart city development—for instance, ‘smart agriculture.’

To improve the accuracy of the scope, I referenced South Korea’s national industry standard definition of smart city technology. Like Taiwan, South Korea considers smart city development an industrial goal. Moreover, South Korea is one of the first countries globally to invest in the Fourth Industrial Revolution through national strategies, establishing a solid industrial foundation for developing smart city technologies. On the methodological front, the Korean Intellectual Property Office (KIPO) has created a distinctive definition of smart city technology by utilising patent classifications—a unique approach not found elsewhere. These classification titles include ‘transportation,’ ‘energy,’ ‘environment,’ ‘housing,’ ‘life and welfare,’ and ‘administration.’ According to the KIPO’s identified classification titles, I eliminated less relevant areas: ‘smart business’, ‘smart agriculture’, ‘smart education’ and ‘smart health care’, listed in the ‘Smart City Taiwan’ policy because they are not applied to urban areas or with too specific purposes and for smaller scale applications.

[3] This is the most fundamental policy for the development of the smart city industry in Taiwan. The policy is implemented by the Industrial Development Bureau (IDB) under the Ministry of Economic Affairs (MOEA) (see Chapters 1 and 6).

Combining these two references, the titles ‘transportation,’ ‘energy,’ and ‘environment’ remain unchanged, with smart logistics included under ‘transportation.’ I also created two additional titles: ‘governance/surveillance’ and ‘city service.’ ‘Governance/surveillance’ combines three KIPO-identified areas—‘housing,’ ‘life and welfare,’ and ‘administration’—and incorporates the Taiwanese government’s listed area of ‘smart safety.’ ‘City service’ primarily corresponds to the ‘smart touring’ area identified in Taiwanese policy and includes additional techniques, which I explain in the next section. Ultimately, the five common smart city technology application domains adopted in this research are: 1) ‘transportation,’ 2) ‘energy,’ 3) ‘environment,’ 4) ‘governance/surveillance,’ and 5) ‘city service.’ These domains represent different functions of a city. The categories defined by these domains are discrete and can encompass most so-called smart city technologies.

In addition to application domains, smart city technologies can also be categorised into different technical sections. This categorisation is based on three key elements of smart city technology—instrumentation, interconnection, and intelligence—identified in IBM’s executive report *A Vision of Smarter Cities* (Dirks and Keeling, 2009). Building on these elements, my research categorises smart city technologies into four technical sections: 1) data collection, 2) data transmission, 3) data accumulation, and 4) data use and application (Dirks and Keeling, 2009). Regarding the nature of the techniques, the first two sections are hardware-oriented, while the latter two are software-oriented.

In summary, based on the above guidelines provided by governments and industries, this research preliminarily defines smart city technology as a set of technologies designed to collect, transmit, accumulate, and use city data within the application domains of transportation, environment, energy, governance/surveillance, and city service. Further details about each domain and explanations of the techniques comprising the smart city technology set are provided in the methodology chapter.

2.3 A Regional Development Perspective on Smart City Technology Production

The first part of this section reviews key regional development theories, which offer profound insights into the interrelation between innovation and regional development, broadly exploring theoretical explanations of how smart city technology production can transform a region. The second and third parts of this section provide an in-depth review of evolutionary economic geography (EEG) theory and its empirical studies. As the theoretical foundation of this research, EEG offers comprehensive explanations of regional changes driven by innovation, helping explain the production of smart city technologies within regions.

2.3.1 Local and regional development and changes

In a rapidly changing world, local and regional development follow diverse trajectories, often resulting in uneven development processes (Pike, Rodríguez-Pose and Tomaney, 2017). Each period introduces new dynamics in technology, economy, society, politics, and the environment. Economic geography theories help explain the reasons behind and processes driving the emergence or transformation of economic activities and their distribution across geographical spaces. In other words, these theories shed light on why and how the economic landscape responds to various changes.

In economics, Krugman (1991; 1995) brings together the two deemed countered (from their proponents' viewpoint) while essentially inseparable theories that are economics and geography. He pioneered in creating new economic geography as a subdiscipline within economic for discovering the effect of geography on the economy (Sheppard, Barnes and Peck, 2012). This new theoretical trend has challenged the axiom and methodology in orthodox economics to explain the economic landscape, i.e. homogeneous economic actors, static equilibrium and rational decision-making.

Early in the 1990s, Krugman (1991) embarked upon the analysis of uneven development by inquiring into exogenous factors with the original model of the NEG. He explains the spatial economies concerning production with the concept of spatially centripetal and centrifugal forces (Krugman, 1998). In NEG, the external economies of spatial concentration can help benefit innovation activities (Pike, Rodríguez-Pose and Tomaney, 2016). Namely, an innovation that can fuel economic growth is produced and diffused endogenously as both an outcome of increased industry output and an instrument of revenue or profit generation. Meanwhile, the externalities of positive information can facilitate local knowledge accumulation (Pike, Rodríguez-Pose and Tomaney, 2016).

Among these arguments, technological innovation in a region has been considered to be driven by endogenous or internal forces. However, smart city innovation does not originate from local systems and does not result from external economies. Apart from this, Krugman (1998) assumes that objects (places) for analysis and modelling are neutral spaces (Boschma and Frenken, 2006), which disregards the significance of contexts. Besides, the real-world economic landscapes pose contradictions to the equilibrium presumption of NEG (Boschma and Frenken, 2006).

From the 2000s, theories of economic geography began to centre around the process of regional transformation in response to changes in the industrial environment. Two approaches, EEG and relational economic geography (REG), receive particular attention, which underline the importance of exploring the process of regional transformation. Both EEG and REG elucidate the unevenness of local and regional development from a disequilibrium perspective. EEG understands changes in regional development from the perspective of history. Specifically, EEG examines the changes in economic agents embedded in spaces to explain the regional evolution process (Martin and Sunley, 2007). On the other hand, REG explores the process of regional development by unfolding relations between economic agents, their interactions and social processes across spaces (Bathelt and Glückler, 2003). The factors for analysis proposed by REG range from endogenous elements (the local and regional development approach) to multi-scalar relations (network and geography scales approaches) (Yeung, 2005).

In both theories, three concepts, 1) context, 2) path-dependence and 3) contingency, are fundamental to understanding the process of change (Martin and Sunley, 2010; Bathelt and Glückler, 2003). However, compared to REG's interest in the causal process, EEG focuses more on the formative process of local and regional development. These two theories are based on different points of view to explain how the processes are shaped or formed. In REG, the dynamic changes in the economic landscape are traced to actors at different spatial scales, which involve local and non-local elements (Yeung, 2005). Conversely, EEG tends to explain the innovation-driven changes in a region 'from within', namely local components (Kogler, 2015). The evolution approach provides a general theoretical base to understand change over the processes varied across varied times and spaces (Frenken and Boschma, 2007). Both theories emphasise the significance of innovation. From the relational perspective, innovation is understood as an interactive social process involving multiple actors within and across different entities (Bathelt and Glückler, 2003). In contrast, evolutionary thinking views the innovation activities of firms as the primary driving force perpetuating the process of change (Boschma and Frenken, 2006). The relational perspective focuses on interactions between actors, while the evolutionary perspective examines changes driven by actors.

While EEG and REG attempt to incorporate a sociological perspective into economic geography studies, the asymmetric dynamics over the local and regional development process have not received adequate attention in their arguments. The theory of global production network (GPN), initiated in the 2000s as well, highlights the effect of power asymmetries of governance structures on regional development (Coe, Dicken and Hess, 2008). The production systems in the global economy are composed of intricate connections between various actors on multiple scales across nations (Coe and Yeung, 2019). Accordingly, regional economic activities of firms are driven by the network that these actors embed in, which is substantially determined by non-local factors. This theory focuses on relatively globalised industries, like apparel or agro-food (Coe and Yeung, 2019). The networks linking a region to the globe can be critical access to innovation, helping create a new development path, and global lead firms play a big part in coordinating these networks (MacKinnon, 2012; Yeung, 2022).

After the 2010s, geographical political economy (GPE) received increasing attention in economic geography studies. Sheppard (2011) picks Marxist economic geography up to reinstate the role of power/politics in economic geography (Sonn and Hsu, 2020). He considers the disequilibrium nature of economic landscapes to be caused by the conflictual and unstable essence of capitalism (Sheppard, 2011). GPE is proposed to explore the asymmetrical dynamics between biophysics, society, politics, and culture over the process of production (Sheppard, 2018). In the theory of GPE, social relations are critical elements produced through economic activities (Pike, Rodríguez-Pose and Tomaney, 2016). Those relations can then consolidate the advanced role of specific regions. Innovation in GPE arguments has been discussed as one of the contributing factors to the economic development of the regions that maintain their prior place in the global economy.

Among contemporary economic geography and regional development theories, the extent to which they explain the impact of innovation on regional development varies. NEG and EEG place greater emphasis on technological innovation compared to the other three theories. However, EEG moves beyond NEG's equilibrium-focused approach by explaining the dynamic processes of regional change driven by innovation and considering the cultural, political, and social contexts of regions. While REG, GPN, and GPE also consider innovation, their primary focus is on collaboration between firms and the relationships embedded in economic activities that extend beyond specific regions, with little attention given to the significance of local policies. This research adopts EEG as the foundation for its theoretical framework because it aligns with the study's focus on change and the role of technological innovation in transforming regional industries. EEG's emphasis on the actions of economic agents and structural shifts throughout different stages of evolution helps explain how regions adapt their endogenous elements to accommodate innovation.

2.3.2 A review of the evolutionary economic geography theory

This research aims to explore how production activities and state industrial policies for smart city innovation in Taiwan have driven the transformation of regional industries, contributing to regional evolution. Such economic landscape evolution can be accompanied by regional decline, growth, or even restructuring (Martin and Sunley, 2010). Accordingly, the EEG theory, which examines spatial transformation and uneven regional development driven by innovation, is applied here to uncover the regional evolution resulting from the growth of the smart city industry.

The fundamental argument of EEG is that historical processes illuminate changes in the economic landscape over time (Boschma and Frenken, 2018). In other words, a place's history is a critical determinant of how a region or city evolves, as no two regions share an identical history. Consequently, differences in a place's context lead to diverse trajectories of regional and urban evolution (Martin and Sunley, 2010). In this chapter's review of EEG, I aim to clarify how to understand and analyse the history of a place, i.e., its context. EEG explains historical embeddedness through three key aspects: 1) regional innovation and knowledge production capability, 2) institutions and power dynamics, and 3) industrial structure and actors. Each of these is detailed in the following part of this subsection.

2.3.2.1 Innovation and knowledge generation

i. Evolutionary path driven by innovation

Evolution is a continuous process but does not always occur at an even pace or along a smooth path; a region may evolve drastically when significant changes take place (Castellacci, 2006). Typically, a new evolutionary path begins when an innovation is introduced to or originates within a region, as innovation has long been recognised in regional development literature as a key factor driving regional development (Sonn, 2021) and thus has played a critical role in the region’s evolutionary process (Castellacci, 2006). Lambooy (2002), a pioneering scholar in EEG, views innovation as a means of materialising knowledge and emphasises the central role of knowledge and innovation in urban evolution. These forces driving technological development can lead to structural transformation in the economy, significantly influencing regional development and production (Frenken, 2000). Technology, as defined by Dosi (1982), is ‘a set of pieces of knowledge, both directly “practical” (related to concrete problems and devices) and “theoretical” (but practically applicable although not necessarily already applied), know-how, methods, procedures, experience of successes and failures and also, of course, physical devices and equipment.’

Innovation has been driven not only by market needs (demand-pull) but also by technical progress (technology-push) (Mowery and Rosenberg, 1979). Dosi (1982) summarises that the demand-pull approach is based on the idea that innovation originates from purchasers’ needs and users’ preferences. In contrast, the technology-push approach emphasises the role of scientific advancements, the growing complexity of R&D activities, the correlation between R&D efforts and innovative outputs, and the uncertainties inherent in inventive processes as key drivers of innovation. Mowery and Rosenberg (1979) further argue that these two forces simultaneously underpin innovation and shape the directions of technology development.

EEG literature thoroughly describes local innovation and creative capacity and their effects on regional evolution. The path dependence approach is widely used to demonstrate how local capability fosters regional or urban innovation and knowledge generation. Boschma and Frenken (2006) consider that the path-dependent process helps explain the association of past events, which contribute to a set of current conditions of a place, with the probability of future scenarios. From a historical perspective, this approach in economic geography enables a dynamic analysis of the spatial distribution of economic activities.

Martin and Sunley (2010) contend that new industrial paths, especially opportunities for entrepreneurs (Schumpeter, 1983), in the contemporary world emerges from places with a set of local conditions that are beneficial to their resources and knowledge accumulation. Accordingly, the path creation of a region, to some extent, is pre-selected rather than entirely random, although historical accidents are considered the trigger of the emergence of new paths in path-dependence literature. Martin and Sunley (2006) argue that while critical junctures achieved by a series of unintended actions are vital clues about path creation, they should be examined along with the purposive actions of agents and preconditioned local factors, such as relations and institutions. This result is because 'places' can determine two aspects of the new path origin: first, the generation of entrepreneurial variety, and secondly, the selection process, collective supports (competencies, connections and critical firms) and new pathway emergence (Martin and Sunley, 2010). Freeman (2007) emphasises Schumpeter's (1939) concept of innovation clustering as a spatial feature that supports the growth of new firms and industries.

Among the discussions of innovation, radical innovation is described as an enabler of path breakthroughs and new path creation (ibid). This concept has been used to explain new product groups that descend from existing technological paths (routines) while branching to become new technologies (Frenken and Boschma, 2007; Castaldi, Frenken and Los, 2015). Compared to incremental innovation, which focuses on improving production efficiency for existing services or products, radical innovation—following the Schumpeterian pattern of innovation activities—represents extraordinary progress achieved through deliberate development efforts (Dosi, 1982; Castellacci, 2006). It drives innovations in products, processes, and organisations, ultimately leading to structural changes (Freeman and Perez, 1988). In short, radical innovation can lead to the emergence of new industries (Frenken and Boschma, 2007), triggering structural changes in existing regional industries—specifically, transformations in sectoral composition (Lambooy, 2010). However, the evolutionary approach's explanation of radical innovation-driven path creation follows the rationale of intrinsic dynamics (Castellacci, 2006) and therefore does not fully capture the regional evolution driven by the emergence of smart city technology, as the path dependence approach fails to account for innovations that originate outside existing development trajectories.

ii. Innovation factors

Beyond the path dependence approach, EEG literature has explored local conditions for innovation by examining a place's endogenous elements, as evolutionary thinking views changes as emerging from intrinsic characteristics (Castellacci, 2006). In this context, technological progress is often seen as originating from and being driven by local sectors. Kogler (2015) highlights Schumpeter's theory (1934; 1942) of 'creative destruction' to illustrate the ongoing process of economic evolution that is a course of accumulated changes of the economic structure 'from within'. In other words, a system's endogenous entity embedded in its society and economy is the radical force of change to the evolution of the economic landscape (Kogler, 2015). Martin and Sunley (2010) summarise key components of industrial innovation and path creation, including entrepreneurial culture, social structure, connection, support from specialists and customers, institutions, venture capital, and corresponding infrastructure by the government. These components are basically endogenous as well.

The regional innovation system concept has been used a lot in EEG to explain how the composition of local actors affects a region's innovation and knowledge generation and determines its economic landscape evolution. A regional innovation system is sustained by an interactive and dynamic structure and composed of actors and their collective actions across industrial, governmental, and organisational sectors. The actions of firms utilising their competencies can be conditioned by an innovation system containing enterprises, science organisations and government (Lambooy, 2002). While Lambooy (2002) raises the significance of actors other than firms (e.g. government and science organisations) to an innovative system and its evolution, firms still receive substantial attention in EEG.

EEG considers firms to be critical actors in industries, driving innovation. Entrepreneurs with the capability to create and diffuse variety (Stam, 2010) are regarded as 'prime movers' in a new economic cycle, facilitating evolutionary economics in line with Schumpeter's (1934) notion of economic evolution. Furthermore, Martin and Sunley (2010) argue that the dynamics and heterogeneity of firms form the foundation of a selection environment, which can be understood as a space of competition. Faced with competitive pressure, firms are driven to innovate, which generates heterogeneity (Schumpeter, 1942; Essletzbichler and Rigby, 2010). Apart from heterogeneity, the concept of variety has also been widely adopted in EEG to analyse the composition of industries. Frenken, Van Oort and Verburg (2007) use Jacobs' externalities (Jacobs, 1969) and portfolio theory (Montgomery, 1994) from business economics to understand the diversification of industries. Based on those theories, they propose the concept of related and unrelated varieties to explain the effects of different forms of industry composition (i.e. diversification of firms or sectors) on regional economies. These studies establish a theoretical foundation in EEG to crystallise the role of firms as drivers in regional innovation and evolution.

Building on the micro-level focus on firms, Lambooy's (2002) review of regional knowledge creation argues that competition and cooperation among firms at the micro-level, as well as among regions at the macro-level, through 'networked' organisational structures, can drive innovation. These EEG arguments highlight critical endogenous elements that determine and facilitate regional innovation, ultimately triggering evolution. However, the new phase of regional evolution driven by the emerging smart city industry was shaped by exogenous elements. The concepts for these new technologies were imported from outside and later developed, resulting in deficiencies in local capabilities to produce them—a phenomenon defined as exogenous-driven innovation (Pike, Rodriguez-Pose, and Tomaney, 2017). Because the existing EEG theory is built upon endogenous innovation framework, it has theoretical difficulties in explaining exogenous innovations. This does not mean that EEG researchers do not engage in empirical studies of such phenomena (see 2.3.3). For example, Canfei He's works on the role of export in innovation deals with the influence of foreign market on local innovations (He, Guo and Rigby, 2017; He, Yan and Rigby, 2018). There are also works on the knowledge spillovers from multinational corporations to local firms (He, Guo and Rigby, 2017). However, at theoretical level, the literature still mainly based on endogenous innovation framework.

iii. Innovation processes

In general, there have been a few different approaches to revealing the processes of firms innovating. Essletzbichler and Rigby (2007) build upon theories of population dynamics to develop the theoretical foundation of EEG from the perspective of biological metaphor and analogy. They argue a region's fitness is rendered by its population, which comprises a variety of firms at different performance levels, and the environment will select these firms with various properties through their entry and exit over the evolution process (Essletzbichler and Rigby, 2007). This variety-selection-retention mechanism can be considered the fundamental process of evolution. Building on the same theoretical strand, Essletzbichler and Rigby (2010) further describe how two crucial local conditions influence regional growth and competitive advantage. The first is the process of learning, imitation, and innovation undertaken by firms to enhance their performance, and the second is technological change (Price, 1970; Metcalfe, 1998; Andersen, 2004b, 2004a). Lambooy (2002) explores the effects of knowledge on regional development. He argues the acquisition of knowledge (i.e. the fuel of evolution) happens when actors with specific cognitive competencies gain knowledge through an interactive learning process.

Lastly, from the industry angle, Martin and Sunley (2010) adopt the concept of the industrial life-cycle to explain path dependence and the accompanying evolution of innovation. In the cycle, geographical clusters are more likely to form at their early stage. The industrial revolution, which follows the logic of path dependence, is based on continuous entries of firms along with the accumulated capabilities over time (Klepper, 1996, 2002). While these EEG scholars tried to generalise several evolution courses, the regional development trajectories are, in fact, varied. Martin and Sunley (2010) contend that an evolutionary trajectory can hardly follow one single way, which can hinge upon conditions of a given place, e.g. compositions of heterogeneity, multi-level structures and interactions across layers. I agree with Martin and Sunley (2010) about the complexity of innovation process and propose that, such complexity can be better studied when we understand how individual actors' choices differ under similar structural constraints. I will come back to this issue in 2.3.2.3.

2.3.2.2 Institution

i. Institution as media of evolution

It is essential for this research to review the theoretical strand of EEG literature explaining the relevance between institutions and evolution. As mentioned above, regional evolution usually starts with innovation. Then, throughout the evolution process, institutions are unique elements that strongly correlate with innovation. Boschma and Frenken (2006) specify the linkage between industrial innovation and institutions. They contend that in sectoral innovation systems, the dynamics of evolution can commonly drive old institutions to restructure into new forms. In other words, when a structural change occurs in the economic landscape, its affiliated institutions can also evolve to adapt to emerging activities.

By drawing on the concept of the formation of institutions across multiple spatial scales, Boschma and Frenken (2006) further argue that firms (operating organisational routines) at the micro-level, sectors and networks at the meso-level, and spatial systems at macro-levels can manifest the differences between institutions among regions. Some other EEG literature elucidates the effect of local conditions, particularly institutions, on innovation activities and their accompanying regional evolution. Essletzbichler and Rigby (2007) argue a region's innovation trajectory is shaped by its unique historical and geographical conditions that endure in the forms of institutions and social networks. An institution can fundamentally guide firms' behaviours and form their habits and routines that are regarded as essential 'hereditary units' of evolution (Hodgson, 1993). These EEG arguments show a visible interrelationship between institutions and innovation activities across spaces over the evolution courses.

ii. Forms and effects of institutions

EEG literature highlights institutions as one of the critical local conditions determining the pathways of regional evolution, providing a thorough description of their role. Boschma and Frenken (2009) argue that institutional theory can help explain the formation of fundamental constituents—social practices and routines—within an evolutionary environment, as institutions are considered carriers of history through which these constituents are (re)produced and perpetuated (MacKinnon *et al.*, 2009).

Institutional influences are often materialised as standards, relations, or networks. However, these elements are, to some extent, considered too general to fully explain whether or how institutions significantly affect firms' behaviours or the subtle differences in routines among firms within a region or across territories (Boschma and Frenken, 2009; Hassink, Klaerding and Marques, 2014). These effects are long-lasting and can shape the trajectory of regional or urban evolution.

Hassink, Klaerding and Marques (2014) critique Boschma and Frenken's (2009) approach for presuming 'a clear line between evolutionary and institutional theories,' which complicates EEG literature's ability to present how institutions shape evolutionary processes (MacKinnon *et al.*, 2009). Furthermore, they argue that EEG literature underestimates the significance of power in evolution—such as control over production, the capacity to mobilise resources, and the immanent and performative capacities of individuals to exert actions (Hassink, Klaerding, and Marques, 2014). These two limitations—processes of change and power in evolution—present areas for further exploration.

Still, such explanations about power are insufficient to contextualise the industrial evolution in a country like Taiwan, with a unique role of the state, state-business relations and embedded autonomy to facilitate industry development. (Another limitation is explained in the following part.)

Concerning power, Hassink, Klaerding, and Marques (2014) propose incorporating concepts from GPE and REG into EEG. The concepts of capital, state, and labour from GPE can help identify critical institutions that structure economic activities (Hassink, Klaerding and Marques, 2014). Similarly, the notion of 'power geometries,' proposed by Yeung (2005) in REG, suggests that the extent of power differences influencing economic and spatial changes can be examined through three dimensions of relationality: actor-structure, socio-spatial, and scalar. Within these approaches, the industry structure is not viewed as a whole but as a collection of individual constituents linked in an organised manner. However, such explanations of power are insufficient to contextualise industrial evolution in a country like Taiwan, where the state plays a unique role. Taiwan's state-business relations and embedded autonomy have been critical in facilitating industry development. (Another limitation is discussed in the following part of this subsection.)

iii. Institutions in the evolution process

In terms of the process of change, an institution is considered a fundamental element in observing changes. Changes caused by innovation over regional evolution are substantially reflected in institutions. Institutions, on the one hand, have been recognised to play a proactive role in enabling human action and structuring synergy between actors (Essletzbichler, 2009), and on the other hand, been considered as the reflection of the co-evolution of new technology and market over an extended period (Nelson, 1995). An institution can be both an enabler and a perceiver of changes. With respect to the change in institutions themselves, they are formed through a reproduction process to respond to continually emerging powers.

To address the limitation in explaining the change process concerning institutions, Hassink, Klaerding, and Marques (2014) advocate incorporating institutional economic geography (IEG) into EEG. They suggest that IEG's descriptions of how institutions interact with one another and co-evolve with endogenous and exogenous changes in environments (Gertler, 2010) can help address EEG's lack of focus on human agency in evolution. MacKinnon *et al.* (2019) argue that the IEG approach aligns with the notion of path dependence, which highlights the impacts of past decisions and experiences on development trajectories. Aligning with the approach of incorporating IEG into EEG (Essletzbichler, 2009), Essletzbichler (2012) further clarifies that the institutional environment reflects the balance of power dynamics. A group of dominant firms (or, more broadly, industrial actors) plays a leading role in shaping institutional settings to mobilise resources, improve efficiency, and maintain their advantage over other firms (Boschma and Van der Knaap, 1997; Boschma and Lambooy, 1999; Essletzbichler, 2012).

In addition, the network approach based on REG is introduced by Hassink, Klaerding, and Marques (2014) to improve the EEG's explanation of the evolution process. They argue the cross-scale exploration of the networked relations of agents and social institutions can be attentive to the downward and upward causation processes (Bathelt and Glückler, 2011) and thus balance the micro-level inclined EEG that focuses on the analysis of firms.

REG helps identify which elements should be explored to better understand evolutionary processes. However, its open approach to analysing multi-level relationships between industrial actors tends to capture conditions at a specific point in time rather than emphasising the dynamic process of change.

2.3.2.3 Industrial structure and actors

As discussed in the review above, innovation is a key contributing factor in facilitating regional evolution. At the same time, institutions play a crucial role in shaping development trajectories throughout the evolution process. Beyond highlighting their respective significances, the preceding EEG literature on innovation and institutions also addresses aspects of the evolution process. Building on these reviews, the final part of this subsection focuses on the fundamental mechanism underlying the evolution process: the recursive interactions between agents and structures. This process of change forms the basis of evolution.

i. The evolutionary process: a path dependence approach

In the path dependence understanding of EEG, the path can be explained as an ongoing process, and the regional evolution entails processes of the intricate interplay between 'path dependence, path creation and path destruction' reproduced by actors (Martin and Sunley, 2006). Besides, Martin and Sunley (2006) argue the regional economic space can determine the path-dependent processes, while perceiving changes and transforming over the processes. They raise the concern of an insufficient description of how economic agents and regional economic space interact with each other in this approach and suggest exploring the human agency in EEG. MacKinnon *et al.* (2019) move forward with agency theory to specify which forms of agency can facilitate regional branching and the mechanism of path creation that can restructure regional economic space. However, their research simplifies the process of how structure informs human agency to become only a few representative groups of actors and their actions. Their explanation of the process of the structural changes in a region for the path creation is mainly based on agglomeration economies, but they do not explain how economic agents transform the structure of regional industries.

ii. The evolutionary process: a complexity thinking approach

In order to clarify the process (path) consisting of interactions between the structure of a region and actors, a significant strand of literature has sought an approach to illuminate the dynamic evolution process based on complex science. Martin and Sunley (2007) approach the evolution of the economic landscape from a complex system perspective. The non-linear interactions between elements within a complex system constitute a distinction between itself and other types of systems (Martin and Sunley, 2007). Intending to explore the evolution of an economic landscape, they apply the self-organisation concept from complexity thinking to explain the generic principle of recursive interactions between an organised structure and its components. A non-equilibrium system has dynamics to produce components, such as actors, firms, institutions, and infrastructures, and meanwhile, these components operate the structure of a system that further generates components (ibid). These processes are constituted as the course of self-organisation. Martin and Sunley (2007) claim cities or regions as complex systems can respond to either internal or external changes through the continual self-organisation and adaptation from micro-level dynamics (interactions between proximate components), the macro-level structure and multi-level co-evolutionary mechanism. This self-organised and adaptive process is constituted by the recursive interaction between structures and agents explained above, which is considered the fundamental mechanism of evolution.

iii. The evolutionary process: an actor-structure approach

Apart from the complex approach, Lambooy (2002) also emphasises the duality of environment and agents. He argues the selection environment and the structure, in which society within a specific time and space frame has been embedded, can influence agents (including not only firms but also other actors, like government and science organisations) and vice versa. In a nutshell, the evolution process is based on this two-directional and recursive interaction (Lambooy, 2002). Besides, this interaction can happen cross-scale. From a relational perspective, Bathelt and Glückler (2003) illustrate the relationship between multi-scalar activities of agents and the structure across an economic landscape. They argue that agents (firms) are embedded in social relations that can be conceptualised as networks existing at multiple levels of space (Bathelt and Glückler, 2003). Despite these varied approaches to elucidating the evolution process, it has been commonly agreed in EEG that studying a system's evolution cannot be reducible to the analysis of either agent or structure. Their interactions constitute the fundamental mechanism of evolution. This is a right direction for the theoretical development of EEG, but EEG researchers are not making enough progress in that direction. In particular, explanation of how agents (industrial actors) and their activities (actions) influence or alter a structure has been even less theorised than how the structure limits the actors' choices.

iv. The role of places in evolutionary processes: complexity thinking and generalised Darwinism perspectives

In economic geography literature, locality and localisation have always been foregrounded to explain industrial and regional development. Building on the actor-structure framework, EEG uses the understanding of locality and localisation to reify the concept of structure. Existing studies extensively explore the role of spaces in regional and urban evolution through both complexity thinking and generalised Darwinist approaches. First, from the perspective of complexity thinking, Manson and O'Sullivan (2006) argue that the variability of space, where both economic and social elements are embedded, shapes agents' behaviours and constitutes a key component of a system's complexity. Similarly, Martin and Sunley (2007) assert that a complex economy is composed of networks embedded within or across different spatial entities. Conversely, a spatial entity, such as a region or city, can be part of multiple socio-economic systems. Within such networks, each system interpenetrates others. Considering this interpenetration among complex systems, the challenge of delineating a closed system's boundary may arise at the operational level in empirical studies.

Second, Essletzbichler and Rigby (2007), drawing on the generalised Darwinist approach, illustrate the spatial evolution of socio-economic activities through three principles of evolution: variety, selection, and retention (continuity). They also examine the dynamics of a population composed of competing agents, namely firms, and argue that the pressure of competition among firms pursuing profits facilitates the generation of variety. In a world of multiple regions, each region possesses a set of place-specific characteristics that distinguish it from others (ibid). According to their argument, these regions can be conceived as selection environments, reified as spatial entities with embedded institutions and social networks, which this research considers as critical parts of industrial structure. They can also be interpreted as competition spaces involving firms' production activities. In sum, the concept of competition forms the foundation of the selection environment, shaping firms' behaviors. To maintain competitiveness, firms must innovate, learn, imitate, and keep up with technological change—activities considered deliberate searches for performance improvement (Price, 1970; Metcalfe, 1998; Andersen, 2004b, 2004a; Essletzbichler and Rigby, 2010).

Building on Fisher's (1930) and Price's (1970) population thinking, Essletzbichler and Rigby (2007; 2010) view the selection process as a competition among firms. This competition is reflected in the variance within the population of competing economic units, manifesting in growth and decline, i.e., entry and exit of firms. As a result, the selection environment can change alongside changes in the population. Regarding competition and cooperation between regions, distance is identified as a crucial factor influencing whether selection environments across regions can merge, allowing agents to pursue efficiency (Essletzbichler and Rigby, 2007; 2010).

While exploring the role of space offers a more comprehensive understanding of structure, the interactive process of the actor-structure duality in existing EEG literature remains insufficiently clarified. As a result, understanding how firms' actions transform the selection environment (structure) has been challenging—a critical area for EEG to explore, as highlighted by Essletzbichler and Rigby (2007).

2.3.2.4 Summary

EEG has laid the foundation for economic geographers to explain how innovation and a new industry emerge from a given region and lead to regional evolution. The EEG scholars commonly trace the firms' innovation activities, institutions, and interactions between regional structures and actors to interpret regional evolution.

Firms are regarded as the key component of regional innovation and evolution when most economic geographers explain the evolutionary process of an industry and its relevant regional development. Accumulated activities of firms can represent how industries evolve. These industrial actors directly perceive the variation in the industrial environment over time. Then, they take action to respond accordingly. As such, the firms' activities at different evolutionary stages are depicted clearly in the EEG to elucidate how a region evolves with new industrial activities or even with the development of a new industry. Moreover, over the course of evolution, institutions that have prolonged effects on firms' behaviours serve as carriers of history. Thus, there is a significant amount of argument in the EEG exploring the roles of institutions over the evolution. Institutions are enablers and perceivers of innovation; meanwhile, they can co-evolve with new activities as a structural change happens in an industrial environment. In terms of the evolutionary process, regional evolution is constituted by recursive interactions between the structure and economic actors. A regional or urban system can adapt to changes or innovate through the process of these interactions, which are fundamental to evolution.

While EEG provides a framework for understanding regional changes and identifying critical factors in regional evolution, it presents ambiguities in three key areas: 1) explaining evolution driven by radical innovation that exceeds local capabilities (i.e., arising beyond endogenous dynamics), 2) clarifying the state's influence over institutions through industrial policies, and 3) detailing the mechanisms by which actors' actions alter the industrial structure. The limitations of EEG in explaining regional evolution driven by smart city innovation will be further discussed in the theoretical foundation chapter.

2.3.3 A review of empirical studies of evolutionary economic geography

The last subsection of the EEG review examines the empirical research founded on this theory. Three prominent groups of EEG empirical studies: 1) externalities of diversification and specialisation, 2) institution, and 3) cluster (Boschma and Frenken, 2011; Hassink, Klaerding and Marques, 2014), are reviewed here to explore the manifestation of the effects of innovations, institutions, and interactions between the structure and actors on regional evolution in the real world. In the last subsection, those effects have been interpreted as theoretical elements, but whether the elements accord with the findings of the EEG empirical research is examined below.

2.3.3.1 Externalities of diversification and specialisation

The contrast between diversification and specialisation has been raised by Glaeser *et al.* (1992) to reason the source of innovation for regional growth. Empirical studies on their externalities and corresponding local conditions reveal what can catalyse diversified or specialised development. Previous research by He, Guo and Rigby (2017) proved the relationship between local diversification and specialisation can be affected by the liberalisation of the market and the power of the state. Meanwhile, the population composition of a given region can determine its tendency to diversification or specialisation, which results in a certain level of agglomeration externalities. As such, the heterogeneity of firms in a region is related to the trajectory of regional evolution towards spatial concentration or scattering when a new industry emerges. Spencer (2015) examines the spatial formation of knowledge production industries in three Canadian city-regions. They find that the creative industry tends to concentrate spatially in a central city area; in contrast, the science-based industry is located in a low-density suburban location. An industry's characteristics are related to its actors' properties and behaviours and, as a result, determine the form of a social network, which is reflected in the spatial formation forming its unique knowledge base.

A major approach of empirical studies on diversification and specialisation is to disclose the cause of knowledge spillover, which is considered the origin of agglomeration externalities. In a study investigating the Chinese manufacturing industry, Zhu and He (2019) prove that local knowledge spillovers can benefit the performance of firms. However, not every type of firm contributes to the same level of knowledge spillovers to the local industry. The research found that private-owned enterprises have more input into knowledge spillovers than state- and foreign-owned enterprises (Zhu, He and Luo, 2019).

The above studies emphasise the state's unique role in diversifying or specialising local sectors. Their interventions in production activities can be done through industrial policies or participation in the network, but in the existing EEG theory, the significance of the state has been undervalued. Besides, empirical research has also studied the relevance between spatial formations and production activities. The way those activities are located reflects the interactions between industrial actors and structure, but quantitative research can barely present the actions taken by firms to shape regional industries and the processes of interactions, which has not been fully explored in the theoretical discussions of EEG.

2.3.3.2 Institution

The power dynamics among politics and industries can significantly influence the technological evolution of regions or cities via institutions. The abstract institutional elements explained in the EEG theories are analysed in empirical research by examining specific policies, networks, organisations, governmental agencies etc. In a region lacking technological relatedness, two factors, the above local level institutions and external connections, can facilitate its success in path creation. An empirical study on Chinese manufacturing industries by He, Guo and Rigby (2017) proves that the three exogenous components—regional institutions, state interventions and global connections—can help direct external knowledge to local and improve local relatedness and diversification. Institutions have been proven to determine the emergence of a region's new industries. Dawley (2014) uses the case of the UK's new offshore wind industry to explain the effects of social and institutional agencies, carried out by extra-regional actors and relations, on path creation. The agencies he identified are beyond the firm level. Despite these empirical studies recognising the significance of varied institutional factors, current EEG theories rarely address the supralocal forces that can directly cause structural changes, such as the multi-scalar effects of globalisation, regional institutions and national policies on the local industry structure, or the emerging agents' proactive role in transforming structure.

Another approach to institution study explores the co-evolution of institutions, technology and innovation and the market. MacKinnon *et al.* (2019) investigate the path creation process in both a large metropolitan region, Berlin, and a specialised industrial region, Pittsburgh. They found that over the evolution courses, the two regions above with distinct properties are sustained by different dynamics for their industrial transformations and conditioned by different institutional environments. The big metropolitan area prospers again by promoting innovative entrepreneurs while the specialised cluster works well with institutional entrepreneurs for industrial revitalisation. The two examples in their research require different institutional supports. However, in this research, the existing theoretical explanations are insufficient to clarify the dynamic and interactive process between institutions and innovation activities. Although EEG scholars claim that progressive changes over the course of evolution are at the core of the theory, they elucidate the examples of Berlin and Pittsburgh only by identifying the regions' institutional components that cannot reflect the changing environment and the process of transformation.

2.3.3.3 Cluster

Clusters, containing firms in related sectors, are materialised as spatial concentrations of industries (Porter, 1998). Their emergence and disappearance constitute parts of the evolutionary processes of regions or cities. The empirical studies on the evolution process of different industrial clusters are conducted through the analysis of technological transformation, the composition of networks, the interactions between different actors, and changes in the population (aggregated firms). The explanation of cluster evolution has particularly relied on the path dependence theory (Boschma and Frenken, 2011). Fleming and Sorenson (2001) prove that technological invention over the evolutionary process has been realised through continuous and interdependent recombinant search works among existing components. Thus, without the reintroduced dynamics, the life-cycle of technology development will not endure. Kogler and his colleagues (2017) emphasise that 'the structure (or the relativeness) of local economic activity' (Boschma and Frenken, 2011) plays a vital role in industrial branching during the evolution process with an empirical study analysing patent data in the region of EU 15. They investigate the evolution of specialisation in the European knowledge production region, revealing that the proximity of different technology classes to knowledge cores among regions can intensely condition the technological development pattern, i.e. diversification (entry) and abandonment (exit) (Kogler, Essletzbichler and Rigby, 2017). Giuliani (2007; 2010) demonstrates that the network of knowledge and innovation has a skewed structure by studying the wine industry in Italy. She further indicates that a knowledge network that is with intensive knowledge linkages can benefit the performance of firms, while a broad business network cannot have the same degree of effect (Giuliani, 2010).

Fitjar and Rodríguez-Pose (2015) raise the issue of the nuance of innovation processes between different types of industries among clusters. They argue that EEG fails to systematically explain how actors in various sectors with different innovation and knowledge production processes shape the pathway of regional evolution. In theory, firms in certain industries are supposed to require more scientific inputs for innovation over their practice processes, i.e. interactions with universities and research institutions. However, they prove that interactions with 'science, technology and innovation' (STI) partners are crucial equally to the innovation of either the manufacturing industry or construction and retail firm industries.

The mechanism of entry and exit can be the fundamental dynamics of regional evolution. Østergaard and Park (2015) analyse historical events and the population data (entry and exit) of a Danish wireless communication industry cluster. They find that each agent has different levels of connection to the external systems and thus can exit the local system in different situations. For example, foreign multinational corporations (MNCs) have a higher level of connection to the external systems than local firms, and thus are relatively footloose (Østergaard and Park, 2015).

The above studies on clusters presume innovation is derived from local industries even though beyond local connections have been identified as a critical component of regional innovation. Innovation disconnected from the local development path cannot be explained with the existing EEG theory. This endogeneity-based perspective is formed under the existing theoretical framework of EEG. In addition, their quantitative methodologies cannot reflect the continual process of changes. Instead, they only present certain states over the evolution process and thus cannot identify the critical point of transformations. This propensity of methodology shows the limitation of the theory.

2.3.3.4 Summary

There is a bias in favour of quantitative study in the methodology of the EEG empirical study. Significant amounts of research devote exclusive attention to firms and their characteristics, which is consequently endogeneity-focused. These studies reveal how different types of industries evolve in terms of spatial distribution and economic performance. Their objects include the industrial relatedness, the industrial composition (population) of a region, the tendency towards specialisation or diversification, and the number of entries and exits. However, as far as the smart city industry is concerned, the innovations are not derived from the local high-tech industries. The concept of a smart city was not locally invented. More importantly, the innovation of smart city technologies is beyond any sector's original technological capability. Firms in the related sectors are motivated and facilitated to provide new products or solutions by exogenous elements.

Apart from firms, EEG scholars pay considerable attention in their empirical studies to specific factors like institutions, state policy, and connectedness of firms to local or global actors in evolutionary processes. These factors work at multiple scales, and most importantly, they can structurally transform the system of a region. In this research about the smart city industry, the influence of the government over the technological innovation process is more significant than that in other sectors. Most firms innovating in smart city technologies need to work with their primary clients, i.e. governmental agencies. In this case, promoting smart city development can be used as a measure to help achieve the industry goal. Thus, the state's industrial policy is a critical factor that should be considered in this study when analysing the evolution of a smart city industry.

Lastly, among previous studies, manufacturing, high-tech and creative industries are three commonly analysed sectors. The emerging smart city industry has not yet been studied in existing EEG studies. The development of this industry is cross-sector, which involves the participation of varied industrial actors. Their synergy can thus transform a region's industry into comprehensive technology providers.

Chapter 3: Theoretical Framework

3.1 Introduction

Based on the characteristics of the smart city industry and the theoretical approaches of EEG, I propose three research questions. These questions focus on: radical innovation (RQ1), state industrial policies (RQ2), and structural transformations driven by actors (RQ3).

Although existing EEG arguments describe gradual regional evolution in details, they cannot fully account for evolution driven by radical innovation that disrupts the normal progress of an existing path—primarily aimed at improving production efficiency. Radical innovation is, by nature, exogenous to the local industry, and its emergence can be significantly facilitated by state industrial policies. In addition to these limitations—regarding the exogenous perspective and the state's involvement—EEG requires further enhancement to address a longstanding research gap in describing the roles of actors in shaping the regional structure for industrial development. Consequently, to reveal smart city-driven industrial evolution, this research must develop a new theoretical framework for EEG.

Accordingly, this study incorporates three strands of theory – the window of locational opportunity (WLO), the developmental state, and the structuration – to better furnish an EEG able to reflect the unique dynamics of the smart city industry. This new sector's emergence provides opportunities for more economic actors and enables innovation activities. Those actors and activities were not part of the regional high-tech industry system before but have now become indispensable to smart city innovation. Meanwhile, the development of the smart city industry is heavily affected by the state's industrial policies. Accordingly, the theories of WLO and developmental state can help enhance the explanation of the structural changes responding to innovation caused by external forces and the state's industrial policies. Structuration theory is then used in this research to clarify the involvement of different new industrial actors in Taiwanese ICT industries in changing the structure of the industrial environment over the evolutionary process.

In the following sections, I first explain why existing EEG theory cannot adequately depict the development of the smart city industry. Next, I describe how arguments from the three theories I have borrowed can complement EEG.

3.2 EEG's Limitations

Characteristics of Smart City Technology Production

EEG provides a generic framework for understanding the gradual emergence of a new industry in a region, including change processes and key components for analysis (Boschma and Frenken, 2018). However, three unique characteristics of smart city innovation-driven regional evolution pose challenges for directly grounding arguments in existing EEG theory.

First of all, developing the smart city industry constitutes radical innovation that is distinct from local industries in most regions. While the local context can influence how industries develop smart city products and services, most firms initially learned about the smart city concept from IBM's *Smarter Planet Initiative* (Palmisano, 2008). In other words, a foreign technology firm promoted the innovation of these new technologies (Hollands, 2015), rather than local industries initiating it. Accordingly, in most countries, smart city-related innovation was inspired externally and remained detached from local industry. Therefore, when exploring the evolution of the smart city industry, it is important to consider how innovations driven by exogenous elements impact the local industrial environment—beyond what local capabilities alone can achieve. Consequently, smart city innovation can trigger a new development path that breaks away from the gradual process of product improvement—producing new technological products and enabling the emergence of new sectors—thereby constituting a radical break.

Secondly, the state is integral to the industrial structure (Hsu, 2017; Yeung, 2017) for developing the smart city sector in the Taiwan. The link between the state and the industry environment is twofold. On the one hand, Taiwan's developmental state legacy determines its economic and industrial development paths (Wade, 2018). In a developmental state, the structure of its industrial environment has primarily been shaped by the state's embedded autonomy (Evans, 1995). The influence of this state-level industrial development structure goes beyond individual industry policies. On the other hand, due to the nature of the smart city industry, the government is its primary client, and thus, the state can leverage city development to facilitate the growth of this industry (Chang, Jou and Chung, 2021; Joo, 2023). As a consequence, it is critical to reveal the state's role in developing this new industry through policy approaches.

Lastly, combining the two points above, developing radical innovation, like the smart city industry in a developmental state country, can cause fundamental changes in the structure of the industrial environment. In practice, such structural transformation is the collective actions of industrial actors (Giddens, 1984). Conversely, a region's creative capability that manifests in innovation activities is critical to realising the development of a new industry (Boschma, 1996; Martin and Sunley, 2010). Accordingly, throughout the process of radical innovation-driven regional evolution, a structural transformation occurs in the local industry, with industrial actors taking decisive actions that steer industries away from their established paths. Therefore, this study needs to know how the collective actions of various actors generate changes in the landscape of the industry and then revolutionise a regional structure. However, the EEG studies presented thus far provide evidence of significant research gaps that make it difficult to explain the regional evolution driven by smart city industry development, as the theory tends to portray evolutionary processes as gradual and incremental, shaped by a region's industrial structure (see the summary in Table 4).

Limitations of EEG in Explaining Smart City Technology Production

The first limitation concerns EEG's explanation of how an exogenous element impacts regional evolution. EEG elucidates how changes emerge along the existing industry development path and among endogenous elements of given regions and their corresponding evolutionary course (Boschma and Frenken, 2006; Martin and Sunley, 2010). Even changes like radical innovation done by industrial actors (firms) in a regional system are explained under this framework. Specifically, among existing EEG arguments, radical innovations have been considered as new technologies branching from endogenous elements in local industries through the process of diversification (Frenken and Boschma, 2007; Castaldi, Frenken and Los, 2015). The emergence of radical innovation can cause a series of gradual changes in the components of a region. This explanation echoes structural functionalism's emphasis on the structural aspects of societies. Parsons (1948) highlights in the structural functionalism that the individual agent's actions are contingent on its embedded physical, social and cultural environment, i.e. the structured social system (Castro, 2009). Meanwhile, the structure of the system has been equipped with the functions to respond to changes in the environment. These arguments about structure-enabled and -constrained human actions are relatively endogenous-focused. Nonetheless, the radical industrial transformation, like the development of the novel smart city industry, is distinct from the endogenously emerging and adapted elements depicted in the existing EEG theory. The exogenous elements, like smart city innovations, can directly impact and immediately transform a region (see Figure 4). In this case, local systems can barely have an extended period to absorb the external effects and evolve step by step.

Secondly, in EEG literature, there have been limited descriptions of the state's role in regional industry development. The firm-inclined EEG explanation (Dawley, 2014) of the industrial structure centres around constituent entities while neglecting that the state can generate structural changes through institutions embedded in the industrial environment. Admittedly, in EEG, the discussion of the significance of institutions has clarified how institutional factors, such as standards, relations, networks, etc. (Boschma and Frenken, 2009), shape innovation activities (Boschma and Frenken, 2006). However, Hassink, Klaerding and Marques (2014) argue that the understanding of institutions in existing EEG theories cannot reflect the power and dynamics that can determine the pathway of regional industry evolution. They attempt to rectify this shortcoming of EEG by incorporating geographical political economy (GPE) and relational economic geography's (REG's) emphasis on the importance of critical institutions and various relationalities. In an empirical study, Dawley (2014) identifies that state and industry policy interventions can facilitate the creation of a new path for regional industries through certain agencies. Still, these theoretical and analytical findings have not been fully incorporated into a systematic explanation of the state in EEG theories. Especially in the industrial development context of Taiwan, the developmental state legacy reified in the forms of institutions underpins its high-tech industry and thus, to some extent, determines the future evolution trajectory. The smart city industry has profound relevance to the government's city development policies. Therefore, the institutional endowments built by the state to the industry structure have significant influences on its development.

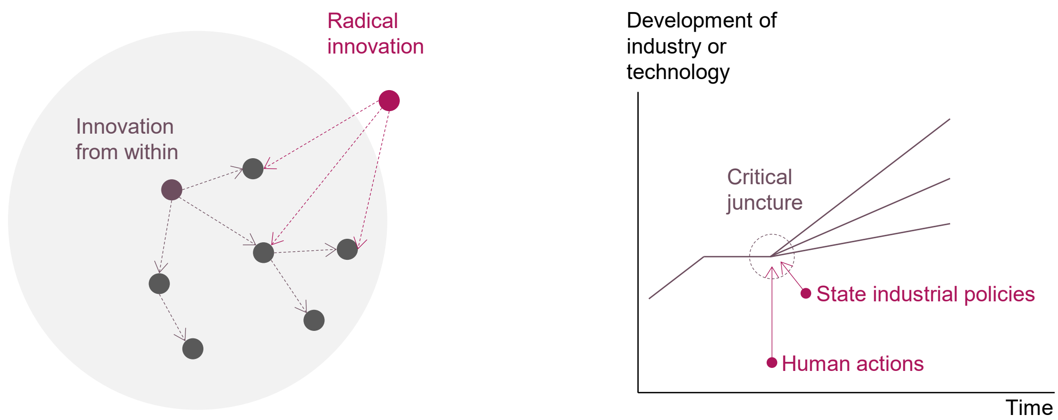
Lastly, the most significant limitation of EEG refers to agents and how their actions transform the regional structure of industrial development. EEG illuminates that economic agents can interact with the structure, which contributes to regional evolution (Martin and Sunley, 2007). Under this theoretical framework, economic agents, namely firms, are highlighted as pivots of the industry evolving. EEG reveals the dynamics of regional evolution by clarifying a region's structural changes in terms of different evolutionary stages and the activities of firms (Martin and Sunley, 2010). The explanations of the actor-structure interactions in EEG are mostly based on complexity thinking (Martin and Sunley, 2007) and the biological analogy perspective, Darwinism (Essletzbichler and Rigby, 2007). Both approaches suggest that these interactions constituting regional evolution are two-directional. However, the process of how the structure and embedded actors interact with each other has not been fully clarified in existing theories. While, like Parson's structural functionalism, the concept that actions are structure-determined is explicit among EEG arguments, there is a lack of explanation of how agents change the structure of a regional system and how they do to reshape the industrial environment. The accumulated actions of all agents relevant to the industry are fundamental to structural change and regional evolution. Existing EEG theories have not illuminated what critical junctures that cause structural transformations in industries can be and how they happen. Furthermore, few empirical studies have examined how these interactions are practised in the real world with a qualitative method. As the smart city innovation is not a bifurcation of local industries but is motivated by the exogenous environment, the structure-focused explanation can hardly be used to understand its emergence. In order to reveal the development of this radical innovation, the EEG must consider the converse effect of actions that change regional industry structure.

Table 4 EEG's limitations in explaining smart city innovation-driven regional evolution

Theoretical aspects in EEG	**Characteristics of smart city innovation**	**EEG's limitations**
Innovation	• Smart city innovation was initiated by overseas companies. • Initial gaps in technical capabilities hinder local industries from developing smart city innovation, making it an exogenous element.	• Endogenous-focused: The evolutionary path has been examined by focusing on endogenous elements; however, this perspective hardly explains how a region develops innovation beyond its local capabilities.

Theoretical aspects in EEG	**Characteristics of smart city innovation**	**EEG's limitations**
	• Developing smart city innovation differs from gradual efficiency improvements because it involves creating new technology sets and new sectors; hence, it is regarded as radical.	• Incremental based: The innovation process has been explained in a gradual manner, based on local industries' incremental improvement mechanisms; however, this framework can hardly account for the extraordinary progress in technology development.
Institution	• State-level industrial policies can facilitate smart city innovation, triggering changes in the industrial structure. • The government, as the primary client of smart city firms, can leverage city development to promote relevant innovation.	• Firm-focused: In EEG, firms are the primary focus when examining how evolution unfolds, so the significance of the state in driving changes in the industrial structure receives less attention. • State role neglected: The theoretical framework of EEG does not clearly elucidate how state intervention through industrial policies transforms the industrial structure, thereby driving regional development.
Actor-structure interactions	• State industrial policies and actions taken by industrial actors can trigger changes in the industrial structure.	• Structure-determinism: The EEG's structure-determinism perspective can hardly capture the reverse effect of actions that alter the existing structure of local industries; in particular, when the innovation is exogenous, this structure-focused perspective becomes inapplicable.

(Source: author's own compilation)



The theoretical limitation of radical innovation

The theoretical limitations of state and actor-caused structural changes

Figure 4 Research gaps in existing EEG theories

(Source: author's own compilation)

3.3 A New EEG Theoretical Framework

Three critical themes have emerged from the studies discussed so far. First, EEG requires further development to explain how interventions by exogenous elements and state industrial policies influence regional evolution, and how industrial actors make changes in existing structures. Accordingly, my study will apply the notion of the WLO and the concept of the developmental state to examine the effects of radical innovation and state industrial policies. Finally, structuration theory will be employed to clarify how industrial actors and structural factors mutually reproduce one another. The following three subsections illustrate how these complementary approaches are used to advance EEG.

3.3.1 Window of locational opportunity

The concept of the WLO in the existing EEG framework

Before reconstructing the new EEG theoretical framework for my research, I begin by incorporating the WLO concept from EEG literature. WLO describes either a new industry that facilitates the relocation of social resources or a revitalised old industry that drives the restructuring of its product, production processes, or employment relations (Scott and Storper, 1987). Boschma (1996), building on Scott and Storper (1987), was one of the earliest to stress the importance of considering the WLO in evolution theory. In contrast, Scott and Storper's (1987) explanation of WLO pays less attention to the preexisting conditions of a region. Instead, they focus on defining non-locally fostered innovation and explaining how a place creates conditions that accommodate relevant developmental activities.

Boschma (1996) introduces the concepts of unpredictability and discontinuity to balance the deterministic perspective in evolution theory. He conceptualises a region's response to the WLO as its creative capacity, providing useful entry points for understanding the impact of the WLO on regional evolution. However, Boschma's WLO concepts have not been fully incorporated into EEG's detailed explanation of local conditions, largely because a more robust theoretical foundation for EEG was not established until the 2010s. The existing evolution theory remains insufficiently concrete to capture changes in regional industry structure driven by the WLO. Thus, this subsection builds on Boschma's ideas, integrating them with critical EEG arguments to further specify the elements that reflect WLO-driven regional evolution.

The role of WLO in regional evolution

According (Soete, 1985), the WLO explains the catch-up process that bridges the technological gap between countries near the technological frontier and those lagging behind. This concept has been incorporated into explanations of the evolution of technological paradigms, as it facilitates the development of interrelated technology systems that collectively form the paradigm (Perez and Soete, 1988). Dosi (1982) conceptualises the technological paradigm as a model and pattern for problem-solving through technology, based on a set of underlying principles. This paradigm shapes a technological trajectory by clustering possible technological directions and balancing trade-offs among various technological variables. Within a paradigm, each technology system comprises knowledge, skills, experience, and externalities. Moreover, the emergence of a new technological system drives the advancement of these components (Perez and Soete, 1988).

Freeman (2009) further elucidates the framework of the ICT paradigm and shows how it drives the development of the computer, telecommunications, micro-electronics, and software sectors—especially highlighting the notable emergence of the software sector in the US. In his version, the ICT paradigm emphasises the electronification of workflow and e-commerce. In the late 2010s, ICT usage focused on enabling individuals to access information and communicate more efficiently—a focus that contrasts with its current application across broader domains. At that time, ICT-based technologies that leveraged data applications (such as big data and artificial intelligence) to optimise city efficiency—now recognised as key components of smart city innovation—were not yet mature, nor were they widely promoted. Today's smart city innovation can be seen as a new technological trajectory that facilitates the emergence of technological systems diverging from the traditional ICT paradigm depicted by Freeman (2009).

Although both fall under the ICT paradigm, hardware and software technologies differ fundamentally in their production activities—such as skills, techniques, intermediate inputs, alliances, corporate culture, and physical space (Gregory, Nollen and Tenev, 2007). Hardware production is characterised by the integration of technical and engineering skills (e.g., in electronics, mechanical engineering, and process optimisation), ensuring precision and standardisation in manufacturing processes, and developing deep technical expertise in physical product design (Gregory, Nollen and Tenev, 2007; Yeung, 2022). It also requires significant physical inputs and the management of complex supply chains, fosters long-term partnerships and coordinated supply chain management, operates under hierarchical, long-term planning, and necessitates substantial physical space along with strategically located logistics networks (ibid). In contrast, software production relies more on cognitive skills and flexible, adaptive learning models. It focuses on intangible knowledge assets, building upon intellectual property, open-source frameworks, and digital development tools for innovation (Shapiro and Varian, 1999). Furthermore, software production leverages international alliances through collaborative research, joint development projects, and standard-setting, tapping into global talent and virtual teams, embraces an agile and rapid iteration culture, and favours smaller office spaces and proximity to innovation clusters (Gregory, Nollen and Tenev, 2007).

Within the ICT paradigm, various technology systems with contrasting characteristics exist. Regional industries may have the capabilities to meet the requirements of certain systems; however, when they attempt to develop technologies beyond these systems' scope, structural changes—namely, the emergence of new technological systems that transform the sectoral composition—become necessary.

Smart city innovation as a WLO

The WLO approach provides an exogenous perspective to illustrate the influence of non-local factors on regional evolution, which can balance the endogeneity-inclined attention of the EEG. This fundamental difference regarding the nature of innovation should be restated in the first instance for this smart city industry research. The smart city concept was still new to most countries in the late 2000s. Thus, when Taiwan began developing relevant technologies and industries from 2000 onward, the government drew on overseas experiences—highlighted by the iconic IBM *Smarter Planet Initiative* (Palmisano, 2008)—while deploying accessible local resources. Since smart city technologies are primarily application- and service-oriented, the hardware-specialised Taiwanese industries had to overcome gaps in their software development capabilities. Consequently, they needed to be restructured to meet the requirements of smart city innovation.

Meanwhile, in Taiwan—where the government is the primary purchaser of smart city technologies—it is natural for the state to leverage city development to drive technological innovation (see case background in Chapter 1). Consequently, the development of smart cities and their associated technologies in Taiwan is not derived from local industries but driven by external intervention, namely state industrial policies and the WLO. Because this innovation deviates from the traditional path, the existing explanation of radical innovation in EEG cannot fully account for the emergence of the smart city industry. As this new industry began to emerge, the uncertainty stemming from new possibilities made it challenging to predict its development based solely on the historical trajectory of local industries (Boschma, 1996).

Therefore, we must recognise that the evolution of existing sectors into the smart city phase is driven by exogenous factors. On one hand, this type of innovation presents opportunities for regions that lack dominant technological capabilities in established industries (Scott and Storper, 1987; Storper and Walker, 1989; Boschma, 1996). On the other hand, state interventions aimed at facilitating the development of this new industry serve as an above-local force—extending beyond the decisions of individual firms—to restructure the industrial landscape. Accordingly, this WLO subsection situates exogenous, innovation-led regional evolution within the context of existing EEG arguments, while the specific state-led structural changes in industries will be detailed in the following developmental state subsection.

WLO-induced changes in regional evolution

In WLO literature, Boschma (1996) and Boschma and Frenken (2009) emphasise that two elements—spatial formation and human agency—drive evolution propelled by radical innovation. Notably, the WLO perspective differs from the EEG interpretation because it does not view radical innovation (or the emergence of a new industry) as originating from local industries. According to Storper and Walker (1989), a new industry arising from radical innovation can create the necessary conditions for growth. The changes in local conditions required for locational specialisation—supporting the development of radical innovation—primarily involve shifts in labour, resources, and customer bases, mediated through firms (ibid). When spatial transformation becomes part of regional evolution, the WLO is likely to be wide open, indicating discontinuity (Boschma, 1996). In such cases, production spaces are either formed or reshaped by new economic and innovation activities (Storper and Walker, 1989), linking spatial formation with human agency, which in turn generates creative capacity (Boschma, 1996).

The creative capacity or abilities that can foster supportive conditions in a region are critical to determining the evolution trajectory caused by the WLO. Storper and Walker (1989) describe a firm's or industry's capacity to gain elements (i.e. labour, resource and customer) needed for locational specialisation as locational capabilities. In a dynamic evolution system, this capacity can be realised through four factors: 'technological innovation, organisational advance, labour rationalisation and skill development, and rate of investment' (ibid). The holy trinity—technological, organisational and territorial dimensions—that Storper redefined in 1997 to emphasise the process of regional development can be used to illustrate these factors further in EEG.

The first dimension is technology. 'Technological innovation' can be analysed to determine how it creates local conditions for radical innovation by examining the variety of technologies in a region—a concept referred to as diversification in EEG literature. Next, with regard to the organization of firms, 'organisational advance' can be examined by analysing the composition of actors (firms) that collaborate in production. Finally, concerning territory—the final two factors determining creative capacity—'labour rationalization and skill development' and the 'rate of investment' can be assessed through untraded interdependencies (i.e., conventions and relations that facilitate coordination), which are formed through long-term proximate location. In short, the dynamics of WLO-induced evolution differ from the dominant arguments in existing EEG literature. In this case, critical agents (industrial actors) and their actions drive regional evolution, rather than the existing industrial environment, which cannot support the emergence of a new or revived industry without restructuring.

For regions catching the opportunity, the development of the smart city industry is not a gradual process that evolved from a region's local high-tech industry. Instead, its evolution is driven by exogenous forces. Subsequently, endogenous elements of the regional system may change to adapt to a series of radically new demands for industrial development in a relatively short time. Boschma (1996) argues the selection environment that proactively shapes the industry evolution, explained in existing EEG, is inapplicable to understanding the external force-driven regional development. Instead, uncertainty and accidental events are fundamental to the WLO-enabled evolution and can cause major innovation in a region, offering alternative development paths (Boschma, 1996). Revealing the actions taken by industrial actors could help clarify what exactly these uncertainties and events are. According to the review above, when examining whether WLO opened in regions, two factors should be included in EEG for the initial analysis: 1) if there was a spatial discontinuity and 2) if accident events happened. Furthermore, the holy trinity in EEG can be used to analyse the creative capability that generates the local conditions necessary to enable critical innovation-driven evolution (see Table 5 for a summary of insights from the WLO perspective).

Local conditions and WLO emergence

The WLO focuses on radical innovations unrestricted by the local context (Scott and Storper, 1987). This type of industrial innovation is discontinuous in an existing environment (Boschma and Lambooy, 1999). The discontinuity of innovation can radically break routines and institutions that impede changes (Boschma, 1996). Boschma and Lambooy (1999) argue rather than specific parameters, generic resources can be more favourable for initially nourishing a new industry in a given region. Still, where the new industry enabled by WLO can burgeon has been debated among EEG literature. Essletzbichler and Rigby (2007; 2010) mention the WLO in EEG studies, emphasising the condition of a place can influence how an industry evolves through new technological innovation. Whether a place can successfully nourish a radical innovation-driven industry is not speculative. Storper and Walker (1989) contend that regions with a certain level of industry foundation are favourable for the WLO, such as those near big cities (Storper and Walker, 1989) or with relevant sectors (Boschma, 1996). Despite these extensive debates, the elucidation in the WLO theory about what and how local industrial conditions respond to and evolve with new technological innovations has not been fully incorporated into EEG.

Admittedly, the co-evolution process highlighted by the WLO demonstrates how exogenous elements can potentially influence regional evolutionary trajectories. However, existing EEG literature does not fully explore the regional co-evolution process driven by radical innovation that accommodates the WLO—specifically, the changes in production spaces and human agency (such as innovation patterns and institutions) (Scott and Storper, 1987; Boschma, 1996). To operationalise the abstract concepts discussed by Boschma within EEG, an empirical study is required to clearly identify what constitutes the creative capability that drives radical innovation. Therefore, a more systematic approach is necessary to thoroughly understand this creative capability. The roles of industrial actors and their actions are further examined in the structuration subsection, which clarifies how the dual concepts of agency and structure in EEG can be used to explain their impact on regional evolution.

3.3.2 Developmental state

The embeddedness of the state in the industrial structure

As mentioned in the previous subsection, the government is the primary client of smart city technologies. Although EEG pays little attention to the state's role, it is critical to reveal how the state and its industrial policies enable industries to develop these technologies. To understand the Taiwanese state's role in industry development and the effects of its policies on the industrial environment, this research borrows concepts from developmental state literature to refine EEG's description of political and institutional influences on industrial development. The state's intervention in industrial development can make a structural change. The industry development formulae of Taiwan and a few East Asian economies, including Japan, South Korea, Singapore and Hong Kong, have been described as 'developmental states' (Wade, 1990). Developmental state literature reveals the significance of the state that determines the institutional endowments embedded within the structure of a region. The concept of institutions among existing EEG literature has not been understood in this way to explain the power dynamics behind industry evolution driven by the state, not seeing the structure as a whole but as constituents linked with each other.

Between the 1950s and the 1980s, east Asian countries enjoyed rapid economic and industrial growth by virtue of orchestrated economic plans and instruments and closely bound state-business relationships (Stubbs, 2017; Wade, 2018). In their bureaucracies, technocrats were responsible for conceiving national industry development schemes that identified specific sectors to develop (Stubbs, 2017). Then, the state supported their growth with government resources and powers. The approaches included setting import and export strategies, helping capital dominate capital-labour relations, maintaining a high rate of investment to gross domestic product (GDP), providing public funds, controlling financial sectors, and penetrating public and private enterprises for oversight through quangos or industry associations (Wade, 2018). Conversely, these countries' political and government systems reflect the results of the economic dynamics. Evans (1995) describes this interwoven relationship between the state, enterprises and society achieving national development goals as embedded autonomy.

The state's unique role forms an asymmetric power structure influencing national industry development. Which sectors would be developed and which companies would become leading firms in industries in developmental state countries were not stochastic but highly influenced by the state's decisions and interventions. This structure, in which industrial actors were involved, was composed of close state-business relations and synergistic quango-business networks. Meanwhile, the state mainly controlled where the resources, especially capital, were invested, and intervened in the market to mitigate early-stage innovation risk when domesticating foreign innovations and developing technology frontier (Wade, 1990; Wade, 2018). Such context of developmental state countries is critical to understanding the role of institutions in regional evolution because this is the environment in that firms' actions were (re)produced and perpetuated.

After the 1980s, the original East Asian developmental state model mutated into a new phase because of changes in the global trade and political context, the democratisation of societies and the rise of neoliberalism in East Asia (Wade, 2018; Hamilton-Hart and Yeung, 2021). As a result, the state has withdrawn the power over capital-labour relations (Pirie, 2018) and the power over credit allocation to support specific industrial actors (Wade, 2018). Despite the changes, the mindsets of many of those governments, such as South Korea and Taiwan, regarding economic planning and international trading remain similar to the developmental state governments (Chu, 2021). Thurbon (2014) argues whether a country remains a developmental state is not judged by if its government's interventions are persistent but if the ambition to develop and consensus between elites exist in a country to sustain imperative institutional capabilities and interventions.

Institutional effects of the state on regional evolution

Over societal, economic and political changes, the institutions supporting national development goals could be reconfigured or mutated to adapt to the dynamic environment. In Taiwan, the way the government steered industry development shifted from running state enterprises and overseeing industry associations to building public-private collaborative models (Wade, 2018; Chu, 2021). Since the 1980s, the collaborative relationship between the Taiwanese government and industries has been maintained by a steering body under the highest state executive branch, the Board of Science and Technology (BOST), comprised of members from the government and businesses, in the central government, as well as publicly funded agencies that are low-level quangos (Wade, 2018). Until now, Taiwan's new technology development and industry upgrade strategies are still guided by BOST, and mainly facilitated by quangos, such as the Industrial Technology Research Institute (ITRI) and Institute for Information Industry (III), together with industries (Chu, 2021). These elements determining industry development are embedded in the industry structure as a part of 'hard' (formal) and 'soft' (informal) institutions (Rodríguez-Pose, 2013). The capabilities to realise developmental goals have been inscribed in institutions by the state; those institutions significantly influence the trajectory of industry evolution.

In Taiwan, hard institutions in the form of BOST and low-level quangos are the core of government-business collaboration relations and networks, which have dominance over development goals. Its most essential soft institution is the developmental consensus between different sectors. In short, the structure of the industrial environment is underpinned by various institutions that determine the government's economic and industrial development goals, trading strategies and the government-business network.

The existing EEG literature explains the structure in a generic way that originates from industrial actors-related constituent entities and institutions. Thus, developmental state literature can complement EEG by elucidating how state actions shape structure through institutional approaches (see Table 5 for the key arguments discussed above). When probing smart city industry development in a country with a developmental legacy, we need to incorporate the above explanation of the state's effects on the regional industrial structure in the EEG. Unlike a pure neoliberal economy, industrial actors in Taiwan do not participate in the global market with minimum government constraints when developing a new industry. Instead, their target markets are highly influenced by national import and export policies. Moreover, the government's industrial policy-making and -implementation greatly determine how a new sector develops and how national industries transform. Therefore, EEG's argument about institutions and an industrial structure must include the abovementioned elements.

3.3.3 Structuration

The existing EEG framework in understanding changes in evolutionary trajectories

Based on the review above, it is evident that exogenous elements' and the state's effects on industry evolution are significant driving factors in regional transformations. However, we must find a systematic way to situate these factors in the evolutionary course to analyse the smart city-driven industrial evolution. In the EEG theory, exogenous innovation has been mentioned under the concept of accidental events in the path dependence approach to explaining regional path creation, but those events are understood as random and by chance (Martin and Sunley, 2006). This perspective does not weigh the significance of local conditions when revealing the evolution process.

Another theoretical strand in EEG uses regional branching to interpret radical innovation. Those EEG studies explain evolution out of regional branching originates from local elements (Martin and Sunley, 2006; Frenken and Boschma, 2007; Castaldi, Frenken and Los, 2015). The effect of exogenous innovation on regional evolution has been underplayed and fails to elucidate the evolution process that consists of interactions between regional economic space (structure) and agents (actors) (Martin and Sunley, 2006; MacKinnon *et al.*, 2019). Although regional conditions and human agency have been recognised as critical components shaping and reflecting regional evolution, EEG literature has not fully clarified how their interrelationship makes changes in the path-dependent trajectories and how to identify critical junctures of regional reconfiguration (see Chapter 2). Therefore, this subsection examines the fundamental evolution mechanism – interactions between structure and actors. This concept has been used extensively in EEG but without detail of how the structure and actors interact. Building upon a complete understanding of the interaction process, we will be able to systematically analyse how the factors of exogenous elements and the state shape the evolution processes and paths.

The duality of structure and actor proactiveness in industrial transformation

Neither actors nor the structure alone can determine the evolution, which instead can understand with the structuration framework. Sophisticated discussions on the relationship between 'structure' and 'agency' can be found in sociological theory that I will borrow to reveal the intricate transformation process of regional industries. The process involves technological, organisational, and territorial changes caused by various economic actors in the emerging smart city sector. Giddens (1984) elucidates the role of 'agency' and 'structure' and their interactions in his structuration theory. Its core concept is the duality of a structure, i.e. a recursive process reproducing social practices (Giddens, 1981). Basically, the duality is sustained by social systems comprising structured properties (understood as structure) and actors with knowledgeability, accounted as an embodiment of the systems (Dyck and Kearns, 2006).

In *The Constitution of Society* (1984), Giddens comprehensively describes elements within the framework of structuration. The thorough descriptions of those elements can be used to complete the EEG's explanations of agency, structure and their interaction. The following three aspects of the structuration conception help illuminate the EEG's arguments.

Firstly, actors' actions should be understood under the structure rather than as an isolated entity. Giddens (1984) argues that, on the one hand, actors have knowledgeability embedded in their practical consciousness, while their actions done out of practical consciousness cannot be discursively expressed. On the other hand, they can basically describe the reasons for their conduct based on the discursive consciousness. It is critical to understand the routinisation concept in the structuration theory to have a grasp of the actors' day-to-day activities. The routinisation of social practices, rooted in practical consciousness, is sustained by the mechanism of reflexive monitoring, while the reflexive monitoring of conduct is integral to the social systems' structural properties. On the contrary, conduct out of motivation, not reflexive monitoring, can deviate from routines. In practice, the actions of industrial actors, namely how they carry out their work (practice) for technology development or production, are reproduced over this structure-constrained and -enabled recursive process.

Secondly, the existence of structure is bound to the actors' practices and memory traces because the structure has been saved in memory traces of actors motivated by discursive or practice consciousness linking to the agency (Giddens, 1984). In other words, the structure couples with human agents and is, to some extent, formed by their memory traces. In dynamic systems, structures have been transforming with changes in social systems that comprise human agents' activities and are reified as patterns of social relations (Giddens, 1984). Meanwhile, the structure is intrinsic to the reproduction of social systems. We can broadly define a structure as a society's structural properties—for example, its institutionalised features—while the structural principles that organise societal totalities represent the most deeply embedded aspects of these properties (see Table 5 for a summary of how these two aspects are operationalised).

Giddens (1984) specifically argues structures are constituted by rules and resources organised in sets that are recursively involved in institutions. Concerning the spatial aspect of structures, we should bear in mind three critical notions Giddens (1984) summarises: time-space distanciation, regionalisation and time-space edges. Time-space distanciation is the extension of social systems stretching across time-space through social and system integrations that are reciprocity of copresent (social) and non-copresent (system) actors' or collectives' practices. Then, regionalisation that can be in the same or across different locales means the zoning of time-space relating to the formation of actors' routines. Lastly, time-space edges represent the connections between societies that can have varied or similar structural properties. The preceding explanations of systemness and temporality/spatiality of structures clarify how to analyse structures and how they are related to actors.

Critical junctures in regional evolution

How actors and the structure draw on each other is explained above. The description of changes is the final key component that the structuration concept can lend to EEG. The essence of the EEG is its elucidation of how changes happen in regions and lead to their evolution. As stated previously, the path dependence approach to EEG argues accidental events are path creation but does not clarify the process that the structure of a region transforms with changes. Thus, using structuration theory's actor-structure duality can illuminate how social changes occur. The notion of episode is at the core of the analysis of social changes that generate structural transformations in societies. An episode can be identified with an opening and an end bracketing a particular sequence of changes that can impact institutions within a societal totality or cause transitions between societal totality types. When a set of changes happens rapidly, long-term momentum for evolution can be generated. Those changes can be revealed by analysing the acts or events and the institutional transmutation process. Another contention of structuration theory, which should be applied to improve EEG, is its non-endogeneity inclination toward the explanation of the evolution process. Giddens (1984) critiques the endogenous-focused perspective of evolution toward understanding changes because societies naturally have connections with intersocietal systems. Intersocietal systems involve relations stretching across societal totalities. The varying forms of the intersocietal system significantly influence episodes. Meanwhile, episodic changes occur at the conjunctions of events or circumstances within a given context that includes actors' reflexive monitoring. Consequently, variations in context cause episodes to unfold along different trajectories. Table 5 summarises the key arguments regarding the operationalisation of the critical juncture.

Jessop (2005) expands on structuration theory, highlighting actors in relation to the structure, arguing that while Giddens made a contribution in delineating fundamental elements within a social system, his approach neglects the ontological proposition. He argues the analysed structure must be treated as strategically-selective based on its form, content and operation. Jessop conflates structuration theory with Bhaskar's transformational model of social activity and Archer's morphogenetic theory to make a more comprehensive structure-agency theory that can provide a contextualised and temporal-sensible theoretical base. Incorporating the viewpoints of these two approaches enables structuration theory to be attentive to the pivotal parts of a system because this advanced theoretical framework thoroughly considers relations under a given context.

The reviews of the three aspects of the structuration conception above indicate the key components of the regional evolution over the process of change. Actors and the structure are inseparable when we examine the evolutionary process of systems. All relevant elements and practices within such systems should be viewed under the actor-structure duality. When revealing the evolutionary process of the smart city industry from a structuration perspective, Giddens (1984) suggests two analytical approaches that should be considered: one focused on actors and the other on institutions. First, the analysis of strategic conduct examines the reflexive monitoring of actors' actions and the rules and resources they draw on to take these actions within given institutional conditions. The second approach, institutional analysis, explores the structural principles and the conjunctures of these principles within intersocietal systems, considering the skills and awareness of actors. The institutions analysed are the resources and rules that are continually reproduced. It should be noted that, since actors and structures are inseparable, both approaches account for the other, rather than focusing solely on actors or institutions. Specifically, each approach examines changes in one role as the key object, while the other is analysed in relation to those changes as complementary information. With these clear objects of analysis and the preceding understanding of the duality mechanism, the process of actor-structure interactions that EEG touches upon can be elucidated comprehensively.

Table 5 The upgraded EEG theoretical framework and its analytical operationalisation

Limits of existing EEG	**Upgraded EEG theoretical framework with imported concepts**	**Operationalisation for empirical analysis**
Innovation • Endogenous-focused • Incremental based	Critical concepts: • Diversification of sectoral composition initiated by exogenous elements • Discontinuity in evolution: both path-dependent and accidental events • Local capabilities manifested through triple transformations	Elements for analysis: • Technology: The variety of technology. • Organisation: The composition of firms. • Territory: Proximate, untraded interdependencies. Methodological principle: • The empirical analysis needs to examine the sectoral composition from three

Limits of existing EEG	Upgraded EEG theoretical framework with imported concepts	Operationalisation for empirical analysis
		aspects and identify whether any systems have emerged that diverge from mere improvements in existing production.
Institution • Firm-focused • State role neglected	Critical concepts: • Collaborative relations and networks under a developmental state's institutional endowments • Cross-sector consensus • The role of government, including quango agencies, in business interactions	Institutional aspects for analysis: • Maintenance of government–business relations and networks by both high- and low-level governmental agencies. • Developmental consensus between government and business. • Modes of intervention in the market. Methodological principle • The empirical analysis needs to reveal the institutional mechanisms of policy delivery, including government–business relations, development consensus formation and market intervention.
Actor-structure interactions • Structure-determinism	Critical concepts: • The duality of structure • Actors' practices • Social systems' structural properties	Elements for analysis: • Episodes of change and conjunctures of events. • Reflexive monitoring of actors' conduct and motivations.

Limits of existing EEG	**Upgraded EEG theoretical framework with imported concepts**	**Operationalisation for empirical analysis**
		• Systems' structural principles and properties (institutionalised features). • Regionalisation and time-space edges: systems and intersocietal systems. Methodological principle • The empirical analysis needs to identify key industrial actors and reveal their actions in transforming regional institutional features; in addition, it should capture how critical events motivate these actors to make different choices.

(Source: author's own compilation)

Chapter 4: Methodology

Adopting a case study method, this research aims to understand the evolutionary process within regional industries driven by smart city innovation in Taiwan's industrial development context. This approach captures the configurational context of emerging production activities for smart city innovation and evaluates the new EEG theoretical framework introduced in this study (Blatter, 2008). Based on Yin's (2017) definition of a case study, the research examines the emerging phenomenon of smart city industry in Taiwan, with data collection and analysis guided by EEG and incorporating multiple data sources and multiple methods.

This methodology chapter is composed of five sections. First, the research methods proposed by this study are outlined. This is followed by two sections describing the data collection and the quantitative and qualitative analysis conducted to answer the three research questions. The fourth section explores the collected data prepared for analysis. Finally, information is provided about the research ethics application and risk assessment approved by the Bartlett School of Planning and the UCL Research Ethics Committee.

4.1 Research Methods

This research examines the evolution of Taiwan's smart city industry from 2001 to 2020. As explained in Chapter 1, during this period, the industry developed under pressure to upgrade its ICT sector and align with global smart city trends. The case selection is inspired by Flyvbjerg's (2011) guideline for a paradigmatic case, which is based on intuitive decisions but remains accountable to the research field in which the study is situated. This type of case can reflect broader characteristics of the societies being studied, with its value determined by validity claims.

Accordingly, this research selects Taiwan as the focus of this research. This island is among the few countries that are capable of producing wide range of smart city technologies. While many countries engage in research and development in sectors related to smart city technologies, only a select few possess a strong foundation in ICT and related industries, enabling them to lead in the comprehensive production and implementation of these technologies. By looking at various quantitative measures such as US patents, those who have comprehensive background are, the US, Japan, South Korea, Taiwan, and China (Prato and Nepelski, 2014; 經濟部智慧財產局, 2021; OECD, 2025). Other countries with high rate of innovation ICT, which are Finland and Sweden, have areas each excel, but none of them have innovative and productive capacity in wide variety of ICT sectors like the five listed above (OECD, 2025). Among those five, Taiwan holds a unique position in more concerted efforts among private and public sector, and longer-term commitment to smart city concept compared to others, which resulted in growth of smart city industry as a distinct sector.

In the US, the smart city concept was pushed by global ICT firms such as Alphabet, Amazon, and Cisco among others. These companies, however, quickly dropped their smart city businesses. For example, the Sidewalk Toronto, Alphabet's waterfront smart city project was cancelled in 2020 (Cecco, 2020). Cisco, which has been claiming that it has built the world's first smart city in South Korea turned out to have done much less than they claimed (Huh *et al.*, 2024) ceased promoting the Cisco Kinetic for Cities, the company's smart city platform. Japan had had innovative ICT sector and is still unreplaceable in some of high-value added parts of ICT value chains (e.g. semi-conductor producing machines). However, it lacks visible success in production of ICT products in recent years and lag its East Asian neighbours in applying new technologies to cities (Khera and Xu, 2022; Ono, 2022). Unlike Japan, China used smart city concept extensively. However, in recent years, China targets international excellence in each of ICT sectors such as internet-connected vehicles, artificial intelligence, semiconductor among others with less emphasis on smart city as integrated use of ICT for cities (Yan, Liu and Tseng, 2020; Wang *et al.*, 2021; Marvin *et al.*, 2022). South Korea is probably the closest to Taiwan in continued emphasis on smart city also active in promoting smart city industry but the construction sector has strong influence on the direction of smart city policy (Sonn et al., forthcoming) unlike Taiwan where smart city policy is considered a government-wide initiative to upgrade ICT sector, which makes Taiwan a more suitable case for exploring the effects of smart city concept on ICT industries.

To address my three research questions on different aspects of industry evolution, I adopted a mixed-method research design that integrates quantitative and qualitative data collection and analysis (Tashakkori and Creswell, 2007). This approach allows for the exploration of complex evolutionary processes and outcomes using multiple methods, thereby reducing potential bias (Creswell, 1999). Following Creswell's (1999) framework, the two sets of data are presented sequentially: the qualitative analysis builds upon the findings of quantitative analysis. In this research, the quantitative data offers an exploratory overview of the evolutionary outcomes—specifically, whether the transformations are radical—which the qualitative data then expands upon to explain the processes of industry evolution, including how industrial actors transform the structure and how state industrial policies facilitate these transformations.

In the next section, data collection and quantitative analysis, specifically patent analysis, are used to address the research question regarding the radical break. Subsequently, the third section presents collection and analysis of qualitative data, drawing from in-depth interviews and policy reviews, to address the research questions related to the role of the state's industrial policies, industrial structure, and actors. Details of the research design are provided in the sections below.

4.2 Addressing Research Question 1: Data Collection and Quantitative Analysis

The first research question (RQ1) is: 1) Does smart city innovation represent a structural change within Taiwan's ICT sector? The corresponding hypothesis is that there were triple transformations, and thus it was radical break from the path of incremental progress in Taiwan's ICT sectors. Together, they focus on the significance of radical innovation in the evolution of regional industries. Based on the principles summarised from the theoretical framework, structural change can be analysed by examining the sectoral composition and identifying how regional technological systems have diverged from those of the original ICT sector. Accordingly, the quantitative analysis uses patent data to reveal the outcomes of triple transformations—across technology, organisation and location—on the sectoral composition (including hardware ICT, software ICT and non-ICT) of Taiwan's high-tech industries, to determine whether these outcomes constitute a radical break that generates new technological systems within the industrial structure (see Chapter 3 for a full review of the theoretical elements used in the analysis).

The data used for this analysis are the US patent records. Patents are considered a good proxy for knowledge, and their citations—as well as the institutional and geographical contexts—can have important implications for analytical models that both reveal technological changes and help explain the evolution of knowledge production activities (Jaffe and Trajtenberg, 1999; Kogler, Rigby and Tucker, 2013; Balland and Rigby, 2017; Kogler, Essletzbichler and Rigby, 2017; Rigby, 2017).

Existing literature lacks a systematic framework to define smart city technologies and their related sectors. As a result, it is difficult to identify which sectors within ICT industries can produce smart city technologies or whether their production extends beyond the ICT sector. Drawing on policy documents from governments and industries, this research proposes a preliminary definition of smart city technology: a set of technologies designed to collect, transmit, accumulate, and use city data across application domains of transportation, environment, energy, governance/surveillance, and city services. Based on this definition, this study develops a method to identify smart city technologies (patents) by collecting and sorting technical terms through interviews, and subsequently constructs a smart city patent dataset for quantitative analysis.

This section explains the process of collecting and sorting keywords, the database used, and the steps taken to select and analyse smart city patents.

4.2.1 Phase one interview: collecting and sorting keywords

The smart city industry is a relatively new sector that has developed alongside the emergence of the 'smart city' concept since 2008 (Willis and Aurigi, 2018). Understanding this industrial sector remains ambiguous in both academia and industry. To address this, I conducted phase one interviews with local industrial actors to identify the specific technologies developed in Taiwan for smart cities. The information collected from these interviews forms the basis for deducing which industries are producing these technologies.

Accordingly, I interviewed eleven engineers and entrepreneurs to identify key technical terms commonly used in the industry. All these interviewees (see Table 6) are involved in developing smart city technologies, with expertise spanning the five smart city application domains: 1) transportation, 2) energy, 3) environment, 4) governance/surveillance, and 5) city services, as well as data-related techniques (see Chapter 2). Their roles in the companies are at the management level, involving participation in product development and making them familiar with the technical terms used to describe smart city patents. Their companies either have experience participating in projects funded by the ‘Smart City Taiwan’ policies or collaborating with those funded companies. The interview voice recordings were transcribed and analysed to create word clouds. Frequently occurring technical terms—specifically, those repeated four times or more—and key terms highlighted by interviewees were selected as keywords for the patent selection phase to identify smart city technologies.

Apart from the interview information, I also took Future Cities Catapult’s (2018) smart city report as a reference for technical keywords. The report summarises one hundred fifty UK and international smart city demonstration projects. The measure of selecting keywords from the report is the same as that I used when dealing with transcriptions, i.e., using the word cloud generator to determine technical terms that are repeated four times or above in the report. Based on the interview and supplemented with the information from the Future Cities Catapult (2018), I have selected 158 keywords.

Table 6 Phase one interviewees

The core business of the interviewee’s company	**Interviewee’s position**	**Most relevant domain**
Infrastructure construction, planning, and design	Innovation Manager	Governance
Telecommunications	Senior Manager	Governance/surveillance; city service
Self-driving bus	CEO	City service; Transportation
Transportation data analysis	CTO	Transportation
Transportation data analysis	COO	Transportation
EV ridesharing	CEO	Transportation; environment

The core business of the interviewee's company	Interviewee's position	Most relevant domain
Energy management system	Product Development Director	Energy
Air monitor	Product Manager	Environment
IoT hardware device	CEO	Data
Electrical engineering (University)	Associate Professor	Data

(Source: author's own compilation)

Finally, I worked with three smart city field professionals: 1) an R&D engineer at a semiconductor manufacturer, 2) an innovation manager participating in public projects and 3) a patent engineer to develop a structure for keyword and technology categorisation. The keywords are initially divided into two groups: 1) domain-based and 2) data-related. Under these two groups, we further sorted those keywords into sub-categories based on their attributes. The technical keywords and their categorisation will be presented in the fourth section of this chapter.

4.2.2 Database

This research used data from the United States Patent and Trademark Office (USPTO). Compared to other primary international patent databases that are owned by the European Patent Office (EPO) and Japan Patent Office (JPO), the USPTO has more Taiwanese patents and is more accessible in terms of its database for bulk download. According to the latest statistical report published by the USPTO (2015), the sum total of patents originating in Taiwan in the US database between 2001 and 2015 was ranked fourth among all foreign countries. Accordingly, this database can provide sufficient data for this research to reveal if there has been radical innovation in Taiwanese high-tech industries.

In addition, the USPTO database contains complete information on patent citations[4], assignees and inventors' located cities that are essential for this research to analyse how and where technology emerges. Despite some reservations about the noise in patent citations caused by actions of being added by examiners, patent citation analysis is an agreeable measure to observe the knowledge flows (Jaffe et al., 2000; Sonn and Storper, 2008; Rigby, 2012). While that means patent citation data is beyond inventors' original claims, this approach can still represent the related sets of technology instead of tracing the exact flows of knowledge (Rigby, 2012).

Patents included in my database were selected based on the criterion that at least one inventor is located in Taiwan. The analysis timeframe covers patents issued between 2001 and 2020, with the year of a patent in the USPTO database referring to its issuance date.

4.2.3 Patent selection

Existing patent classification systems do not yet include a specific category for 'smart city' technologies. Therefore, I used the technical terms identified in phase one interviews as keywords to search patent abstracts in the USPTO database for patents relevant to smart city technology. Before searches, I set four rules (see Table 7) to organise keywords meaningfully. The first two rules are mainly for domain-based keywords. The first rule is to select a patent when its abstract contains one word under the domain-based group's 'Integrated technology' sub-category. Rule Two is: selecting a patent with an abstract involving one word from the 'Individual technology' sub-category plus one word from the 'Issue' sub-category. Then, the other two rules are based on keywords from the data-related group. Rule Three is for the sub-categories of 'Communication' and 'Application' in this keyword group. In this rule, a patent can be selected when its abstract includes any keywords from these two sub-categories and meanwhile has one word from the 'Issue' sub-category of the domain-based group. The last rule is to select a patent if a technique keyword from the 'Processing' sub-category of the data-related group and a domain-based keyword of the 'Issue' sub-

[4] Aware of the database's limitations, I analyse patent citations to explore how smart city technologies relate to previous technological innovations, rather than focusing on direct knowledge flows between inventors.

category is included in its abstract. This research counts a patent that meets one of the four rules above as a smart city patent.

Table 7 Rules for keyword organisation used to select smart city patents

	Number of keywords required for inclusion	**Category of keywords**
Rule One	1	'Integrated technology' (domain-based group)
Rule Two	2	'Individual technology' (domain-based group) and 'Issue' (domain-based group)
Rule Three	2	'Communication' or 'Application' (data-related group) and 'Issue' (domain-based group)
Rule Four	2	'Processing' (data-related group) and 'Issue' (domain-based group)

(Source: author's own compilation)

The patents singled out by the four rules above are listed as the 'core technology' in this research's smart city patent dataset. As a result, 121 smart city patents are identified. Then, I analysed the first listed classifications[5] of all 'core technology' patents. Frequently repeated classifications can be selected to be another basis for further patent selection. By referencing the classifications of US-invented smart city patents, I determined seventeen highly relevant 'Main Groups' of international patent classification (IPC) (see Table 8) to be smart city technology. We can clearly understand which subject field a patent belongs to from the 'Main Group' title of its IPC (WIPO, 2022). After that, the patents under the identified 'Main Groups' of IPC are considered the 'supporting technology' and downloaded to build the dataset for analysis. A 'Main Group', which has been refined to reduce heterogeneity, combines patents with similar technological characteristics (Park and Yoon, 2017)

[5] The patent classification that this research use is the international patent classification (IPC) because patents registered in the Taiwan Intellectual Property Office follow this classification system.

while containing a sufficient number of patents for analysis. Finally, 9,693 patents have been identified as smart city technology.

Based on the identified smart city patents, I used the program—DB Browser for SQLite—to fetch three sets of patent data, including 1) classifications of smart city patents, their cited patents, and their cited patents' classifications, 2) assignees of smart city patents and 3) inventors' located cities of smart city patents from the USPTO database.

Table 8 Smart city patent classifications and numbers

Classification	Classification title	Patent Number
G01C 21	Navigation; Navigational instruments not provided for in groups G01C 1/00-G01C 19/00	225
G01C 22	Measuring distance traversed on the ground by vehicles, persons, animals or other moving solid bodies, e.g. using odometers or using pedometers	21
G01S 13	Systems using the reflection or reradiation of radio waves, e.g. radar systems; Analogous systems using reflection or reradiation of waves whose nature or wavelength is irrelevant or unspecified	119
H04B 7	Radio transmission systems, i.e. using radiation field	578
H04L 12	Data switching networks	939
H04L 29	Arrangements, apparatus, circuits or systems, not covered by a single one of groups H04L 1/00-H04L 27/00	520
H04Q 7	Selecting arrangements to which subscribers are connected via radio links or inductive links	149
H04W 4	Services specially adapted for wireless communication networks; Facilities therefor	522
H04W 52	Power management	144

Classification	Classification title	Patent Number
B60Q 1	Arrangement of optical signalling or lighting devices, the mounting or supporting thereof or circuits therefor	408
F21V 29	Protecting lighting devices from thermal damage; Cooling or heating arrangements specially adapted for lighting devices or systems	542
G05D 1	Control of position, course, altitude, or attitude of land, water, air, or space vehicles, e.g. automatic pilot	111
G06F 15	Digital computers in general; Data processing equipment in general	938
G06F 19	Digital computing or data processing equipment or methods, specially adapted for specific applications	585
G06F 9	Arrangements for program control, e.g. control units	855
G06K 9	Methods or arrangements for reading or recognising printed or written characters or for recognising patterns, e.g. fingerprints	2447
H04N 9	Details of colour television systems	590
Sum		9,693

(Source: author's own compilation)

4.2.4 Patent analysis

Patents, considered the 'minimal quantum of invention' (Griliches, 1998), and their associated production activities are analysed to trace knowledge flows and understand technological changes (Jaffe and Trajtenberg, 1999). For the data analysis in this study, in addition to the smart city patents identified in this research, the ICT patent classifications defined in an OECD report[6] (Inaba and Squicciarini, 2017) were employed as a reference to compare their development trajectories. This approach was used to analyse whether triple transformations occurred in industries that triggered a radical break from the established trajectory of traditional ICT sectors—which have historically followed an incremental path and have been prominent in Taiwan for six decades, particularly in hardware manufacturing.

Empirical studies have largely analysed the evolution of technology using patent data by examining knowledge complexity (Balland and Rigby, 2017), technological relatedness (Rigby, 2012, 2015; Kogler, Rigby and Tucker, 2013; Kogler, Essletzbichler and Rigby, 2017) and the concept of co-occurrence (Kogler, Rigby and Tucker, 2013; Kogler, Essletzbichler and Rigby, 2017; Lee, Kogler and Lee, 2019). Balland and Rigby (2017) use data on patent classes (classifications) and the locations of inventors to analyse the knowledge complexity index of US cities, thereby shedding light on these cities' development trajectories in relation to their technological compositions. Rigby (2012, 2015) develop a model that uses patent citation data to analyse the relatedness of the six primary (aggregate) technology classes in US cities. The model focuses on how knowledge specialisation has evolved over time, demonstrating the relevance between patent classifications as a means of understanding the technological compositions of regions. Building on this model, Kogler, Essletzbichler and Rigby (2017) analyse the relatedness of European cities. Their study clarifies the concept of technology class co-occurrence, highlighting the notion of paired classifications. Lee, Kogler and Lee (2019) further integrated citation data into the co-occurrence matrix to define the directions of knowledge flows between technologies, using network analysis to reveal which specific patent classifications have been significant for subsequent technological innovation.

Among the methods described above, with regard to technological transformation, this research is built upon Lee, Kogler and Lee (2019). It develops an analytical method that focuses on the technology set of smart city patents to reveal the effects of ICT patents on smart city innovation, rather than comprehensively

[6] Compared to Corrocher, Malerba and Montobbio's (2007) improvement of ICT patent classifications identified by the OECD (2002) and Strack (2003) based on the frequently used technological applications, this latest OECD report (Inaba and Squicciarini, 2017)has involved opinions of global experts participating in the OECD-led Intellectual Property (IP) Task Force to specify the ICT patent classifications based on IPC classes.

analysing all classes in the patent database as done in previous studies by Balland and Rigby (2017), Rigby (2012, 2015), Kogler, Rigby, and Tucker (2013), and Kogler, Essletzbichler, and Rigby (2017). In addition, the analysis of organisational and territorial transformations is guided by the principle of identifying the significant industrial actors and production locations for both patent sets. Accordingly, I first analysed the technological transformation pathway via smart city patent citation data to uncover how this technology set evolved from previous technologies. Citation analysis combines three key elements of industrial evolution, technology, time and geography, to track knowledge diffusion (Jaffe and de Rassenfosse, 2019). With the first two elements, this research can provide an integrated explanation of the technological transformation. Accordingly, I analysed changes in patent classifications and cited patents' classifications between two time periods: 2001-10 and 2011-20. Practically, I used Gephi for this analysis, demonstrating patent citation networks during different periods. The citation counts (i.e. in-degrees) in the analysis can trace the frequently backward cited classifications, revealing what can be the origins of existing smart city technologies. Besides, comparing the differences in citation networks between the two decades can clarify changes in technology development paths. The software—Microsoft Power BI—is used to visualise the technological and locational data analysis results.

Secondly, I analysed organisational transformation with patent assignee data. Patent assignees are entities that own patents. In other words, they have property rights to patents. The analysis of patent assignees can reveal the changes in the dominant actors producing smart city technology between two decades in Taiwanese industries. With a view to understanding the composition of industrial actors, in this research, assignees are sorted into three groups: 'biggest company'[7], 'research institute'[8] and 'smaller company'[9]. Every year, CRIF China Credit Information Service, Ltd. (中華徵信所企業股份有限公司), a market research company, publishes a statistical report of the top 500 Taiwanese firms in terms of their net operating revenues.

[7] The 'biggest company' group is shown as 'Top 100' and 'G500' in empirical chapters. 'Top 100' means Taiwanese firms with top one hundred high revenue. 'G500' means global corporations ranked top five hundred in terms of revenue. Subsidiaries of these 'Top 100' and 'G500' companies are also counted under the 'biggest company' group.

[8] The 'research institute' group includes both public sector (or government funded) research establishments and universities.

[9] The 'smaller company' group is shown as others in empirical chapters.

Based on survey, the top 100 Taiwanese firms are used as the benchmark of the 'biggest company' in this research. Moreover, the companies listed as the top 500 global companies by the *Fortune* are also counted as 'biggest company'. Enterprises other than the 'biggest company' are grouped into the 'smaller company'. As for 'research institute', an assignee is sorted into this group when its name includes the word: university or research. OpenRefine software cleaned the data to correct inconsistent spellings and formats.

Lastly, the addresses of inventors are used to identify the location of innovations, which are used to generate maps of the two periods, showing the temporal changes in the location of knowledge production. Inventors' address can represent specific places generating new knowledge better than assignee addresses[10]. Accordingly, analysing changes in cities where inventors locate can show the actual locational transformation of knowledge generation.

I used municipality level address rather than the full address of inventors' addresses because cities in Taiwan are small enough to be considered a spatial unit of daily economic and innovative activities. This analysis can further uncover the influences of specific places on technology innovation. Before putting locational data into Microsoft Power BI for visualisation, I used OpenRefine[11] to refine this dataset, making them shown at the same municipal level and excluding invalid values, such as unrecognisable city names.

4.3 Addressing Research Questions 2 and 3: Data Collection and Qualitative Analysis

The second and third research questions (RQ2 and RQ3) are: 2) Did the state play an important role in such structural change? and 3) Did individual actors' choices and actions lead to structural changes in Taiwan's ICT sectors? This research addresses RQ2 by analysing in-depth interview data and policy documents to illustrate the significance of state industrial policies as a determinant of industry evolution. RQ3 is answered by analysing in-depth interview data to explain the structural changes driven

[10] Patent inventors might be employees working in the companies' R&D laboratories that are geographically separated from their headquarters. Inventors' addresses are the locations of those laboratories. However, the assignees' addresses are usually the company headquarters.

[11] OpenRefine is a tool to clean and transform messy data that is displayed in inconsistent spellings and formats.

by industrial actors, viewed as part of the evolution process. The aim of addressing these research questions is to test two hypotheses: 1) policy mechanisms and government-business relations within a developmental state have fostered innovation and contributed to improvements in the ICT industry, and 2) the triple transformations driven by industrial actors have reshaped part of the original structure of Taiwan's ICT sector.

The theoretical framework indicates that the state's role in a developmental state can be empirically analysed by examining three institutional aspects: government–business relations, development consensus formation, and market intervention. These aspects form the foundation for developing interview questions and for examining the rationales behind policymaking and implementation. Regarding the analysis of actor-caused structural changes, the focus is on industrial actors and their actions. In addition, institutional features and critical events—which reflect changes in the industrial structure in response to actions taken by industrial actors—provide essential information. In practice, interview questions and themes guiding data analysis are formulated around these approaches.

The data were collected through in-depth interviews and policy reviews. This section provides an overview of the interview subjects and the policies reviewed in this research.

4.3.1 In-depth interview: clarifying the evolution processes

Aiming to build a new EEG approach that can reflect structural changes in the industrial landscape, I interviewed people from firms and government agencies doing smart city projects to understand how the evolutionary process proceeded. I tried to clarify the technological, organisational and territorial transformations made by various key actors in smart city-related industries. The interview data is also used to explain the state industrial policies' significance for the smart city industry. Accordingly, I conducted semi-structured interviews with a framework setting out questions within overarching while allowing interviewees to describe their involvement in industrial development. Questions for firms were set out based on these four topics: 1) experience in technology development and collaboration, 2) dominant industrial actors, 3) experience of participation in public projects, and 4) policies most relevant to their business (see Table 9). Then, the questions for government agencies focus on policy-relevant topics, which are 1) dominant industrial actors, 2) policy strategy, 3) institutional changes, and 4) differences between the smart city industry and ICT or IoT industries (see Table 10).

Table 9 Interview questions for firms

Topics	Question
1) experience in technology development and collaboration	• When did you start to develop smart city technologies? • What incentivised you to develop new products? • What were the noticeable changes in your collaboration network?
2) dominant industrial actors	• Are any firms or institutions more influential in industry policy-making? If so, why?
3) experience of participation in public projects	• Have your firms tried to be involved in policy-making? • What have you suggested, and have the government adopted suggestions?
4) policies most relevant to their business	• Which policy was the most helpful in facilitating smart city industry development? • What were institutional changes (industrial rules, standards or cultures) caused by policies?

(Source: author's own compilation)

Table 10 Interview questions for government agencies

Topics	Question
1) dominant industrial actors	• Has the government collaborated with specific industrial actors for policy implementation?
2) policy strategy	• What are the government's strategies to support smart city industry development?
3) institutional changes	• What were institutional changes (industrial rules, standards or cultures) caused by policies?

Topics	Question
4) differences between the smart city industry and ICT or IoT industries	• What are the differences between the smart city industry and ICT or IoT industries?

(Source: author's own compilation)

The patent analysis result was one of the references to identify essential actors in the Taiwanese smart city industry. Those patent owners can be broadly sorted into three groups: big tech firms, telecoms and outstanding startups, though their proportions are very different. However, the smart city industry is relatively new and is comprised of high-tech and non-tech firms. Therefore, apart from firms that own patents, consultancies being involved in government-led smart city projects are also critical industrial actors due to their role in shaping industry development. Accordingly, I selected interviewees from consultancies and the three groups above, either owning patents or participating in major smart city projects that are granted by the 'Smart City Taiwan' policy or by MOEA-led national schemes. I interviewed eighteen firms in total for this research (see Table 11).

Besides industrial actors, I interviewed seven individuals from or affiliated with central and local government agencies that proposed or implemented smart city industry policies and initiatives (see Table 12). Specifically, these agencies include the Industrial Development Bureau (IDB), the Board of Science and Technology (BOST), and the National Development Council. The following policy review section explains their roles in facilitating the development of this new industry

The analysis of the interview data adopted a thematic analysis approach, following these steps: familiarising myself with the transcribed data, generating codes deductively, and forming themes—including searching, reviewing, and defining—using theoretical elements (Kiger and Varpio, 2020). Initially, the generated codes were sorted by the topics of the interview questions (four topics for firms and four for government agencies). During theme formation, the following theoretical elements were taken into account: 1) local conditions, 2) firm variety, 3) market competition, 4) social relations, 5) institutional and relational embeddedness, 6) recursive interactions, 7) power, 8) reproduction of institutions, and 9) a guiding role. The first two elements are key factors identified in the innovation aspect of EEG literature (see Section

2.3.2.1), used to examine which local capabilities can support innovation activities and what types of innovation activities have been formed. Elements three to six are emphasised in the actor-structure aspect of EEG literature (see Section 2.3.2.3) to understand the industrial structure that firms draw upon and, in turn, shape. Finally, the last three elements are crucial in the institutional aspect of EEG literature, helping to explore the role of institutions in interacting with firms' activities during regional evolution.

Table 11 Interviewees working in the smart city industry

The core business of the interviewee's company	**Interviewee's position**	**Smart city solution provided by the interviewee's company**
ICT hardware	Sales Agent	Smart parking system
ICT hardware	Senior Manager; Senior Engineer	Kiosks for a bike sharing system; system integration platform
ICT hardware	President	ICT hardware component
Semiconductor manufacturing	Engineer	ICT hardware component
EV	CEO	Smart and electric scooter
EV distributor	President	Smart and electric scooter; EV battery charging system
System integration; data analysis	COO	Transportation data analysis
System integration; data analysis	CEO	Smart grid; smart flooding management system; smart lamppost
System integration	Director	Smart lamppost
System integration	Senior Manager	Smart lamppost
System integration	CEO	Connected infrastructure
Telecommunications	Senior Manager	Connected infrastructure
VR interface software	CEO	Digital governance system interface
Digital consultancy	Partner	Digital governance plan

The core business of the interviewee's company	Interviewee's position	Smart city solution provided by the interviewee's company
Digital consultancy	Founder	City data integration platform
ICT consultancy	CEO	Digital governance plan
Infrastructure construction, planning, and design	Innovation Manager	Digital twin
Public construction and ICT consultancy	Manager	Smart transportation plan

(Source: author's own compilation)

Table 12 Interviewees working in government agencies/research institutes

Organisation	Interviewee's position	Responsibility of the interviewee's organisation
Central government	Director	Proposing policies to improve digitalisation level of the nation
Central government/think tank	Analyst	Implementing industrial policies to upgrade ICT sectors
Central government/think tank	Associate Director	Implementing industrial policies to develop smart city industry
Local government	Director	Implementing smart city development policy
Think tank	Associate Director	Proposing industrial policies to upgrade ICT sectors
Think tank	Director	Proposing industrial policies to upgrade ICT sectors
University	Associate Professor	Studying regional development in Taiwan

(Source: author's own compilation)

4.3.2 Policy review

To reveal the state industrial policies' role in developing this new industry, I analysed government policies concerning the smart city industry implemented by the central government agencies between 2016 and 2020. Since 2016, the Taiwanese central government has implemented multiple industrial policies to facilitate high-tech sectors to transform into a new phase. Most of these smart city-related policies included local (city) governments as critical pillars of implementation.

The data for analysis of polices are official documents published by the government. Note that these documents are used as data to be analysed, rather than literature to be reviewed. Some simple facts and statistics in those documents can be taken at their face value, but the general direction, intended outcome, and underlying logic of policies are to be found rather than learned directly from the policy documents. That is because policies and their documentations are not collation of facts, but a vector sum of various forces that work through the government and its policies. Such forces include politician's desire to be elected again, civil servants' interest in increasing their roles within and outside the government, and private businesses' interests among others. The real motivations and intended outcomes cannot be directly learned by accepting the words and sentences at their face values, but can only be estimated through careful removal of rhetorics, understanding of contexts, and crosschecking against other documents and against other data sources. Such process is closer to discourse analysis than to literature review.

To be specific, this research analyses documents related to five critical policies. The selection was based on their relevance to the fundamental smart city industry policy—'Smart City Taiwan'. Its policy document lists the national Programs that guide the policy-making of the 'Smart City Taiwan'. Then, I clarified with the interviewees, working in government on policy-making processes, if those Programs and policies were significant for the smart city industry and if any critical policy was missed.

The first three Programs in my analysis serve as guides for further policy-making. Then, the last two policies I analysed were set for implementation. Firstly, the DIGI+ Program, an overarching scheme to enhance the digital capabilities of various aspects involving the economy, industry, governance, and society (BOST, Executive Yuan, 2017). DIGI+ Program, constituting the highest-level industry policy, has been delivered by the BOST under the Executive Yuan[12] since 2017 and will continue until 2025. The second and third national smart city industry-related policies I analysed are the ‘Forward-looking Infrastructure Development Program’ (‘前瞻基礎建設計’) and the ‘Program for Promoting Six Core Strategic Industries’ (‘「五加二產業創新計畫」六大核心戰略產業’), proposed by the Executive Yuan in 2017. Both Programs have been implemented by different ministries while being supervised by the National Development Council until 2025. The former Program was proposed to improve the infrastructure while leveraging domestic demand to facilitate industry transformation. However, the object of the latter Program is directly related to industry development. The ‘Program for Promoting Six Core Strategic Industries’ aims to upgrade various industries, one of which is the Internet of Things (IoT) industry—the most fundamental to the smart city industry. Under its guidelines, the National Development Council further proposed the Asia Silicon Valley Development Plan detailing the implementation strategies.

Fourthly, I scrutinised the ‘Smart City Taiwan’ policy through which the government collaborated with industry closely to develop cutting-edge or locally needed technologies for smart cities. The IDB, Ministry of Economic Affairs, implemented this policy between 2015 and 2022, since this agency is primarily responsible for national industry development affairs. Accordingly, the IDB established a project office operated by specialists from a government-owned think tank, the Institute for Information Industry (III), to deliver this policy exclusively. Lastly, I analysed local plans implemented by the Taipei city government from 2014[13] onward. This local government is the most active city in promoting the smart city in Taiwan. The former Taipei Mayor, Mr Wen-Je Ko, created an independent authority—the Taipei Smart City Project Management Office—which advocated for industry involvement in building smart cities. Accordingly, the Taipei Smart City Project Management Office has endeavoured to connect firms capable of providing smart city solutions with the local authorities to carry out pioneering smart city projects. Apart from industry policies, the wider context of the high-tech industry development in Taiwan is also analysed. The

[12] Executive Yuan is the highest executive branch in Taiwan.

[13] The former Taipei Mayor, Mr Wen-Je Ko, set smart city development at the forefront of his policy agenda (Chang, Jou and Chung, 2021). His mayoralty was between 2014 and 2022.

annual industry analysis reports on IT developments, including hardware and software and ICT industries, are used as references.

The policy analysis in this research is influenced by the principles of multiple streams theory, as outlined by Browne *et al.*, (2019), under the mainstream approach[14]. Accordingly, the analysis focuses on problems, policies, politics, and key events—with the key events connecting the first three through the actions of policy entrepreneurs (enablers). These elements were used as a guide to develop themes for coding the interview data for analysis.

Table 13 Policies analysed in this research

Policy names	**Problems to be solved**	**Authorities to propose policies**
'Smart City Taiwan'	Industry and infrastructure upgrade	Board of Science and Technology
DIGI+ Program	Industry and infrastructure upgrade	Board of Science and Technology
'Forward-looking Infrastructure Development Program'	Infrastructure upgrade	Executive Yuan
'Program for Promoting Six Core Strategic Industries'	Industry upgrade	Board of Science and Technology
'Asia Silicon Valley Development Plan'	Local and global connection	National Development Council
Taipei Smart City Project Management Office's plans	Infrastructure upgrade	Taipei city government

(Source: author's own compilation)

[14] The policy review methods summarised by Browne *et al.*, (2019) follow Bacchi's (1999) framework, which includes three categorisations: traditional, mainstream, and interpretive orientations.

4.4 Data Exploration

Before unfolding the data analysis in the next three empirical chapters, this section presents the quantitative and qualitative data that this research obtained via the methodology explained in this chapter. As mentioned in Chapter 1, the quantitative data is used to answer the first research question about radical innovation. The quantitative dataset I built is shown in the first subsection below. Then, the second subsection explains what qualitative data is used in this research to answer the research questions about the state industrial policies and the actor-caused structural changes (see Chapter 1).

4.4.1 The structure of smart city technology categorisation

Building on the definition of smart city technologies derived from existing literature and empirical documents, I collaborated with an engineer specialising in hardware component design and a digital consultant focused on proposing smart city solutions. Together, we developed a framework that defines the relationship between application domains and technical sectors, while also clarifying the meaning of each element within the structure. This structure offers a framework of reference for understanding the functions of most smart city technologies within a smart city system.

The five domains I identified prepare the basics of the smart city technology categorisation structure. First, the transportation domain includes technologies used to improve transportation efficiency or solve traffic problems in cities. A considerable amount of smart city technologies developed in Taiwan are devoted to this domain because transportation is relatively close to everyday city activities. Second, technologies to enhance urban energy use efficiency, like smart meters, are sorted in the energy domain. Third, the environment domain encompasses technology sets that can help achieve environmental sustainability goals or prevent the damages caused by natural disasters. Fourth, technologies used by city governments to collect data on human activities and then monitor or manage urban infrastructure are included in the domain of governance/surveillance. The purpose of their uses is to ensure safety in cities. The last domain, city service, is minor yet innovative. Technologies in this domain are developed for specific service applications, such as food delivery or way-finding apps or parcel delivery drones. Despite the differentiation of these domains, some technologies are, in fact, used as cross-domain applications. Some smart city technologies are generally applicable to any domain.

Besides the application domains, the technologies themselves are categorised into four technical sections: 1) ‘data collection’, 2) ‘data transmission’, 3) ‘data accumulation’, and 4) ‘data use and application’. These sections classify data-related techniques because IBM’s smart city concept primarily centres around data. The first two sections encompass the instrumentation and interconnection elements of smart cities, while the latter two pertain to intelligence functions (Dirks and Keeling, 2009). Specifically, the ‘data collection’ section includes devices or sensors used to acquire various kinds of data in cities. The collected data is then transmitted through networks, which is the focus of the ‘data transmission’ section. After transmission, the data is gathered on a platform for ‘data accumulation’. Finally, the accumulated data is utilised by technological tools, enabling various ‘data uses and applications’ to address urban problems or improve urban efficiency.

The five application domains and four technical sections together form the framework for understanding smart city technologies (see Figure 5). However, some technologies are generally applicable to any domain rather than a specific one, and thus, in this structure for categorisation, above the five identified domains, I highlight some technologies may not belong to one certain domain. In terms of technical sections, the significance of the technology that crosses different technical sections is beyond the benefit of additional uses or applications. Without the system integration technique that connects different technical sections, it would be impossible to realise the vision of a smart city taking advantage of the value of city data. Besides, the technical sections of the ‘data collection’ and ‘data transmission’ mainly include technologies enabled to function by hardware techniques, such as sensors, LoRa, NB-IoT, etc. They are used in equipment installed in cities as part of the infrastructure. The other two technical sections, ‘data accumulation’ and ‘data use/application,’ are used to categorise technologies that are driven by software tools and techniques, such as common data platforms, digital twins, AI prediction, etc.

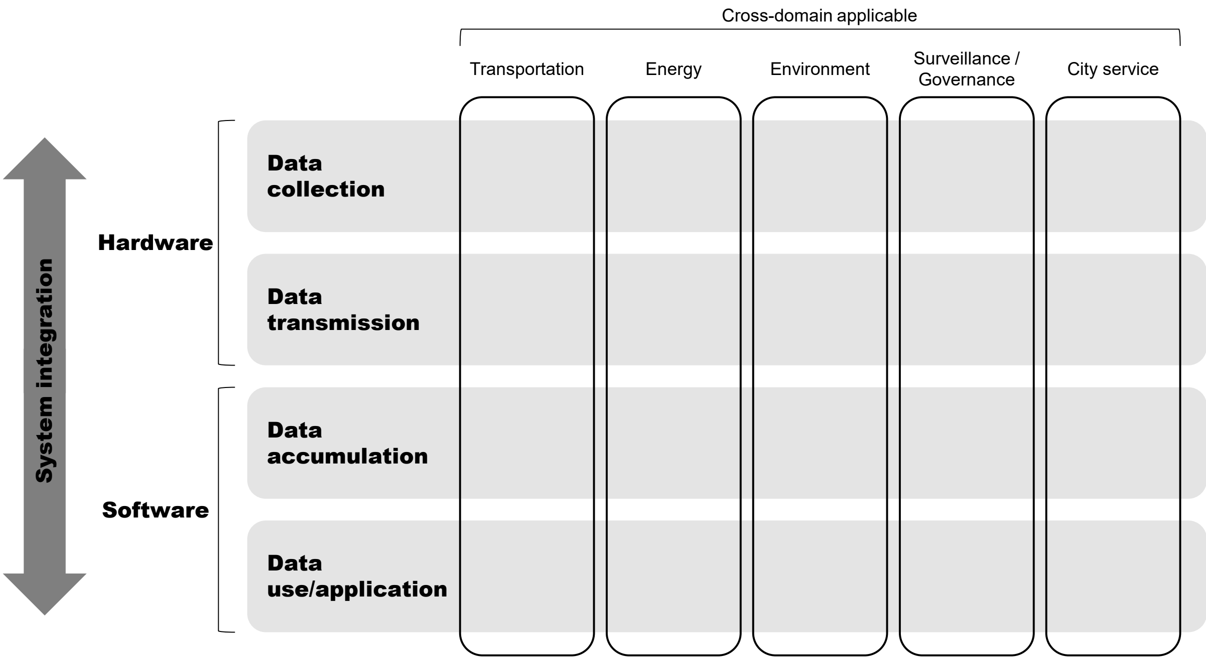


Figure 5 The structure for smart city technology categorisation
(Source: author's own compilation)

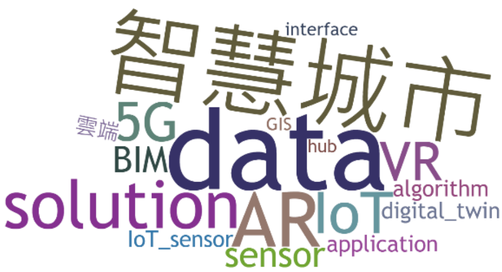
4.4.2 Quantitative data

The quantitative analysis in Chapter 5 is built upon patent data, where I explain the industrial evolution following the demand for technological innovation for smart city development in Taiwan by analysing patent data because a patent is regarded as a 'minimal quantum of invention' (Griliches, 1998). However, as explained, there is no clear definition of smart city technology in the existing literature on which this research can be based to delineate the scope of this technology set and further identify what patents can be counted as smart city technology. Thus, two steps of the methodology are conducted, i.e. keyword and patent identifications, which follow the structure defined in the last section to explore the data I use. The structure can help people have an overview of smart city technology and help this research set out a measure to collect and analyse data. First, the interviewees' professional backgrounds cover the five application domains to ensure the study can collect keywords of technologies in each domain. Besides, the four technical sections are used as basics to understand the keywords I collected from interviews and to sort the patents I identified through the selection process.

In this subsection, the next part prepares the database of technical keywords that are used to describe smart city technology and thus can be referred to when searching smart city patents in the USPTO database. Then, the second part of this section presents the selected patents of the ‘core technology’ group and the selected patent classifications that contain patents of the ‘supporting technology’ group. Furthermore, I use a few specific fields of patent data for analysis, which are also presented in this part.

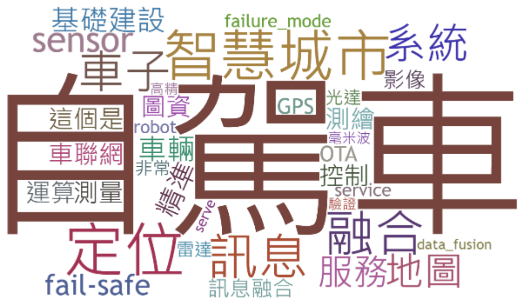
4.4.2.1 Selected technical keywords

I used the transcriptions collected from the phase one interviews and the report published by the Future Cities Catapult (2018) to generate ten word clouds (see Figure 6), and besides, one interviewee directly provided me with twenty-two technical terms. Among all word clouds, four word clouds mainly contain keywords relevant to transportation domains. For the domains of energy, environment and governance/surveillance, each of them is reflected in at least two word clouds. Lastly, there is one word cloud that includes technical keywords only used to describe techniques that can generally process data for any domain, but almost every word cloud has a few keywords relevant to data collection, transmission, and processing.

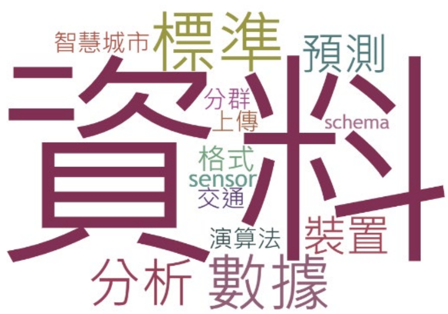


a) Governance/surveillance

b) Governance/surveillance; city service

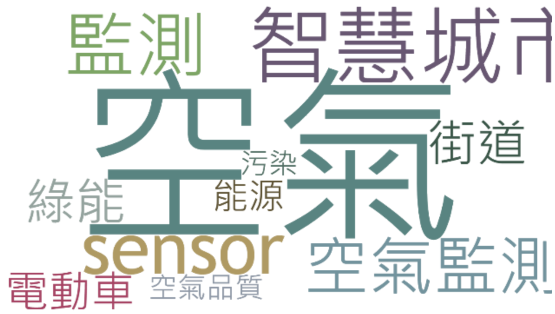


c) City service; transportation

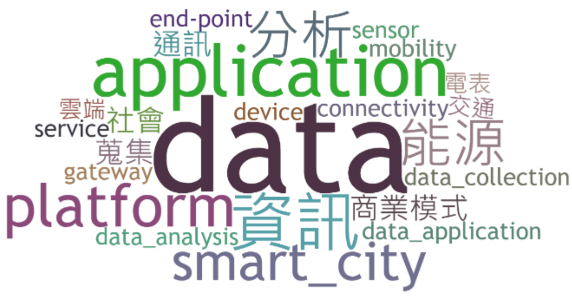


d) Transportation

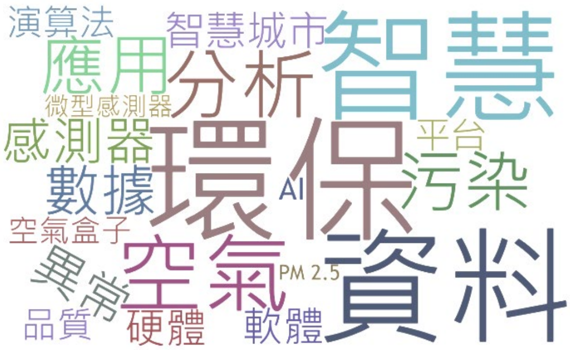
e) Transportation



f) Transportation; environment



g) Energy



h) Environment

i) Data

j) Reference of Future Cities Catapult

Figure 6 Word clouds of collected and referred keywords

(Source: author's own compilation)

Then, there are a total of one hundred and fifty-eight technical terms in the word clouds and in the list provided by an interviewee. After deleting the duplicates, one hundred and twenty keywords[15] are selected and entered into the technical keywords

[15] Two duplicate keywords, 'monitor' and 'flood,' remain and are counted twice as they can be used in both environmental and governance/surveillance domains.

database, within which there are two keyword groups: 1) domain-based and 2) data-related, sorted in accordance with smart technology sorting structure.

Fifty-three keywords representing uses for specific domains are included in the domain-based group. Sixty-seven non-domain-specific technical keywords are sorted in the data-related group. In addition, four subcategories are listed under the domain-based group (see Table 14). These subcategories are ‘integrated technology’, ‘individual technology’, ‘action’ and ‘issue’. Meanwhile, there are six subcategories within the data-related group (see Table 15) for further keyword sorting. Its subcategories of ‘communication technique’ and ‘protocol’ are used to include keywords relevant to data transmission. ‘Technique’, ‘action, and ‘feature’ are three subcategories created for keywords describing data processing technology. Specifically, keywords of these three subcategories can be used to characterise technologies to collect, accumulate and analyse data. The last subcategory in this group is ‘application’, which is set for the keywords of data use technology.

4.4.2.2 Selected patents

With the above keywords and four keyword organisation rules, I selected 125 Taiwanese-invented ‘core technology’ patents. Four repeated patents appearing in more than one search rule were removed among them. Thus, 121 patents remain in the final ‘core technology’ database (see Table 16). Among patents of the ‘core technology’, thirty-five are selected by searching with domain-based keywords. In addition, I identified eighty-six patents by using the data-related keywords supplemented by keywords in the ‘issue’ subcategory of the domain-based group to narrow the search scope on technologies used for cities. The number of data-related patents is higher than that of domain-based patents.

Table 14 Domain-based group keywords

Domain	Integrated technology	Individual technology	Action	Issue
Transportation	V2X, ITM, autonomous driving, autonomous vehicle	GPS, IMU, HD 3D map, RSU (road site unit), control by wire	survey, control, locate, position, verify, global and local path planning; reliability, precise	traffic, transportation
Energy	IoE	smart grid, electricity meter, NILM	monitor	green energy, energy
Environment	airbox	N/A	monitor, trace	air pollution, air quality, PM 2.5, environment friendly, flood
Governance/surveillance	digital twin, smart lighting	BIM, AR, VR, camera, IP Camera, lens, sensor	recognise, dispatch, schedule, manage	crime, flood
City services	Drone, robot	N/A	N/A	city, cities

(Source: author's own compilation)

Table 15 Data-related group keywords

Transmission		**Processing: collection, accumulation, and analysis**				**Application**
Communication technique	**Protocol**		**Technique**	**Action**	**Feature**	
LTE, 5G, LoRa, Sub GHz, small cell, millimeter wave, radar, lidar, ultrasonic,	MQTT, HTTP, FTP, Modbus	**Collection**	crowdsourcing, sensor network	collect, connect	N/A	GIS, OTA, PaaS, SaaS, MaaS, RaaS
		Accumulation	cloud, schema, GTFS, data science	upload, standard, format	N/A	

Transmission		Processing: collection, accumulation, and analysis				Application
Communication technique	**Protocol**		**Technique**	**Action**	**Feature**	
IoT gateway, gateway, portal, endpoint, hub		**Analysis**	big data, motion planning, failure mode, motion planning and control, LSTM, CNN, RNN, BNN, re-enforce learning, deep learning, machine learning, edge computing, AI, AIoT, computing node, cluster	clean, crawl, mine, integrate, fuse, articulate, computing, analyse, detect, predict, forecasting, judge	heterogeneous, spatiotemporal anomaly, anomaly, spatial-temporal	

(Source: author’s own compilation)

Table 16 'Core technology' patents

Patent number	Patent title	Issue year	Selection rule	Classification
10349246	Method and system for vehicle-to-vehicle identification and detection	2019	1	H04W_4/8
10356758	Method and apparatus for requesting and modifying resource configuration in a wireless communication system	2019	1	H04W_4/0
10481475	Smart lighting device and control method thereof	2019	1	H04N_5/222
10536825	System for vehicle-to-vehicle identification and detection	2020	1	H04W_4/8
10703365	Lane tracking method and lane tracking system for an autonomous vehicle	2020	1	B60W_30/12
10719001	Smart lighting device and control method thereof	2020	1	G03B_21/20
10721787	Method and apparatus for improving one-to-one sidelink communication in a wireless communication system	2020	1	H04W_76/14
10750144	Smart lighting device and operation mode transforming method of a smart lighting device for switching between a first operation mode and second operation mode	2020	1	H04N_9/31
8880199	Smart lighting control system	2014	1	G05B_19/18
9091558	Autonomous driver assistance system and autonomous driving method thereof	2015	1	G01C_22/0
9377781	Automatic driving system able to make driving decisions and method thereof	2016	1	G01C_22/0
9772197	Dispatch system for autonomous vehicles	2017	1	G01C_21/34
9821802	Composite autonomous driving assistant system for making decision and method of using the same	2017	1	B60W_30/9
10038543	Many to one communications protocol	2018	2	H04L_5/0

Patent number	Patent title	Issue year	Selection rule	Classification
10527736	Methods and mobile devices with electric vehicle transportation detection	2020	2	G01S_19/49
10602447	Long paging cycle and paging enhancement for power saving LTE devices	2020	2	H04W_52/2
10718620	Navigation and positioning device and method of navigation and positioning	2020	2	G01C_21/32
6684155	Vehicle management system	2004	2, 3	H04Q_7/20
6847307	Traffic signal control system employing universal co-ordinated time (UTC) of GPS as time base	2005	2	G08G_1/95
6847873	Driver information feedback and display system	2005	2	G06F_7/0
7221315	GPS system for receiving and processing GPS signal and traffic information signal	2007	2	G01S_5/14
7498991	Miniature combo built-in antenna structure	2009	2	H01Q_1/24
8106793	System and method for collecting traffic violation data	2012	2	G08G_1/17
8219310	GPS device for displaying traffic conditions and method thereof	2012	2	G01C_21/36
8577601	Navigation device with augmented reality navigation functionality	2013	2	G01C_21/0
8825390	Navigation device and navigation method capable of presenting prompt information with different light effects	2014	2	G01C_21/34
9291115	Vehicle idle-speed warning system and idle-speed detection method	2016	2	G06G_7/70
9398532	Long paging cycle and paging enhancement for power saving LTE devices	2016	2	H04W_52/2
9538279	Headphone controlling system and portable electronic device employing same	2017	2	H04R_1/0

Patent number	Patent title	Issue year	Selection rule	Classification
9551587	Navigation device and navigation method capable of presenting prompt information with different light effects	2017	2	G01C_21/34
9857799	Computer vision positioning system and method for the same	2018	2	G05D_1/0
10225442	Electronic device and method for sensing air quality	2019	2	G01N_21/0
6447731	Cleaning device	2002	2	A62B_7/8
6650244	On-vehicle flood alarm system	2003	2	G08B_21/0
9861925	Smart air cleaner	2018	2	B01D_46/44
10028109	Group communication over LTE eMBMS	2018	3	H04B_7/0
10070461	QoS provisioning for LTE-WLAN aggregation	2018	3	H04W_48/20
10080109	Service continuity for group communication over LTE eMBMS	2018	3	H04B_7/0
10111097	Method for network traffic routing	2018	3	H04W_12/6
10408932	Environment recognition system using vehicular millimeter wave radar	2019	3	G01S_13/89
10526438	Multi-functional carbamate having soft-segments, polyisocyanate obtained via subsequent non-phosgene synthesis methods, urethane prepolymer and elastomeric urethane having soft-segments derived therefrom, and preparation method thereof	2020	3	C08G_18/38
10560529	Vehicle information and environment monitoring compound vehicle system and data processing and transmission method therein	2020	3, 4	H04L_29/8
10565484	Low-energy consumption bluetooth IoT device	2020	3, 4	G06K_19/6

Patent number	Patent title	Issue year	Selection rule	Classification
10594505	System and method for avoiding deadlock in transmission of broadcast traffic in a server system	2020	3	H04L_12/18
10644393	RF energy transmitting apparatus, RF energy harvesting apparatus and method of RF energy transmitting	2020	3	H02J_50/20
10687179	Service continuity for group communication over LTE eMBMS	2020	3	H04B_7/0
10771985	Methods and apparatus for multiple connectivity in heterogeneous network	2020	3	H04W_16/32
10798158	Network system and decision method	2020	3	H04L_12/24
6183705	Method of cleaning and disinfecting contact lens, and apparatus therefor	2001	3	A61L_2/0
6315313	Energy storing bicycle	2001	3	B62M_1/10
6315885	Method and apparatus for electropolishing aided by ultrasonic energy means	2001	3	C25F_3/16
6373840	Stackable networking device and method having a switch control circuit	2002	3	H04Q_11/0
6391209	Regeneration of plating baths	2002	3	C02F_1/32
6567037	Tracking data fusion method in combined radar/ADS surveillance environment	2003	3	G01S_13/0
6573858	Tandem-cycle target/track assignment method in combined radar/ADS surveillance environment	2003	3	G01S_13/0
6580384	Track prediction method in combined radar and ADS surveillance environment	2003	3	G01S_13/0
6596148	Regeneration of plating baths and system therefore	2003	3	C25D_21/18
6598314	Method of drying wafers	2003	3	F26B_3/34
6717331	Piezoelectric ultrasonic motor with multi-layer thin disks	2004	3	H01L_41/8

Patent number	Patent title	Issue year	Selection rule	Classification
6750851	Multi-purpose radio T/R system	2004	3	H04Q_7/32
6796315	Method to remove particulate contamination from a solution bath	2004	3	B08B_3/8
6865948	Method of wafer edge damage inspection	2005	3	G01N_29/8
6869384	Exercising bicycle	2005	3	A63B_69/16
7009933	Traffic policing of packet transfer in a dual speed hub	2006	3	G01R_31/8
7128947	Pre-treating method for plating a Fe-Mn-Al alloy surface	2006	3	B05D_3/12
7192254	Radial fan having axial fan blade configuration	2007	3	F04D_29/30
7315239	Inter-vehicle communication and warning apparatus	2008	3	B60Q_1/0
7408157	Infrared sensor	2008	3	G01J_5/0
7621624	High-efficient ultrasonic ink-jet head and fabrication method of for the same	2009	3	B41J_2/45
7777361	Turbine ventilator for generating electricity	2010	3	F03D_9/0
7915072	Non-vacuum coating method for preparing light absorbing layer of solar cell	2011	3	H01L_21/0
8033794	Wind turbine	2011	3	B63H_13/0
8054745	Call admission controller and method thereof and multi-hop wireless backhaul network system using the same	2011	3	H04J_1/16
8220952	LED lamp	2012	3	B60Q_1/0
8262576	Imaging probe	2012	3	A61B_8/14
8287471	Medical treatment using an ultrasound phased array	2012	3	A61N_7/2
8400049	Tuning fork quartz crystal resonator	2013	3	H03H_9/19

Patent number	Patent title	Issue year	Selection rule	Classification
8564759	Apparatus and method for immersion lithography	2013	3	G03B_27/42
8632221	LED module and method of bonding thereof	2014	3	F21V_29/0
8750926	System and method for coordinating multiple radio transceivers within the same device platform	2014	3	H04M_1/0
8775551	Testing a network system	2014	3	G06F_15/16
8780880	Method of TDM in-device coexistence interference avoidance	2014	3	H04J_3/0
8894249	LED module and method of bonding thereof	2014	3	F21V_29/0
9078275	Bluetooth low energy and LTE coexistence enhancements	2015	3	H04Q_7/24
9117760	Method and system for energized and pressurized liquids for cleaning/etching applications in semiconductor manufacturing	2015	3	B44C_1/22
9232443	System and method for coordinating multiple radio transceivers within the same device platform	2016	3	H04B_1/0
9277565	Bluetooth low energy and LTE coexistence enhancements	2016	3	H04Q_7/24
9298660	Super speed USB hub and traffic management method thereof	2016	3	G06F_13/40
9319851	Radio resource efficient transmission for group communication over LTE eMBMS	2016	3	H04B_7/0
9338070	System and method for operating M2M devices	2016	3	G06F_15/16
9386425	Group communication over LTE eMBMS	2016	3	H04B_7/0
9404784	Surveillance system with electricity converting module and sensors and method thereof	2016	3	F24J_2/0

Patent number	Patent title	Issue year	Selection rule	Classification
9445243	Service continuity for group communication over LTE eMBMS	2016	3	H04B_7/0
9473906	Idle mode reception for group communication over LTE eMBMS	2016	3	H04H_20/71
9479962	Method of TDM in-device coexistence interference avoidance	2016	3	H04W_28/4
9565628	Energy saving functionality for small cells in E-UTRA and E-UTRAN	2017	3	H04W_16/26
9699800	Systems, methods, and appartatuses for bearer splitting in multi-radio HetNet	2017	3	H04W_36/22
9708640	Electrospun nanofibrous membranes and disposable glucose biosensor	2017	3	C12Q_1/54
9791008	Brake disc	2017	3	F16D_65/78
9900911	QoS provisioning for LTE-WLAN aggregation	2018	3	H04W_4/0
10031573	Energy efficiency strategy for interrupt handling in a multi-cluster system	2018	4	G06F_9/46
10152831	Method for sharing real-time recording	2018	4	H04N_9/47
10272357	Mineral composition for generating small water clusters, a small water cluster generating device and a seawater desalination equipment using the same, and a small water cluster generating method	2019	4	B01D_3/34
10422692	Spectrometer device, mobile apparatus, spectrometer system and operating method thereof	2019	4	G01J_3/2
10636271	Indoor air quality control system	2020	4	G08B_21/12
6244254	Power activating device	2001	4	F02M_33/0
7125132	Gauge lighting structure	2006	4	G01D_11/28
7376100	Channel assigning method for ad-hoc network	2008	4	H04B_7/212

Patent number	Patent title	Issue year	Selection rule	Classification
8085134	Wireless sensor network and sampling rate allocation method thereof	2011	4	G08B_9/0
8088685	Integration of bottom-up metal film deposition	2012	4	H01L_21/4763
8427992	Power-efficient backbone-oriented wireless sensor network, method for constructing the same and method for repairing the same	2013	4	G08C_17/0
8428514	Asymmetric and asynchronous energy conservation protocol for vehicular networks	2013	4	H04B_7/0
8516592	Wireless hotspot with lightweight anti-malware	2013	4	H04L_29/6
8726054	Cloud-based energy-saving service system and method	2014	4	G06F_1/32
8885929	Abnormal behavior detection system and method using automatic classification of multiple features	2014	4	G06K_9/62
8891293	High-endurance phase change memory devices and methods for operating the same	2014	4	G11C_11/0
9189889	Method for building a three-dimensional model and apparatus thereof	2015	4	G06T_15/0
9259650	Game method for traffic reality entertainment system	2016	4	A63F_13/21
9534803	Energy saving air conditioning system and air conditioning method thereof	2017	4	B60H_1/0
9799150	System and method for sharing real-time recording	2017	4	H04N_9/47
9977699	Energy efficient multi-cluster system and its operations	2018	4	G06F_9/46

(Source: author’s own compilation)

Then, the first classifications of all patents in the ‘core technology’ group were selected; next, I analysed the frequency of those repeated classifications. Thirteen frequently repeated classifications[16] (see Table 17) were chosen to form the ‘supporting technology’ group. In order to have a reference, I used the same search rule to select all smart city patents in the USPTO database regardless of whether they were invented by the Taiwanese and analysed their classifications. Based on this reference, I include seven additional classifications[17] (see Table 18) in this research’s final ‘supporting technology’ group classifications. Although these seven classifications only appear once among the classifications of Taiwanese smart city patents, they are ranked high when counting the frequency of repeated classifications of the referred patents in the USPTO.

Table 17 Frequently repeated patents classifications of USPTO patents invented by Taiwanese

Classification	**Classification repeated times**	**% of total patent number**
H04B7/0	7	5.79%
G01C21/34	3	2.48%
G01S13/0	3	2.48%
B60Q1/0	2	1.65%
F21V29/0	2	1.65%
G01C22/0	2	1.65%
G06F15/16	2	1.65%
G06F9/46	2	1.65%
H04N9/47	2	1.65%
H04Q7/24	2	1.65%
H04W4/0	2	1.65%
H04W4/8	2	1.65%

[16] A classification can be counted as a frequently repeated one when its percentage of repeated times divided by the total patent number is higher than 1%.

[17] The additional classifications selected by analysing all USPTO patents are G05D1/0, G05D1/2, G06F19/0, G06K9/0, H04L12/26, H04L12/28 and H04L29/6. But because I used the first four digits of classifications for later patent selection, only G05KD1, G06F19, G06K9, H04L12, and H04L29 are counted to be additional classifications.

Classification	Classification repeated times	% of total patent number
H04W52/2	2	1.65%

(Source: author's own compilation)

Table 18 Frequently repeated patents classifications of all USPTO patents

Classification	Classification repeated times	% of total patent number
G05D1/0	338	3.41%
H04L29/6	320	3.23%
G05D1/2	275	2.77%
G06F15/16	217	2.19%
G06F15/173	182	1.84%
H04W4/0	179	1.81%
G06K9/0	170	1.71%
H04L12/28	169	1.70%
G01C22/0	134	1.35%
H04L12/26	123	1.24%
G06F19/0	100	1.01%
G01C21/34	100	1.01%

(Source: author's own compilation)

Based on the 'supporting technology' group, I used the first four digits[18] of those classifications for further patent selection, as these represent the technical nature of a patent (Li and Rigby, 2022). In the end, seventeen four-digit classifications (see Table 19) in the 'supporting technology' group are used as the scope of smart city technology. Among these classifications, six patent classifications show the attributes being applied in specific domains. They are G01C21, G01C22, G01S13, B60Q1, G05D1 and F21V29. The first five classifications mainly contain technologies used in the transportation domain, while the last classification is more relevant to technologies for the governance/surveillance domain. Apart from these six classifications, the other

[18] This four-digit classification contains the international patent classification's (IPC's) section, main class, subclass, and main group.

eleven smart city patent classifications are used to categorise data-related technologies which can be applied in any domain.

Table 19 Smart city patent classifications

Classification	Classification title
G01C21	Navigation; Navigational instruments not provided for in groups G01C 1/00-G01C 19/00
G01C22	Measuring distance traversed on the ground by vehicles, persons, animals or other moving solid bodies, e.g. using odometers or using pedometers
G01S13	Systems using the reflection or reradiation of radio waves, e.g. radar systems; Analogous systems using reflection or reradiation of waves whose nature or wavelength is irrelevant or unspecified
H04B7	Radio transmission systems, i.e. using radiation field
H04L12	Data switching networks
H04L29	Arrangements, apparatus, circuits or systems, not covered by a single one of groups H04L 1/00-H04L 27/00
H04Q7	Selecting arrangements to which subscribers are connected via radio links or inductive links
H04W4	Services specially adapted for wireless communication networks; Facilities therefor
H04W52	Power management
B60Q1	Arrangement of optical signalling or lighting devices, the mounting or supporting thereof or circuits therefor
F21V29	Protecting lighting devices from thermal damage; Cooling or heating arrangements specially adapted for lighting devices or systems
G05D1	Control of position, course, altitude, or attitude of land, water, air, or space vehicles, e.g. automatic pilot
G06F15	Digital computers in general; Data processing equipment in general
G06F19	Digital computing or data processing equipment or methods, specially adapted for specific applications

Classification	Classification title
G06F9	Arrangements for program control, e.g. control units
G06K9	Methods or arrangements for reading or recognising printed or written characters or for recognising patterns, e.g. fingerprints
H04N9	Details of colour television systems

(Source: author's own compilation)

Finally, by using the seventeen classifications in the 'supporting technology' group to search the smart city patents invented by Taiwanese between 2001 and 2020, I selected 9,693 patents. As discussed in Chapter 3, the evolution of Taiwanese high-tech industries can be explored through the dimensions of technological, organisation, and locational transformation (Storper and Walker, 1989). To align with this, three sets of data, patent citations, patent assignees, and patent inventors' located cities, are analysed in Chapter 5 to reveal these triple transformations. The first citation analysis, including three critical elements of industrial evolution: time, geography, and technology, can help understand knowledge diffusion (Jaffe and de Rassenfosse, 2019). Though this study does not analyse the geography of citations, through this measure, the analysis of time and technology citations can create an integrated understanding of the transformation of an industrial landscape. Secondly, the analysis of assignees can help understand the key players in the emerging smart city industry. The last analysis of patent data is the locations of inventors. This analysis can reveal how smart city innovation activities clustered.

The five fields of data I downloaded in my database to analyse triple transformations include 1) issued years, 2) patent classifications, 3) cited patents, 4) cited patents' classifications, 5) assignees and 6) cities of inventors. There are 45,174 cited patents and 51,427 cited classifications downloaded in the database, while the assignee and inventor data have some inconsistent or invalid values requiring further cleaning. The number of original assignee names is 1,514. After the format inconsistency and spelling errors are fixed, the final number of assignee names is 1,186. Then, I excluded 106 invalid values from the 9,721 of the original assignee number. Accordingly, the final total patent assignee number is 9,615.

In terms of the cleaning for location data, a few extra steps are required because of two significant inconsistencies. The first cause was city-county consolidation in 2010. In that year, the administrative boundaries of cities and counties in Taiwan were redivided. Additionally, there were inconsistencies in the filled administrative area levels. For example, some applicants filled in the city column with town names while some with city names. Therefore, I corrected those data from originally 785 various names to 22 official city and county names based on administrative divisions. Also, I deleted 14 patents because they have unrecognisable inventor city names. In the end, the number of inventors' location cities used for analysis is 26,371 (see Table 20). After data cleaning, the patents in the database are sorted by classifications and with the other five data fields explained above (see Table 21). The first two are used to analyse technological transformation; the other two datasets are used for organisational and locational analysis.

Table 20 The patent data cleaning summary

	'Core technology' patent number	**Patent number**	**Cited patent number**	**Cited classification number**	**Assignee number**	**Inventor number**
Before	125	9,693	45,174	51,427	9,721	26,385
After	121	9,693	45,174	51,427	9,615	26,371

(Source: author's own compilation)

Table 21 Smart city patent classifications and numbers between 2001 and 2020

Classification	**Patent number**	**Cited patent number**	**Cited classification number**	**Assignee number**	**Inventor number**
G01C21	225	1,953	2,003	228	488
G01C22	21	66	72	22	59
G01S13	119	597	585	118	351
H04B7	578	3,282	3,846	574	1,422
H04L12	939	4,087	5,297	954	2,765
H04L29	520	2,149	2,292	516	2,368
H04Q7	149	647	649	141	336
H04W4	522	1,873	1,986	521	1,845

Classification	Patent number	Cited patent number	Cited classification number	Assignee number	Inventor number
H04W52	144	377	376	146	619
B60Q1	408	2,206	3,059	289	670
F21V29	542	2,623	2,522	515	1,092
G05D1	111	486	554	104	319
G06F15	938	5,612	8,377	933	2,121
G06F19	585	209	208	588	1,805
G06F9	855	4,263	4,628	875	2,437
G06K9	2,447	11,770	12,018	2,486	6,087
H04N9	590	2,974	2,955	605	1,587
Sum	9,693	45,174	51,427	9,615	26,371

(Source: author's own compilation)

4.4.3 Qualitative data

As explained in the methodology chapter, the qualitative data, comprised of policy documents and in-depth interviews, is used to explore the research questions about the state industrial policies' role and the actor-caused structural changes. This subsection presents the codes that I identified based on the interview data supplemented with the analysis of the four national and one local policies. The identified codes are the foundations of analysis, helping the research form the narratives. The interviewees of this research fall into two main groups: people working in the smart city industry and people working for government agencies.

My measure to identify codes is deductive, guided by the theoretical elements of actor-structure interactions and institution in the literature on the evolutionary economic geography (EEG) (see Chapters 2 and 3). Codes identified in the interview data categorised by the topics of interview questions. For eighteen interviewees from the industry, I designed questions according to four topics: 1) experience in technology development and collaboration, 2) dominant industrial actors, 3) experience of participation in public projects, and 4) policies most relevant to their business. Under the first topic about experiences, there are two sub-topics: 1-1) motivations and 1-2) noticeable changes in the industry. Then, the questions for the seven interviewees from government agencies are developed from the topics of 1) dominant industrial actors, 2) policy strategy, 3) institutional changes, and 4) differences between the smart city industry and ICT or IoT industries.

Based on the codes, five themes have been developed to formulate arguments: leadership in R&D, client-driven technology, market-driven product development, government support, and the role of quangos. The codes derived from the industry interviewees' data are presented and categorised under these five themes in Table 22. They are mostly analysed to explain the evolution of the regional industry caused by the actions of industrial actors leading to changes in industry structure in Chapter 7. I used a few elements, i.e. the local conditions, agent variety, market competition, social relations, institutional and relational embeddedness and recursive interaction processes, extracted from the EEG theory to analyse these codes. Table 23 presents the codes defined from the data of the government agencies' interviews. Chapter 6's explanation of the industry policies shaped by the state for the development of the smart city industry is mainly based on the analysis of these codes and policy documents. The theoretical elements that I used to analyse the codes of government agency interviewees' data are power, institution (or rule) reproduction and guiding role.

Table 22 Codes from interview data of industry interviewees

Topics	Codes
1-1	**Leadership in R&D** • Extension of existing products • Joining other clients' projects • Advantage of local firms to provide low-cost products or solutions **Market-Driven Product Development** • The decline in the revenue • New market opportunity • Market potential and market size • Industry upgrade • Market trend • An opportunity to develop new business models **Client-Driven Technology** • Solve urban problems or improve city efficiency • Local capability request by the government because of data security concerns • Local governments' need for digitalisation • Invited by the government • Led by the government strategies • Pilot projects led by the government to collaborate with universities to experiment with innovative technologies **Role of Quangos**

Topics	Codes
	• Quango's technology development direction
1-2	**Leadership in R&D** • Collaborations with companies in different sectors • Collaboration with system integrators • Collaborations between tech and non-tech companies • Setting common rules for data transmission and uses and developing new industrial standards • Applying telecom's data communication techniques to other domains • Developing local data accumulation techniques, e.g. cloud, for public data • The importance of system integrators and the effort made to be that role • Big companies' advantages • Transforming the products from hardware only to software included • Collaborations between big and small companies • The attempt to develop system integration techniques • The efforts to develop industrial standards • The need for setting data transmission rules or standards • The reorganisation of a firm for the new market • Transforming from telecom to internet, system integrator, and finally, data processing • Collaboration between firms, governments and quangos • The importance of data use and data application in this new industry • The prevalence of the EV charging system

Topics	Codes
	• The industrial alliance enhancing the technology prevalence • Using data to enlarge the scope of technology application • A common start: installing sensors to collect environmental data • The opportunity for startups, their facilitating their emergence • Approaching from the hardware perspective • The importance of system integration for data use and application • The industrial standardisation of driverless vehicles • The cross-domain and cross-development feature **Market-Driven Product Development** • Technology applied to cities • Platform service • Pay attention to the value of data • Integrated solutions **Client-Driven Technology** • The government's regulations to involve private sectors in developing infrastructure • Long-term partnerships between firms and local governments • New business models or collaboration models with governments • The government's digitalisation level • Political factors and concerns • Two dominant domains: governance/surveillance and transportation

Topics	Codes
	Government Support • Local governments' measures to support • Related regulations, e.g. city's parking rules, data protection, etc. • Set-up of data platform • Development of platforms for data accumulation • Experiment with new techniques in some sites in Taiwan • The establishment of the infrastructure for data transmission **Role of Quangos** • Quangos' role in technology innovation • Spinn-off from quango
2	**Leadership in R&D** • The importance of system integrator • The role of telecom: owning data (platform for data accumulation), leading cross-company teams to bid government procurement, building different types of networks for smart transportation, providing network services • International tech companies lacking localised technologies • Local cloud for data accumulation and storage • ODM and OEM lacking capabilities of system integration • Startups' innovation capability • The influences of big tech companies and their extension • Hardware manufacturers in the smart lamppost market

Topics	Codes
	Client-Driven Technology • Governments' approach: consulting big companies' advice and opinions for introducing new technologies in cities **Government Support** • Support provided by the government for big tech companies to enter overseas markets • Balancing voices between traditional and new industries by the government • Innovation funds (e.g. from spectrum auction) for small companies **Role of Quangos** • The role of quango: coordinating between the industry and the government • Personal and institutional level connections: quangos' network
3	**Leadership in R&D** • From e-ticket systems to smart parking systems • The impact on society: job loss • System integration to establish a data platform as infrastructure • The industrial standards for smart scooters • Sensor installation with internet enabling a data-based city • Exploring the value of data **Market-Driven Product Development** • The need for localised products **Client-Driven Technology** • The smart parking system starting from Tainan

Topics	Codes
	• The support from the city council for the budget allocation • The strategies of different city governments • The role of the domestic market • Political factors • The need for public data facilitating collaboration with the government • Government procurement for smart lampposts in many cities • The potential of smart lampposts as a start and its challenges, e.g. budget, cross-department, etc. • Uncertainty in politics: Major elections every four years • Smart lamppost procurement: site and budget • Service contract, not one-off • Smart energy determined by the state-own electronic company • Long-term business opportunities beyond the government’s R&D funds **Government Support** • The drawback of the ‘Smart City Taiwan’ policy, i.e. the division between big and small companies • The limitations caused by procurement regulations • The limitations caused by data regulations • Industrial parks as mini versions of smart cities • Cross-department collaboration • Procurement supporting innovation

Topics	Codes
	• Internet as a critical infrastructure • The subsidy provided by several city governments for citizens to purchase electronic scooters • The need for local cloud (data accumulation and storage) because of data security concern • Improving the digital capability of a group of people within the city government • Data share issues • R&D fund for the early phase • Government agencies studying foreign experiences • Participation of small companies in smart city projects led by big companies • Unknown of the applications of frontier technologies like 5G
4	**Leadership in R&D** • Cross-sector collaborations in smart city projects • The importance of localisation • The importance of platforms for data accumulation • The limitation caused by the local ICT industries' hardware advantage • The key industrial actors' support • The limitation of firms outside the cluster • The importance of data communication techniques **Client-Driven Technology** • Referring to policy documents • A significant determinant: city major's support

Topics	Codes
	• Differences in regulations and standards between cities • Two ways to participate in smart city projects: Procurement and the technology development grant under the ‘Smart City Taiwan’ policy **Government Support** • Product-based technology development supported by the ‘Smart City Taiwan’ policy • The limitation of the previous science park model in developing the smart city industry • Some budgets provided by the central government to a few local governments • Duplicate of technology in different cities • The collaborations between big and small firms encouraged by the ‘Smart City Taiwan’ policy • The ‘Smart City Taiwan’ policy as a form of R&D fund • The subsidy provided by the government to buy EVs • The subsidy provided by the government to install EV charging stations • Experiment sites provided by the governments • The importance of the negotiation between departments and the government and companies • The importance of platforms to accumulate cross-department data • Developing smart cities for the purpose of economic development • The limitation of government procurement
Others	**Leadership in R&D** • Smart city technology: wide-area communication techniques, such as NB-IoT and LoRa, and material for durability in urban environments

Topics	Codes
	• The usage of the edge technique • Similarity to IoT: sensor, detector but different requirement of chips (edge computing for AI) • Challenges of using data: different formats and interfaces • The importance of a unified structure for data communication and processing • Rise and decline (influence on tech industries) between big tech companies and quangos • A new collaboration model formed with the rise of the smart city industry **Government Support** • The immaturity in data regulation • The newly established Ministry of Digital Affairs • Quango's innovation resources supported by the government • The restriction of the use of public data • The advance in infrastructure for data accumulation (storage) than data regulation

(Source: author's own compilation)

Table 23 Codes from interview data of government agency interviewees

Topics	Codes
1	**Leadership in R&D** • Telecoms • The Taipei Computer Association's members • System integrators as leaders

Topics	Codes
	• Multiple industrial actors in one project **Client-Driven Technology** • Highest numbers in transportation and health technologies and then governance **Government Support** • Helping IT hardware manufacturers upgrade and subsidising the R&D costs with the ‘Smart City Taiwan’ policy • Involving industrial actors in Governments’ smart city projects based on the public-private partnership (PPP) concept • Bias towards big companies while being complemented by small companies • The Smart City Exhibition in Taiwan • A project office in the Taipei city government connecting to the industry **Role of Quangos** • The quangos’ network in tech industries
2	**Leadership in R&D** • Based on the ICT industries approaching application domains • Fostering the development of solution-based technology (system integration/hardware-software integration; from hardware to software) • ICT used in cities **Client-Driven Technology** • From the orientation set by industrial actors to the needs of the users • Combining the economic development goal with social improvement (smart governance and services)

Topics	Codes
	• Differences in the city government’s attitudes • Developing frontier technologies and fulfilling local needs • The local city governments’ role **Government Support** • The economic development goal behind the ‘Smart City Taiwan’ policy • Export as an aim • The ‘Smart City Taiwan’ policy led by the Ministry of Economic Affairs • The continuity in relevant policies • From PoC to PoV • Industrial policies shifting from hardware to software • Policies about smart city technology development starting from the application of 4G technology • Providing experiment sites for new technologies • Business viable of innovative technologies • Internet Infrastructure **Role of Quangos** • The collaboration between key industrial players with quangos to set out future industry development blueprint • Quangos’ effort to help the industry with system integration
3	**Leadership in R&D** • Setting an industry standard for smart lampposts • Building platforms to accumulate cross-department data

Topics	Codes
	• Service-based technology • Acquiring startups by big tech companies **Client-Driven Technology** • The governments as primary clients in the smart city industry • Service procurement • Localised technologies **Government Support** • Providing experiment sites, not just funding • Open data platforms • Open API to standardise data format and enable more technology development
4	**Leadership in R&D** • Still exploring the pecuniary value of data • The intersection between ICT and application domains, thus needing system integration • Open data with IoT **Client-Driven Technology** • Building innovative culture within the Taipei city government

(Source: author's own compilation)

4.5 Ethics Application and Risk Assessment

The data protection registration number for this research project is Z6364106/2021/02/80 social research. The risk assessment for this research has been authorised by the Bartlett School of Planning with the reference number: RA045712. The ethics application has been submitted to UCL Research Ethics Committee with the project ID: 17105/001. This project is low risk because it does not involve vulnerable groups or sensitive topics.

Chapter 5: Smart city innovation

5.1 Introduction

Innovation is regarded as a critical driver of regional development. This first empirical chapter aims to explore the research question: does smart city innovation represent a structural change within Taiwan's ICT sector? In this research, innovation activities related to smart city technology development are primarily revealed through a patent analysis that compares the emergence of new smart city innovations with the innovation activities of existing local ICT sectors.

Understanding Smart City Innovation through an Upgraded EEG Theoretical Framework

Drawing on EEG literature, innovation is portrayed as triggering a new phase of regional evolution in its industries (Frenken, 2000; Lambooy, 2002; Martin and Sunley, 2010); however, the way a region evolves with innovation depends on local conditions and the nature of the innovation. Traditionally, the Taiwanese high-tech industry was renowned for its information and communications technology (ICT) production capabilities, with a sector-specific focus on hardware manufacturing (explained in Chapter 1). While ICT is considered fundamental to smart city technology, hardware alone is insufficient for driving smart city innovation due to the critical role played by software technologies and integrated systems. The gap between local technological capabilities and the requirements of smart city innovation makes its development an exogenous force. As a result, the smart city industry in Taiwan could only emerge when radical innovation, beyond mere improvements in production efficiency, was developed. This innovation could lead to structural changes that transform the sectoral composition.

Accordingly, instead of following the established industrial path and being shaped by local conditions, the development of smart city innovation can open a window of locational opportunity (WLO) for certain regions, leading them into a radically new phase of evolution. If the development of smart city technology brings radical innovation to Taiwan's high-tech industry, a series of transformations in the industrial environment would occur, creating the conditions necessary for the new industry's growth. The definition of radical innovation in this research is based on the WLO concept to improve EEG's arguments about exogenous innovation-driven evolution (see Chapter 3). A radical innovation is an innovation of a new industry (or a revived old industry) which is not derived from local industries. Its development requires relocating social resources or restructuring production processes and employment relations (Storper and Walker, 1989).

Firms are critical actors in driving innovation, and changes in their activities reflect the trajectory of regional evolution. EEG studies typically analyse firm activities to understand regional evolution. By examining the sectoral composition of a region—specifically, the diversification of firms or sectors—it is possible to reveal the region's capabilities for innovation. The concept of the WLO provides a new perspective on innovation and regional evolution. From this viewpoint, diversification should not only be analysed as an endogenous element because, in the case of WLO-driven evolution, it begins with exogenous factors. Specifically, radical innovation is the key driver that causes technology and firms involved in technology production to diversify and triggers the emergence of new technologies.

Operationalisation of the Theoretical Framework

In this Taiwanese case, if the development of smart city technology represents a radical innovation for local industries, the resulting diversification of technology and firms should lead to changes in the established sectoral composition. This chapter uses ICT patent[19] data as a base to make comparisons with smart city patents. This measure can analyse whether there have been radical differences between ICT (traditional high-tech industry) and smart city technology (radical innovation). First of all, the discontinuity in the evolutionary path and accident events (Boschma, 1996) should be recognised when analysing the radical innovation-caused regional evolution. As explained in the theoretical framework chapter, Storper's (1997) holy trinity can be used as a structure to examine the technological, organisational and territorial dimensions of a region and reveal its creative capacity to enable radical innovation. The specific elements to analyse for the three dimensions are 1) the variety of

[19] The ICT patent classifications listed in this chapter follow the taxonomy proposed by Inaba and Squicciarini (2017) in the OCED report: *ICT: A new taxonomy based on the international patent classification*.

technology, 2) the composition of firms, and 3) the proximately located untraded interdependencies (see Chapter 3). The evolution of the industry in Taiwan can be revealed through the analysis of the transformations in these three elements over time.

Overview of Taiwanese Patents

Before analysing each dimension of the holy trinity, here is an overview of the changes in the Taiwanese-invented patents between 2001 and 2020. During this period, granted patents invented by Taiwanese inventors increased from 6,574 to 12,864 annually. ICT patents constituted 19.24% and 58.70% of the total in 2001 and 2020, numbering 1,265 and 7,551, respectively. While the trend in the number of ICT patents and the overall patents looks similar over the two-decade period (see Figure 7), the proportion of ICT patents tripled. It is evident ICT is of great significance to the Taiwanese high-tech industry. In the same period, the smart city patents increased steadily from 73 to 861, accounting for 1.11% and 6.69% of the total. The growth was rapid in the first decade but became levelled off after 2011 (see Figure 7). In general, the changes in the smart city patent number were not linked to ICT. The differences between the trends in ICT and smart city patent numbers reflected a different trajectory in high-tech industries. The analyses of transformations in the Taiwanese high-tech industry are structured by three dimensions, i.e. technology, organisation and location, unfold in the following three sections. The following sections will analyse each dimension of the holy trinity in detail.

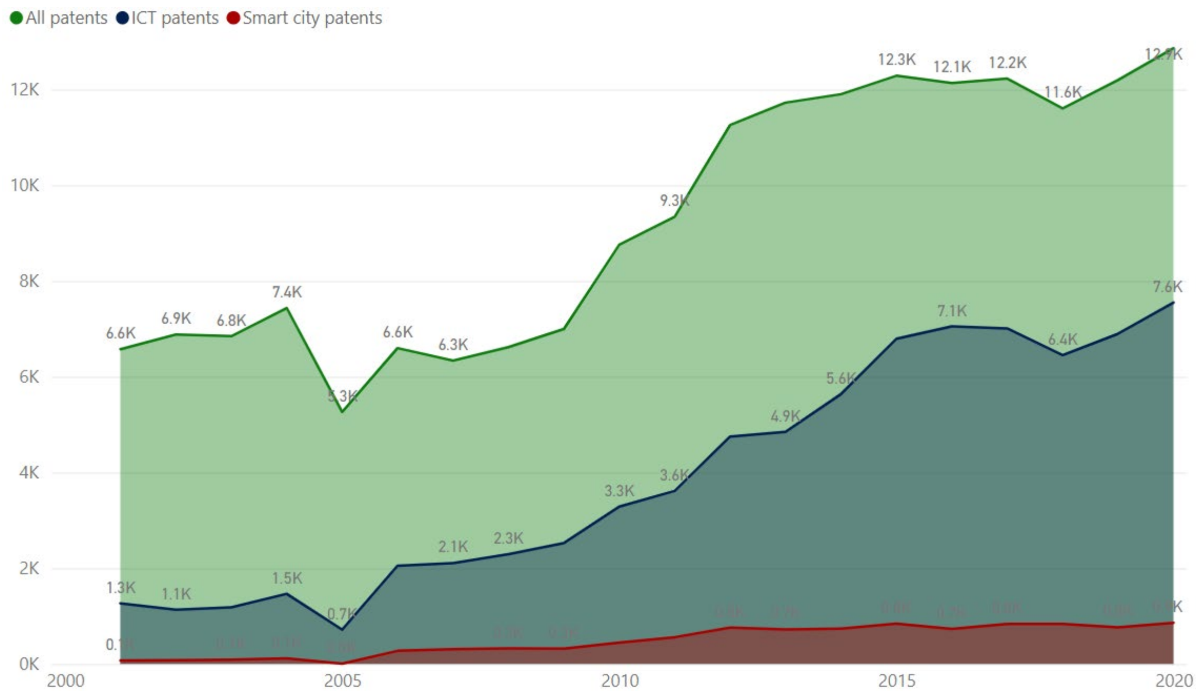


Figure 7 Patents invented in Taiwan between 2001 and 2020

(Source: author's own compilation)

5.2 Technological Dimension

Smart city technological innovation facilitated the diversification of Taiwanese high-tech industries, which were originally composed primarily of specialised hardware ICT production. This section reveals the differences between traditional ICT and smart city patents invented by the Taiwanese by analysing their varieties and citations. Between 2001 and 2020, software-centric patents were dominant among smart city technology, contrasting with the highly hardware-centric ICT patents in the country. Furthermore, the citations of the two technology sets prove that the smart city patents originated from various techniques, while traditional ICT evolved from more homologous technologies.

As explained in Chapter 1, technologically, the current smart city industries comprise a wide spectrum of technologies from hardware to software and their integration. Figure 8 illustrates the structure for the categorisation of smart city technology. Its y axis includes the five application domains: transportation, energy, environment, governance/surveillance and city service, plus some techniques applicable to all-domain and x axis includes four technical sections: devices or sensors for data collection, networks for data transmission, platforms for data collection, and tools for data use and application. Concurrently, system integration (SI) has become an indispensable technique for connecting each section and enabling the application- and service-based smart city technology to function (Senior telecom manager, 2021). Within the structure above, hardware is fundamental to the first two technical sections (device and network), while the latter two (platform and tool) are driven by software. The four technical sections can also be used to categorise all ICT and smart city patents (see Appendix 1).

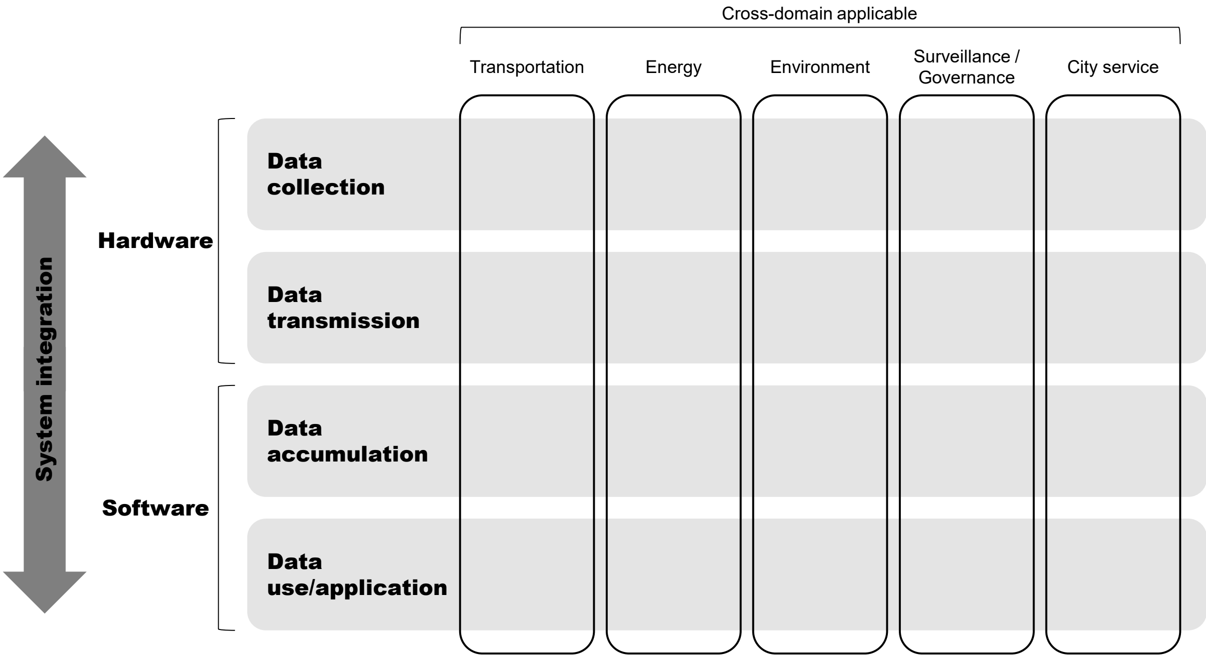


Figure 8 The structure for smart city technology categorisation

(Source: author's own compilation)

5.2.1 The difference between ICT and smart city patent classifications

This chapter categorises all ICT and smart city patents into four technical sections by their classifications [20] to understand their attributes and further characterise whether they are hardware- or software-centric. By sorting patents in this way, we can first reveal the similarities and differences between ICT and smart city patents. There are seventeen patent classifications belonging to smart city technology, twelve of which are classified as ICT (see Table 24). Among those twelve, half are data transmission techniques (H04L12, H04L29, H04Q7, H04B7, H04W4 and H04W52),

[20] Patent classifications analysed in this research are International Patent Classification (IPC).

and four classifications are data use/application techniques (G06F9, G06F19, G06K9 and H04N9). One classification (G01S13) pertains to the data collection technique, and still another classification (G06F15) involves both data accumulation and data use/application techniques. Regarding the five non-ICT classifications of smart city patents, two (G01C21 and G01C22[21]) belong to data collection techniques, and three classifications (B60Q1, G05D1 and F21V29) are data use/application techniques.

The non-ICT techniques under the classifications of G01C21, G01C22, B60Q1 and G05D1 are mostly used in the transportation domain, while F21V29 involves techniques for smart lampposts used in the domain of governance/surveillance (see Table 24 and Table 25). Smart city technologies are designed for urban environments; thus, many of them are initially atypical high-tech techniques, e.g. vehicle navigational and lighting instruments. Due to this specificity of urban application, smart city technology involves techniques beyond traditional ICT technologies. According to the above overview of the smart city patent classifications, while smart city technology is mainly founded on but distinctively composed from ICT. This specific set of technologies does not entirely fall into the traditional Taiwanese high-tech industry. The development of those non-ICT technologies (patents) brought radical innovation to local industries.

5.2.2 The analysis of changes in patent varieties and citations

In the following parts of this subsection, I reveal the variety of technologies over their 20-year evolution (2001-2020) by referring to ICT patent classification to analyse smart city technology's varieties. This analysis can help identify what constitutes a radical innovation in Taiwanese high-tech industries. I use two elements: 1) hardware-centric or software-centric ratio of patents and 2) forward citations to analyse the relevance between these two technology sets. First, analysing the percentage of patents under hardware-centric or software-centric classifications can help clarify whether the industries in Taiwan follow the traditional hardware manufacturing path or not. Secondly, the analysis of citations between classifications in this research is based on the concept of the technology class co-occurrence matrix (Kogler, Rigby and

[21] The classification of G01C21 only has 21 patents over the 20-year period. Thus, the analysis of this classification in this research is combined with the G01C22, which is also under the transportation domain and is most similar to the G01C21 in terms of technique.

Tucker, 2013; Lee, Kogler and Lee, 2019). Through this measure, we can understand the technological proximity of patent classifications and thus describe the source of the evolution of smart city technology. Meanwhile, the development trajectories of the two technology sets, ICT and smart city technology, over the industry's evolution can be identified by comparing the changes in two time periods, 2001-2010 and 2011-2020.

Table 24 Technical sections of smart city patents

Hardware or software-centric	**Technical sections**	**Smart city patent classifications**	
		ICT	**Non-ICT**
Hardware-centric	Data collection	G01S13	G01C21, G01C22
	Data transmission	H04L12, H04L29, H04Q7, H04B7, H04W4, H04W52	
Software-centric	Data accumulation	G06F15	
	Data use/application	G06F15, G06F9, G06F19, G06K9, H04N9	B60Q1, G05D1, F21V29

(Source: author's own compilation)

Table 25 Smart city patent titles

Classifications	**Classification titles**
G01C21*	Navigation; Navigational instruments not provided for in groups G01C 1/00-G01C 19/00
G01C22*	Measuring distance traversed on the ground by vehicles, persons, animals or other moving solid bodies, e.g. using odometers or using pedometers
G01S13	Systems using the reflection or reradiation of radio waves, e.g. radar systems; Analogous systems using reflection or reradiation of waves whose nature or wavelength is irrelevant or unspecified
H04B7	Radio transmission systems, i.e. using radiation field
H04L12	Data switching networks

Classifications	Classification titles
H04L29	Arrangements, apparatus, circuits or systems, not covered by a single one of groups H04L 1/00-H04L 27/00
H04Q7	Selecting arrangements to which subscribers are connected via radio links or inductive links
H04W4	Services specially adapted for wireless communication networks; Facilities therefor
H04W52	Power management
B60Q1*	Arrangement of optical signalling or lighting devices, the mounting or supporting thereof or circuits therefor
F21V29*	Protecting lighting devices from thermal damage; Cooling or heating arrangements specially adapted for lighting devices or systems
G05D1*	Control of position, course, altitude, or attitude of land, water, air, or space vehicles, e.g. automatic pilot
G06F15	Digital computers in general; Data processing equipment in general
G06F19	Digital computing or data processing equipment or methods, specially adapted for specific applications
G06F9	Arrangements for program control, e.g. control units
G06K9	Methods or arrangements for reading or recognising printed or written characters or for recognising patterns, e.g. fingerprints
H04N9	Details of colour television systems

*Non-ICT classifications

(Source: author's own compilation)

5.2.2.1 The varieties of ICT and smart city technologies

The compositions of smart city technology are distinct from the traditionally hardware-specialised production of the Taiwanese high-tech industry. In general, the numbers of hardware- and software-centric ICT patents differed from those of smart city technology (See Figure 9 and Figure 10). The total number of hardware-centric ICT patents (45,028) outnumbers software-centric ICT patents (39,404). The technology area 'Information communication device' under the data collection section had significantly more patent numbers than other areas between 2001 and 2020 (see Appendix 1 and Figure 9) because semiconductor technology, the production of which Taiwanese high-tech firms excel, is categorised under this area.

However, regarding smart city technology, the 3,217 hardware-centric patents are only half the 6,476 software-centric patents. This ratio contrasts with that of ICT. The classification of G06K9: ‘Methods or arrangements for reading or recognising printed or written characters or for recognising patterns, e.g. fingerprints’, which is categorised as the software-centric technology under the data use/application section, had the highest number over the same period (see Figure 10). The second place was H04L12, ‘Data switching networks’ (hardware-centric technology and under the data transmission section), which is closely followed by G06F15, ‘Digital computers in general; Data processing equipment in general’ (software-centric technology and under the data accumulation and data use/application section). Two smart city technology classifications out of the top three are software-centric, and none of them are under the technical section of data collection that includes the highest number of the ICT technology area: ‘Information communication device’. This result demonstrates a significant difference in the compositions of ICT and smart city technology. For smart city technology, the data use/application technical section was the most dominant one among the four technical sections. This composition proves the importance of the application and service in smart city technology. Smart city innovation is not directly linked to the strength of Taiwanese firms, i.e., hardware production, and thus can be defined as a radical innovation. Admittedly, the country’s high-tech firms have a reputation for producing ICT hardware, such as electronic components and electronic devices. The majority of them are initially original equipment manufacturers (OEM) and original design manufacturers (ODM) (Yeung, 2022). Their advantage of entering the smart city industry is being flexible in producing customised products, but these companies are not good at providing technology applications (Senior telecom manager, 2021).

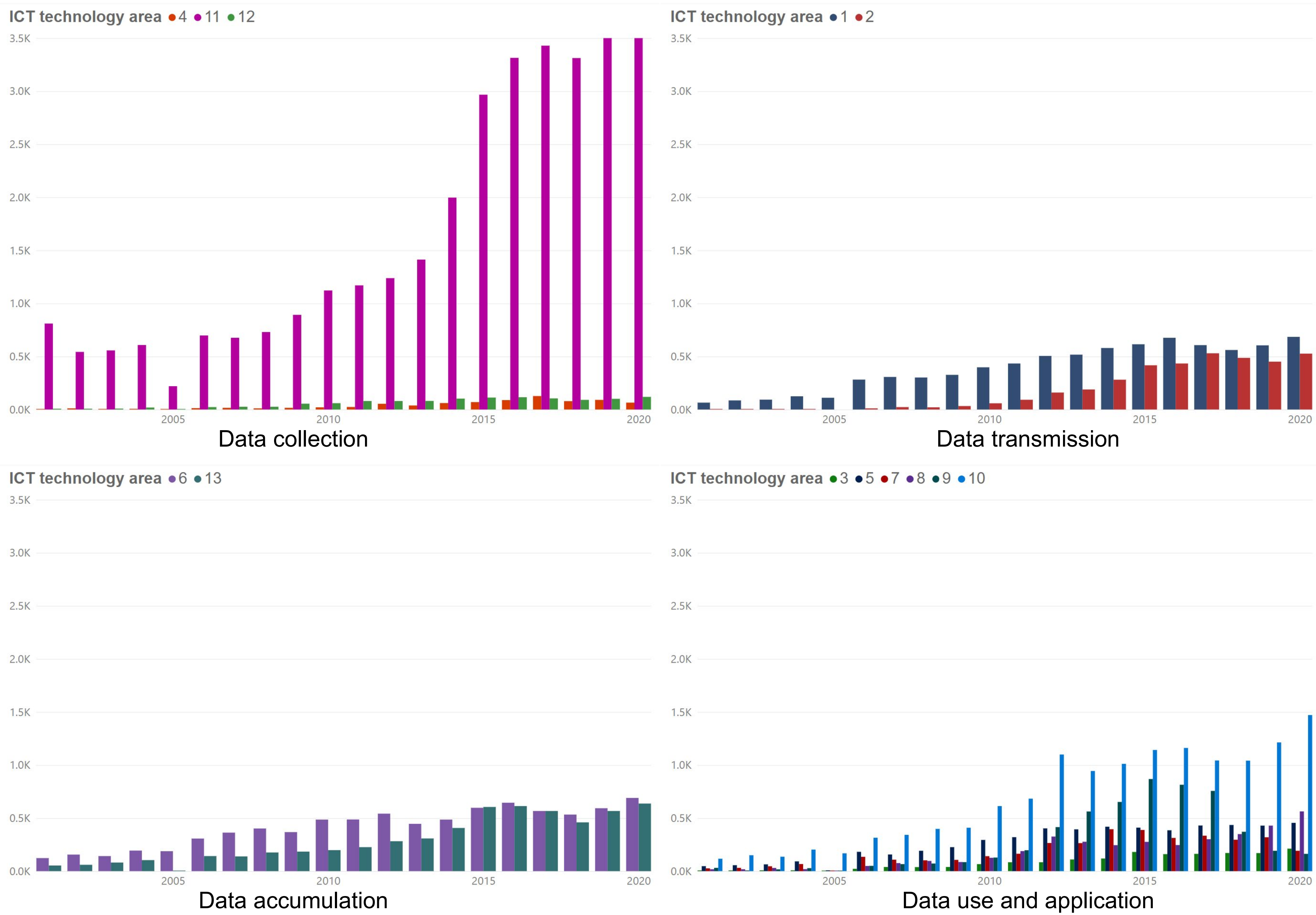


Figure 9 ICT patent (top two: hardware-centric areas; bottom two: software-centric areas) number between 2001 and 2020

(Source: author's own compilation)

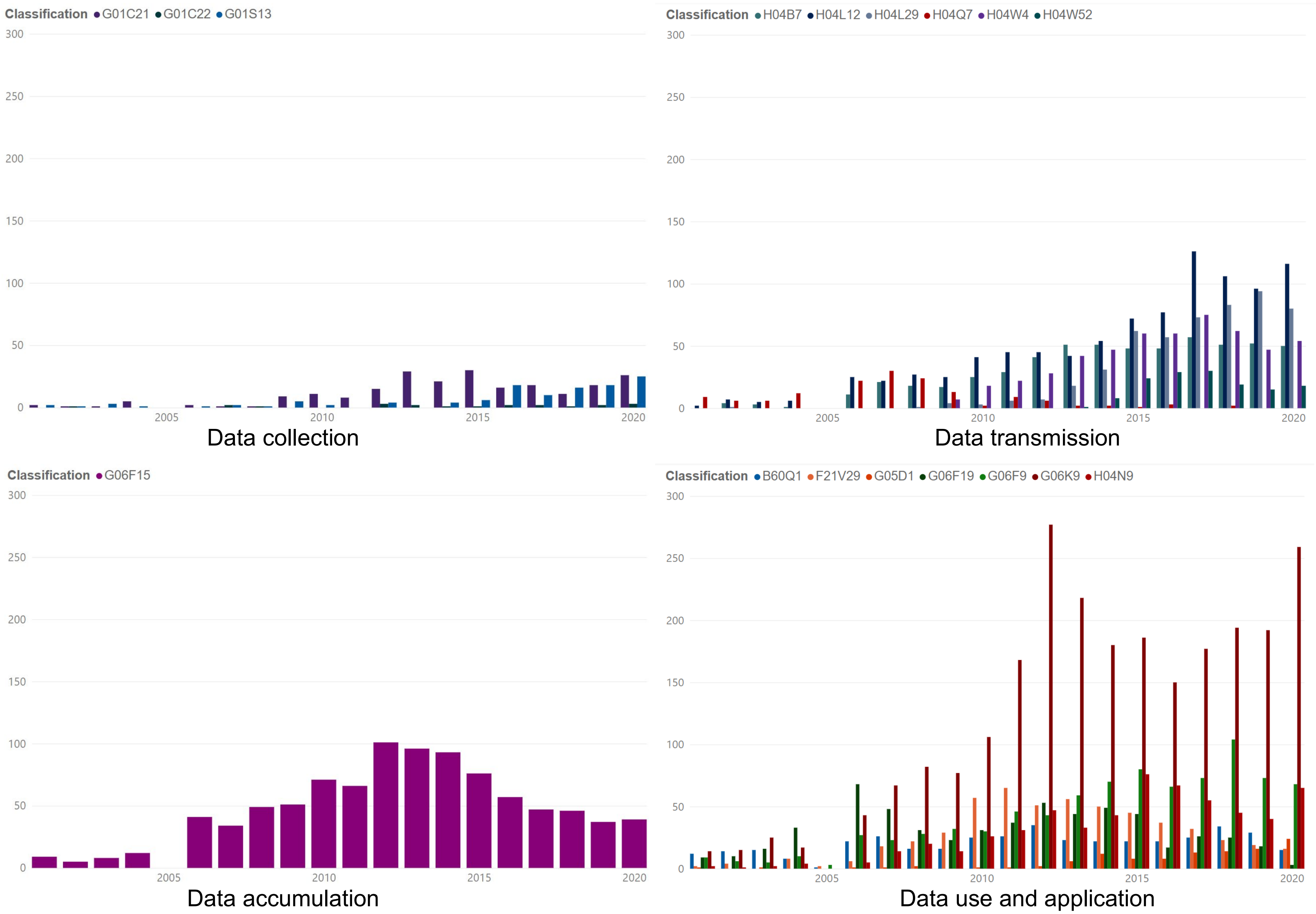


Figure 10 Smart city patent (top: hardware-centric classifications; bottom: software-centric classifications) number between 2001 and 2020

(Source: author's own compilation)

5.2.2.2 The citations of ICT and smart city technologies

The evolution path of ICT patents has been relatively consistent. Both hardware-centric and software-centric ICT patents were derived from only a few sources. In either the hardware-centric or software-centric patent group, only one classification received the highest number of citations in the periods of 2001-2010 and 2011-2020 (see Figure 11, Figure 12 and Table 26). Between 2001 and 2010, the classification cited most by hardware patents was H04B1, which mainly involves technologies under the data transmission section (see Figure 15 and Table 26), and the most cited software patent classification was G06F15, covering data processing technologies under both technical sections of data accumulation and data use/application (see Figure 16). In the following decade, the classification of H01L21 (belonging to the data collection section) for patents related to semiconductor technologies received the most citations in the hardware patent group (see Figure 15 and Table 26), and patents in the software patent group mostly cited the classification of G06F1, which is set to include data processing techniques under the data accumulation section (see Figure 16).

However, smart city innovation has broken the traditional path of Taiwanese high-tech industries. Over the evolution process of smart city industry growth, the innovation in software technology has been more vibrant than in hardware. The network analysis results of patent citations show different courses in the first and second decades. For both hardware- and software-centric patents, the numbers of cited classifications with the highest in-degrees are fewer in 2001-2000 than in 2011-2020 (see Figure 13 and Figure 14). Then, when comparing differences between hardware- and software-centric patents, software-centric patents have more cited classifications with the highest in-degrees than hardware-centric patents have (see Table 27). Overall, the cited classifications of smart city patents became more diversified in the second decade, and the cited classifications of software-centric patents were more diverse than those of hardware-centric patents.

Developing smart city technologies combines techniques from different fields. By analysing which classifications were cited most and how cited classifications are clustered, we can reveal to what extent smart city technologies evolved from ICT or other fields. To begin with, in the first and second decades, the most cited classifications of hardware-centric smart city patents (one in 2001-2010 and six in 2011-2020) are all listed as ICT patents (see Figure 13 and Table 27). The top cited classification in the first decade is set for techniques used for data processing, mainly under the technical section of data use/application. Then, in the second decade, the three clusters of most cited classifications include, firstly, data processing technique (cluster 1 mainly under the technical sections of data accumulation and data use/application), secondly data transmission technique (cluster 2 mainly under the technical section of data transmission), and lastly, the data collecting technique used for vehicles (cluster 3 mainly under the technical section of data collection).

Although the analysis shows that hardware smart city patents were still founded on ICT techniques, their development trajectory became distinct from traditional ICT in Taiwan. On the one hand, the Taiwanese high-tech industry's advantage is hardware production, techniques of which are under the technical sections of data collection and data transmission (most ICT patents in Taiwan were under the data collection technical sections). Over the two-decade period, half of the clusters of hardware-centric smart city patents cited techniques from the software-centric technical sections, which are data accumulation and data use/application (see Figure 17). On the other hand, the more diversified cited classifications covering all four technical sections in the later decade show smart city technologies developed in Taiwan ranged over multiple technical sections rather than specialising in the hardware technique local firms already possess. These results demonstrate smart city innovation in hardware did not follow the traditional path of Taiwanese high-tech industries.

The cited classifications of software-centric smart city patents are beyond ICT. Between 2001 and 2010, the top seven cited classifications for software-centric smart city patents are still ICT (see Figure 14 and Table 27). In this period, patents under the two most cited classification clusters are firstly an integration of techniques for data transmission and data analysis (cluster 1 involving three technical sections across data transmission, data accumulation, and data use/application) and, secondly, an integration of techniques for data transmission and processing (cluster 2 mainly under the technical sections of data accumulation and data use/application). From 2011 to 2020, less than half of the most cited classifications, six out of thirteen, were ICT patents (see Figure 14 and Table 27). Cluster 1 of cited classification represents data processing techniques, mainly under the technical section of data use/application. Cluster 2 integrates techniques ranging from data collecting, transmission and processing to visual and audio interfaces, which involve all four technical sections and also non-ICT. These techniques are used to demonstrate the data analysis results.

Lastly, the both two most cited classifications in cluster 3 are not ICT. They are techniques of lighting systems used for smart lampposts.

This analysis of software-centric smart city patents citations shows clear distinctions between smart city technology and traditional ICT developed in Taiwan. Firstly, compared to the hardware-centric smart city patents, citations of software-centric smart city patents were more diverse between 2001 and 2020, and none of those clusters only cited techniques from the hardware-centric technical sections, i.e. data collection and data transmission (see Figure 17 and Figure 18). It is clear software-centric smart city patents were syntheses of varied technical sections, and their innovation was not derived from the techniques owned by local ICT hardware manufacturers. Furthermore, the beyond ICT citations in the second decade show that smart city technologies as an emerging technology set need innovative technical solutions outside the local technology development path that mainly focuses on ICT hardware production.

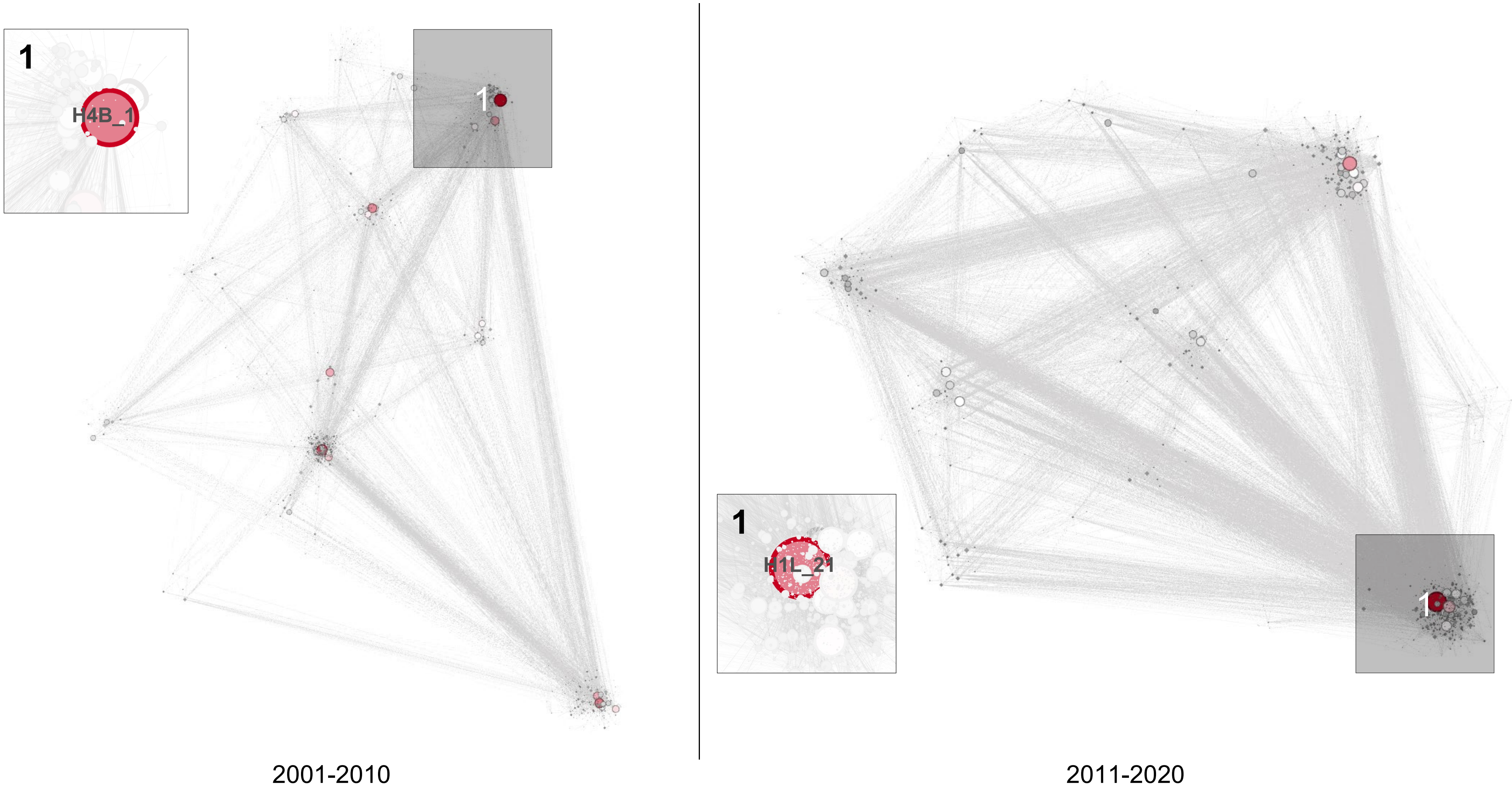
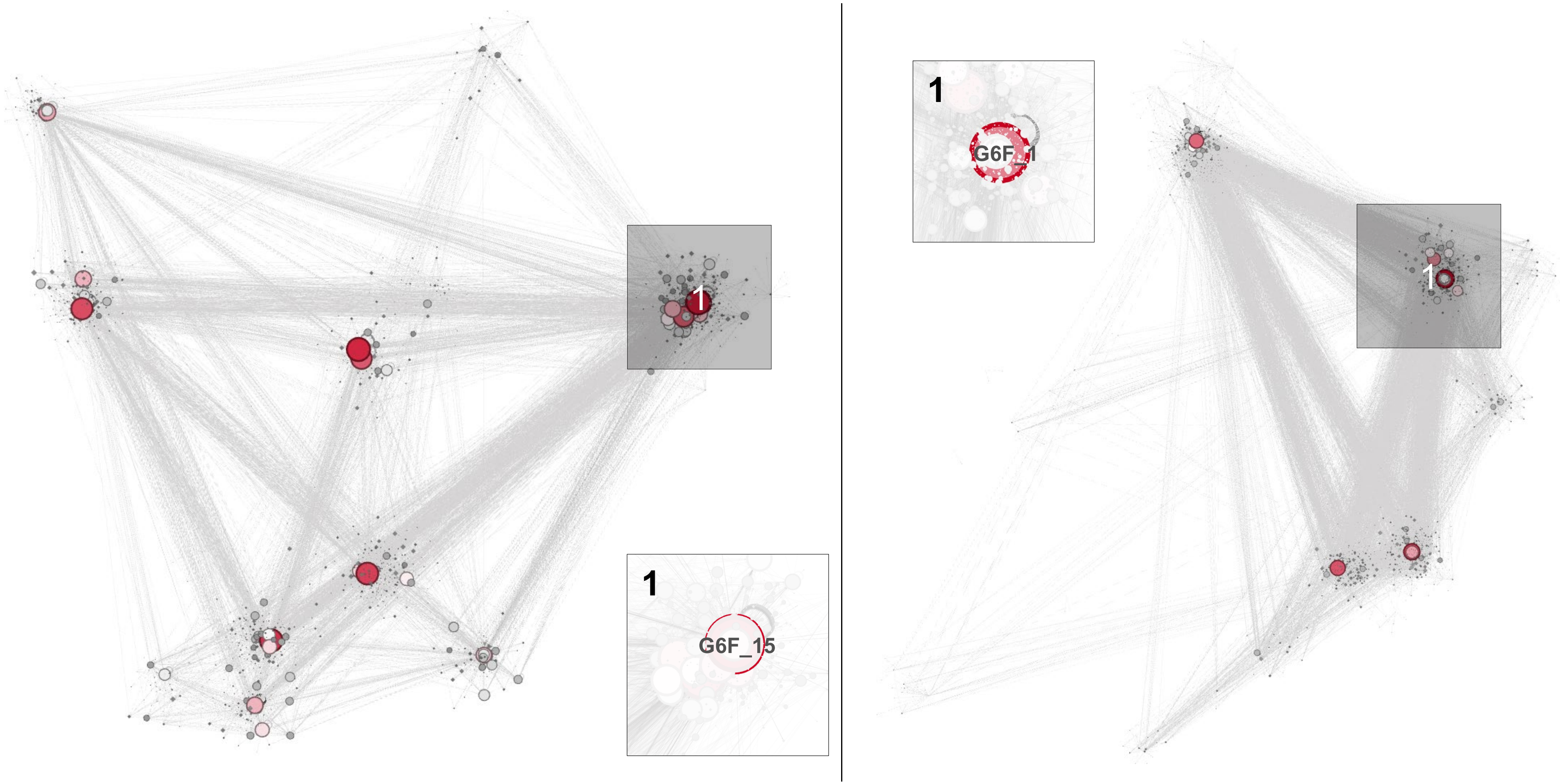


Figure 11 Citation network of the hardware-centric ICT patent classification and clustered classifications

(Source: author's own compilation)



2001-2010 2011-2020

Figure 12 Citation network of the software-centric ICT patent classification and clustered classifications

(Source: author’s own compilation)

Table 26 Cited classifications of ICT patents with the highest in-degrees

Technology groups	**ICT patent classifications**	**Time**	**Highest in-degree**	**Cited classifications**
Hardware-centric	G08B1/08, G08B3/10, G08B5/22-38, G08B7/06, G08B13/18-13/196, G08B13/22-26, G08B25, G08B26, G08B27, G08C, G08G1/01-065, H04B1/59, H03B, H03C, H03D, H03F, H03G, H03H, H03J, H01B11, H01L29-33, H01L21, 25, 27, 43-51, G02B6, G02F, H01S5, B81B7/02, B82Y10, H01P, H01Q, G01S, G01V3, G01V8, G01V15, H03K, H03L, H03M, H04B1/69-1/719, H04J, H04L, H04M3-13,19,99, H04Q, H04B1/00-1/68, H04B1/72-1/76, H04B3-17, H04B7, H04W	2001-2010	73	Cluster 1: H04B1
		2011-2020	220	Cluster 1: H01L21
Software-centric	G06F3/06–3/08, G06F12, G06K1-7, G06K13, G11B, G11C, H04N5/78-5/907, G06F3/00, G06F3/05, G06F3/09, G06F3/12, G06F3/13, G06F3/18, G06E, G06F1, G06F15/02, G06F15/04, G06F15/08-15/14, G06G7, G06J, G06K15, G06K17, G06N, H04M15, H04M17, G06F12/14, G06F21, G06K19, G09C, G11C8/20, H04K, H04L9, H04M1/66-665, H04M1/667-675, H04M1/68-70, H04M1/727, H04N7/167-7/171, H04W12, G06Q20, G07F7/08-12, G07G1/12-1/14, H04L12/14 , H04W4/24, G06F5, G06F7, G06F9, G06F11, G06F13, G06F15/00, G06F15/16-15/177, G06F15/18, G06F 15/76-15/82, G06F17/30, G06F17/40, G06F17/00, G06F17/10-17/18, G06F17/50, G06F19, G06Q10, G06Q30, G06Q40, G06Q50, G06Q90, G06Q99, G08G, G06F17/20-17/28, G06K9, G06T7, G10L13/027, G10L15, G10L17, G10L25/63,66,	2001-2010	79	Cluster 1: G06F15
		2011-2020	184	Cluster 1: G06F1

(Source: author’s own compilation)

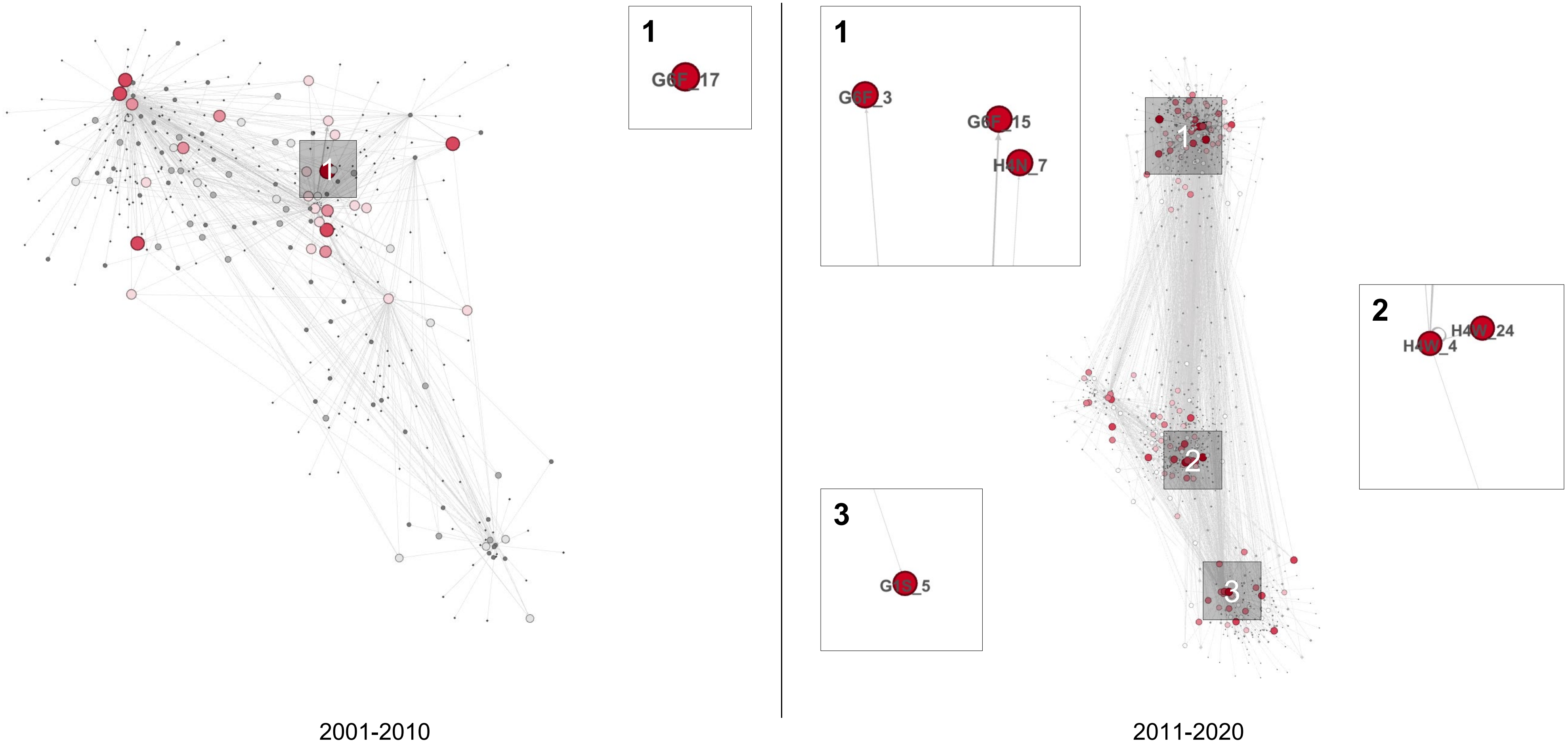
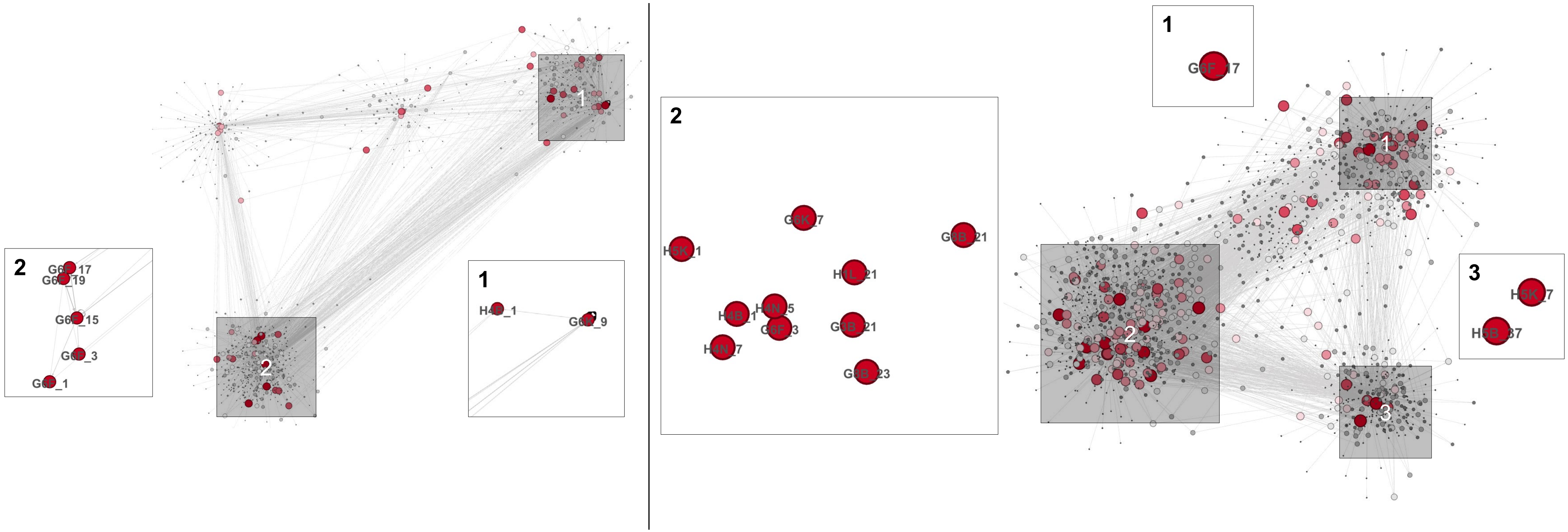


Figure 13 Citation network of the hardware-centric smart city patent classification and clustered classifications

(Source: author’s own compilation)



2001-2010 2011-2020

Figure 14 Citation network of the software-centric smart city patent classification and clustered classifications

(Source: author's own compilation)

Table 27 Cited classifications of smart city patents with the highest in-degrees

Technology groups	Smart city patent classifications	Time	Highest in-degree	Cited classifications
Hardware-centric	G01S13, G01C21, G01C22, H04L12, H04L29, H04Q7, H04B7, H04W4, H04W52	2001-2010	8	Cluster 1: G06F17
		2011-2020	9	Cluster 1: G06F3, G06F15, H04N7 Cluster 2: H04W4, H04W24 Cluster 3: G01S5
Software-centric		2001-2010	7	Cluster 1: H04B1, G06K9

Technology groups	Smart city patent classifications	Time	Highest in-degree	Cited classifications
	G06F15, G06F9, G06F19, G06K9, B60Q1, G05D1, F21V29, H04N9			Cluster 2: G06F17, G06F19, G06F15, G06F3, G06F1
		2011-2020	8	Cluster 1: G06F17 Cluster 2: H05K1*, G06K7*, H04B1, H04N5, H04N7, G06F3, H01L21, G03B21*, G08B23*, G08B21* Cluster 3: H05K7*, H05B37*

*Non-ICT classifications

(Source: author's own compilation)

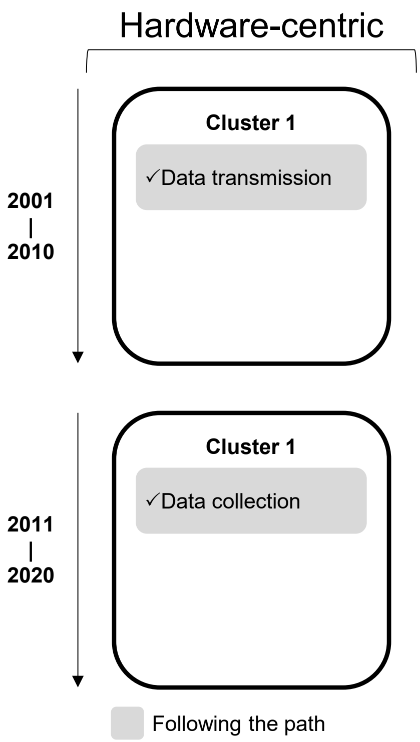


Figure 15 The change in the cited technology of hardware-centric ICT patents

(Source: author's own compilation)

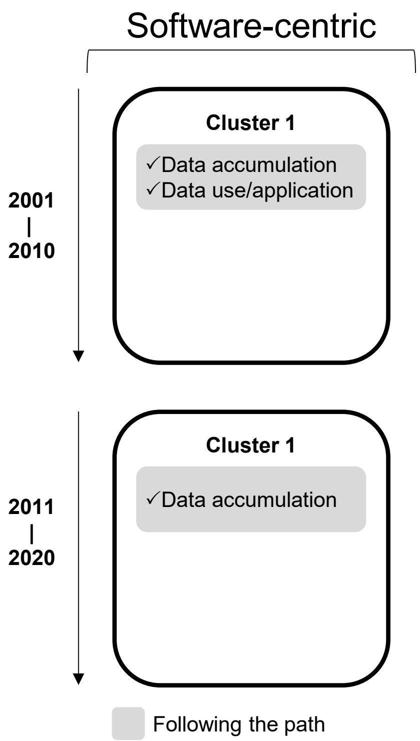


Figure 16 The change in the cited technology of software-centric ICT patents

(Source: author's own compilation)

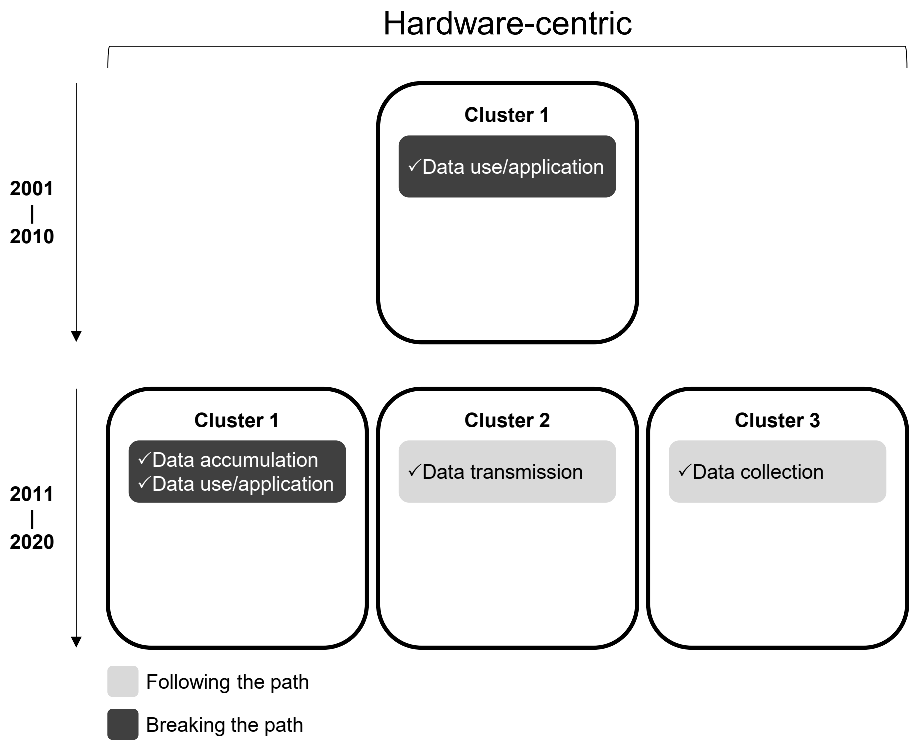


Figure 17 The change in the cited technology of hardware-centric smart city patents

(Source: author's own compilation)

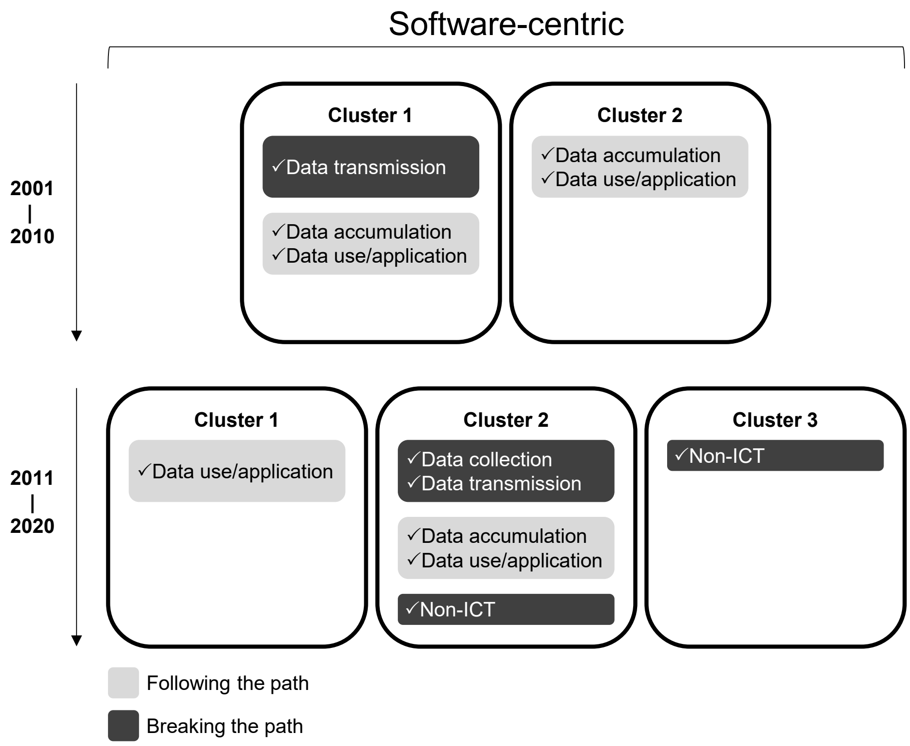
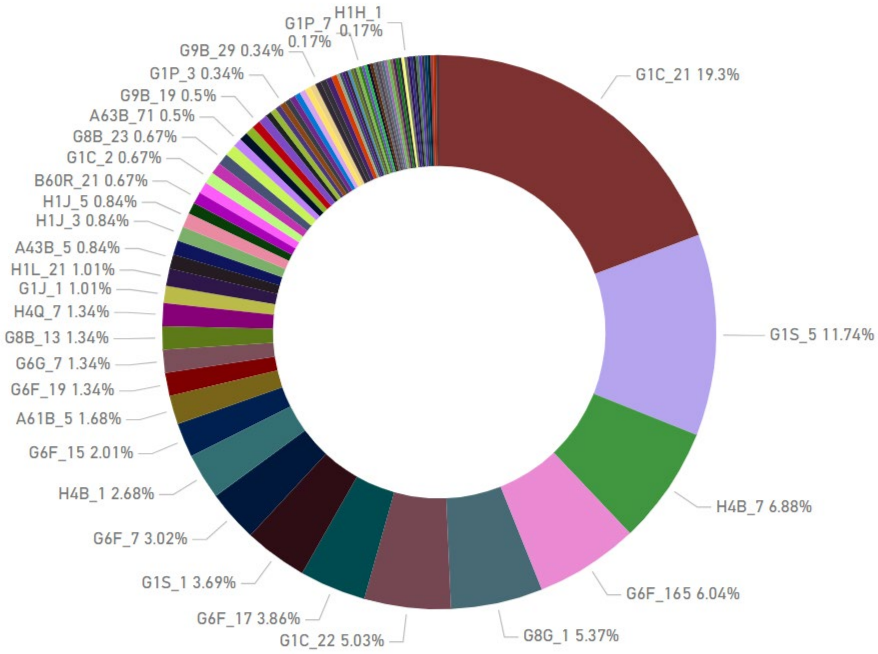


Figure 18 The change in the cited technology of software-centric smart city patents

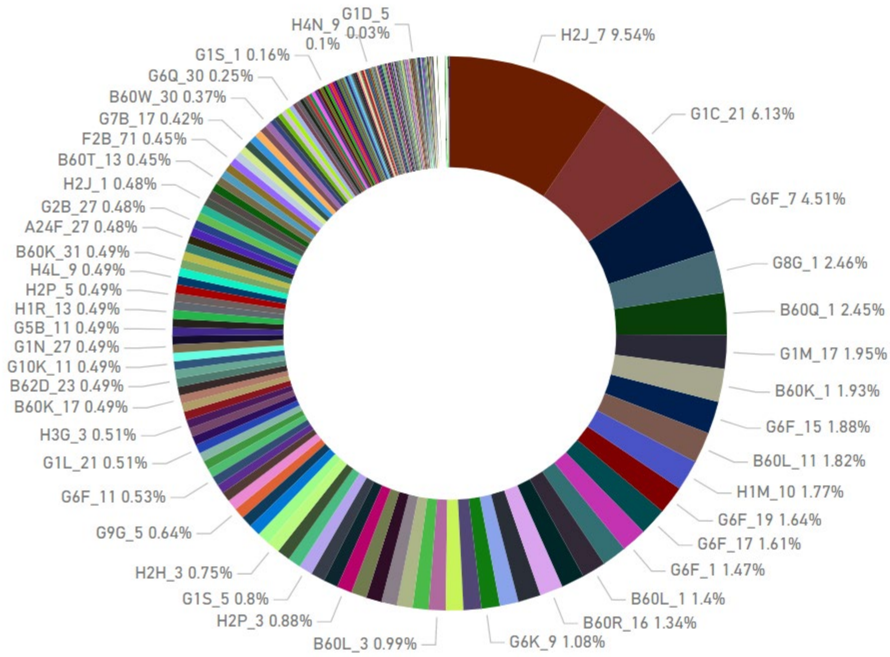
(Source: author's own compilation)

Apart from the overall hardware- and software-centric smart city patents citations, the analysis of five non-typical ICT classifications reveals even more multiple integrations of technologies. As explained, these classifications are radical innovations to local high-tech industries because they are not ICT. Analysing their citations can identify the origins of these technologies and clarify how they could be applied in smart cities. They can be understood as three technology sets in the transportation domain and one in the governance/surveillance domain. The first is the classification of G01C21 (and G01C22) for driving assistant techniques (see Figure 19). Between 2001 and 2010, this classification was most cited, followed by classifications (G01S5 and H04B7) involving techniques for collecting environmental data and data transmission (see Figure 19). However, between 2011 and 2020, the most cited classification (H02J7) was for battery technology. Self-classification-citation became second, and the classification (G06F7) for data processing techniques was ranked third.

Secondly, B60Q1 includes techniques used for a vehicle lighting system (see Figure 20). Over the period of 2001 to 2020, B60Q1 cited itself most, accounting for around 24%. The classification of G08G1, including techniques for traffic control systems, was ranked second and third in the first and second decades. Other frequently cited classifications (G03B21 and F21V29), once ranked in the top three throughout the period, were for visual interface and lighting techniques. Then, in the G05D1 classification, patents are mostly for self-driving technology (see Figure 21). From 2001 to 2010, patents categorised under the most cited classification (B60R21) were driving safety techniques, and under the second most cited classification (H04N1) were data transmitting techniques, specifically for picture information data. From 2011 to 2020, the top cited classification is itself, and the classifications (G06K9 and G01C21) for data analysing and navigation technologies were second and third frequently cited. Lastly, the classification of F21V29 is the technique set applied for smart lampposts (see Figure 22). The classification F21V29 cited most was itself between 2001 and 2020. Other highly cited classifications (G03B21, F21V7, F21V21 and H01L33) contained visual interface, lighting techniques and lighting equipment during the same period.



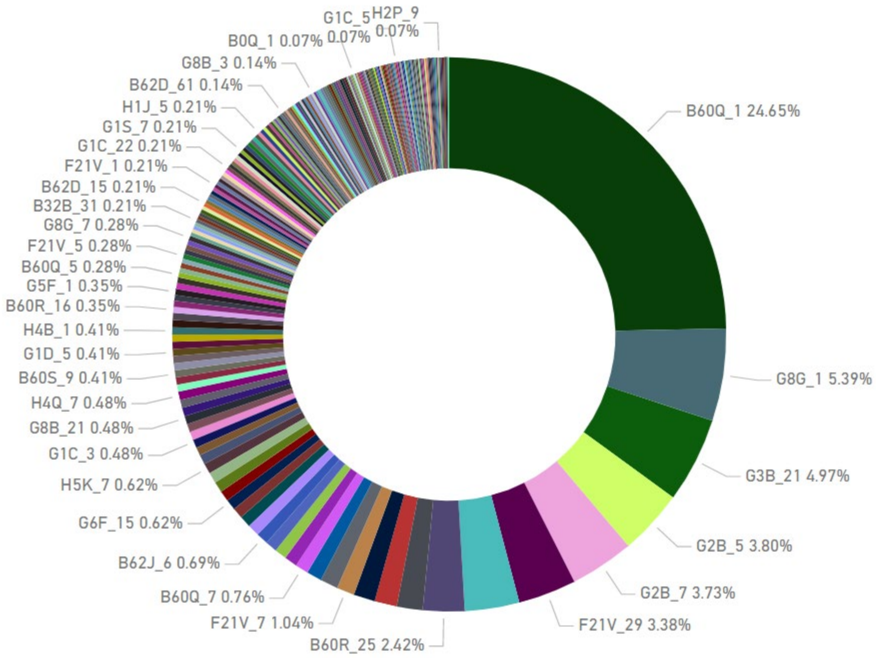
2001-2010



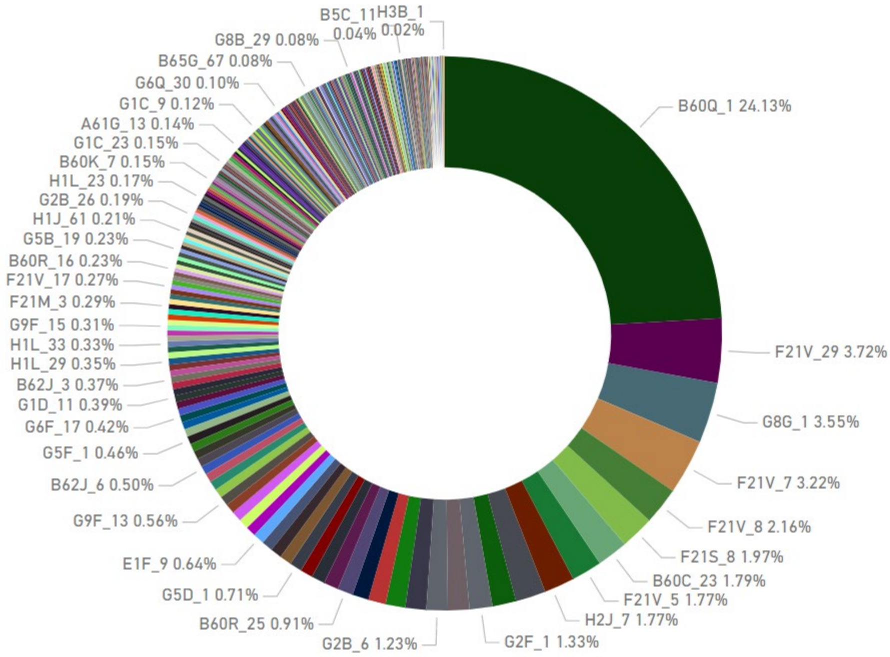
2011-2020

Figure 19 Changes in cited classifications of G01C21 (and G01C22)

(Source: author’s own compilation)



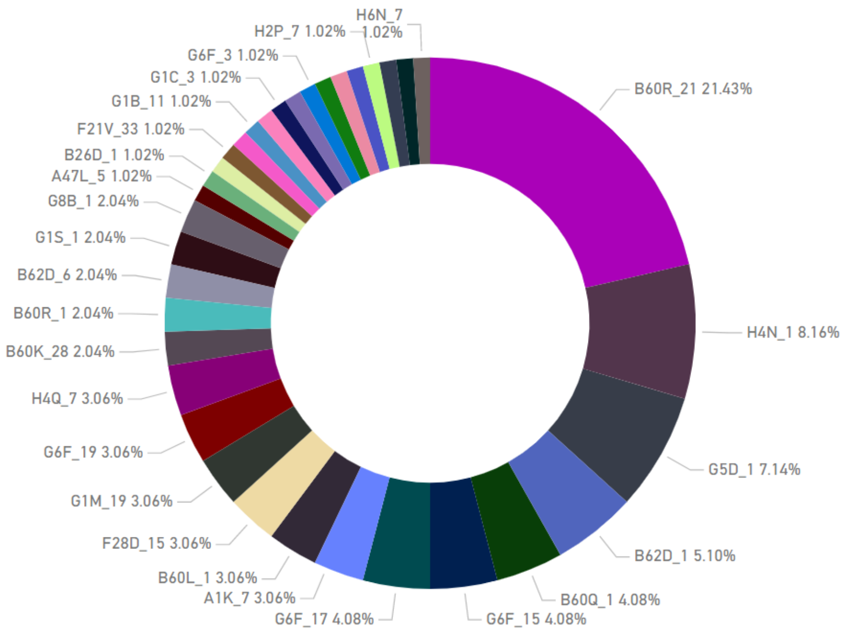
2001-2010



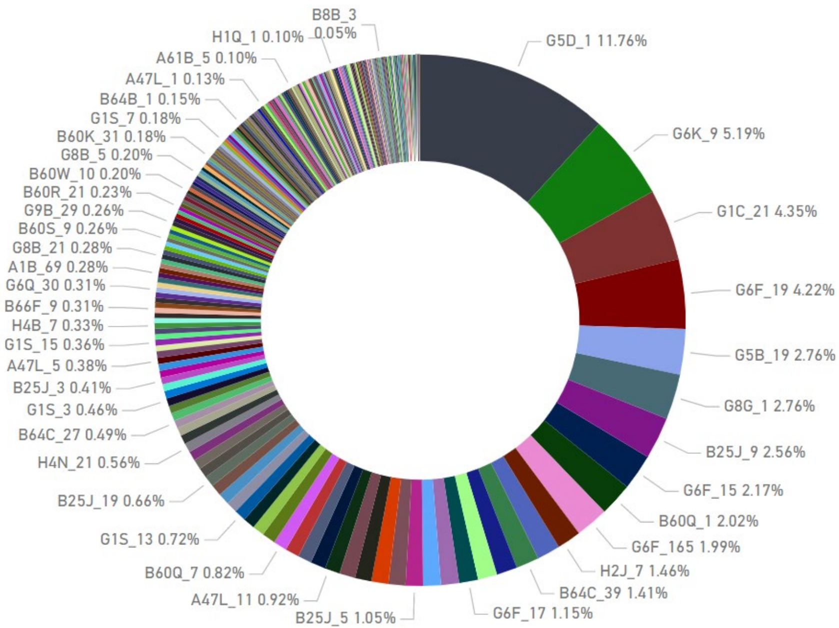
2011-2020

Figure 20 Changes in cited classifications of B60Q1

(Source: author’s own compilation)



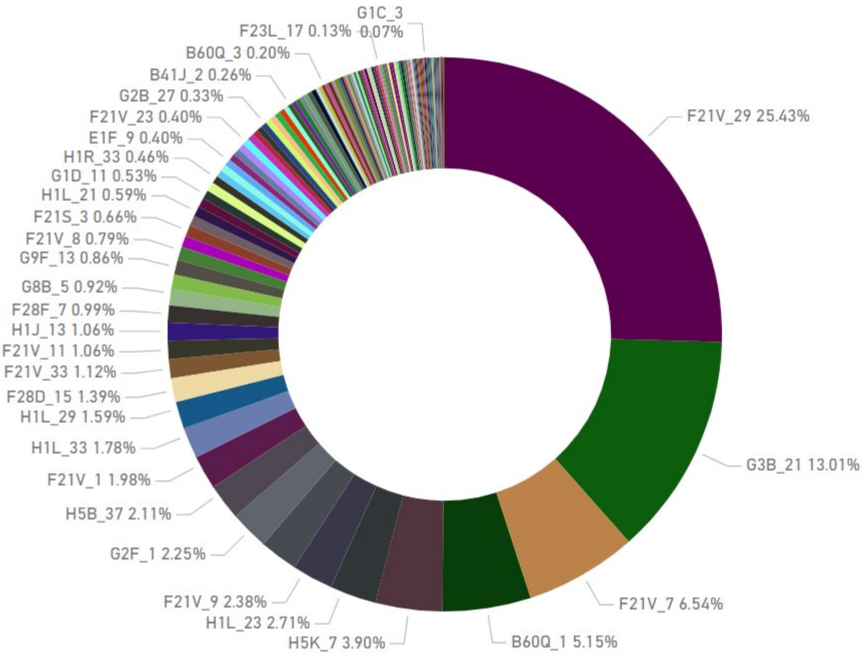
2001-2010



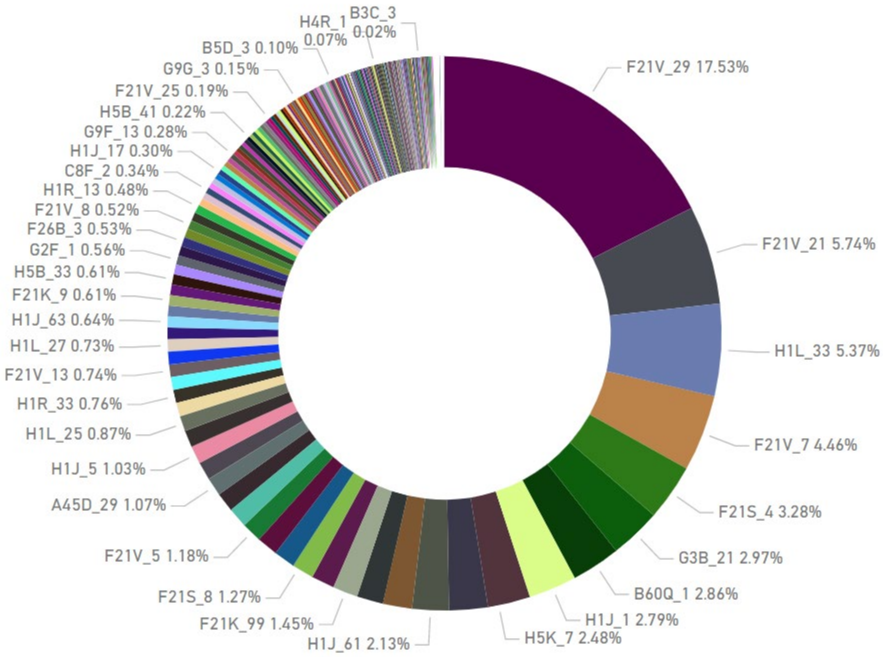
2011-2020

Figure 21 Changes in cited classifications of G05D1

(Source: author's own compilation)



2001-2010



2011-2020

Figure 22 Changes in cited classifications of F21V29

(Source: author’s own compilation)

5.2.3 Summary: Diversifying cited classifications alongside radical innovation

Later in the 20-year period, the cited classifications of all these radical innovation patents became more diverse (see Figure 19, Figure 20, Figure 21 and Figure 22), which represents the diversification of smart city technologies instead of remaining specialisation. Moreover, the citations of these non-ICT smart city patents are across non-ICT patent and ICT classifications (see Appendix 5). Developing these smart city patents brings new technologies to Taiwanese high-tech industries and, meanwhile, reinvents some ICTs. Such development aligns with radical innovation-driven industrial evolution, which goes beyond mere product efficiency improvements. These cross-field combinations of techniques show that when radical innovations emerge, new technologies or technology recombinations—previously absent in local industries—can appear and proliferate, leading to the emergence of a new technological system. Taiwanese high-tech firms have long been specialising in ICT hardware production. However, the need to develop smart city technologies has driven them to innovate to create new technologies beyond traditional ICT produced in Taiwan. As a result, smart city products such as smart electric scooters, self-driving vehicles, and smart lampposts—syntheses of ICT and various non-ICT technologies—have been developed in Taiwan, demonstrating the emergence of new technological systems that lead to a structural change in local industries.

5.3 Organisational Dimension

According to the concept of the holy trinity (Storper, 1997), revealing the composition of firms can help one understand the organisation of local industries. Similar to the analysis of technology transformation, this section compares ICT and smart city patent assignees to identify how the organisation of actors in high-tech industries in Taiwan have been changed by radical innovation, reflecting radical differences between specialised and diversified collaboration models. Multiple industrial actors contributing to the smart city industry from different aspects and at different stages have demonstrated the diversification of smart city innovation in contrast to a single-group-led organisation form for the specialised traditional Taiwanese ICT industries. The industrial actors in ICT and smart city industries have organised in various ways over the two-decade evolution to develop either hardware- or software-centric patents. In

ICT industries, big companies that own most of both hardware and software patents were the most critical industrial actors, while in the smart city industry, research institutes and small companies were visible in their importance in hardware-centric patents in the early stage of industry development, and software-centric patents in the stages. Due to the emergence of smart city innovation, the collaborations between industrial actors have become equal participation by big/small companies and research institutes rather than the original big-companies-centred form based on a hierarchical subcontracting model (Software startup COO, 2021; see Chapter 7).

The proportions of patents owned by big companies, which are the top 100 Taiwanese firms[22] (Top 100), differed between ICT and smart city technology. In general, between 2001 and 2020, 51.92% of ICT patent assignees were Top 100, while these companies only owned 37.59% of smart city patents (see Table 28 and Table 29). This difference represents that these biggest firms are not dominant industrial actors in the smart city industry. OEMs and ODMs, such as the top three companies, HonHai, Pegatron and TSMC, are key players in traditional ICT industries (Telecom director, 2021). However, they are less significant in the smart city industry.

Table 28 The top 100 companies, ranked by net operating revenue, in Taiwan, owing ICT or smart city patents

Rank	**Company**	**ICT**		**Smart city**	
		Patents	**% of total**	**Patents**	**% of total**
1	HonHai Precision Industry Co., Ltd. (HonHai)	3,330	4.19%	789	8.21%
2	Pegatron Corp. (Pegatron)	105	0.13%	15	0.16%
3	Taiwan Semiconductor Manufacturing Co., Ltd. (TSMC)	15,289	19.24%	404	4.20%
5	Quanta Computer Inc.	763	0.96%	153	1.59%
6	Compal Electronics, Inc.	302	0.38%	94	0.98%
9	Wistron Corp. (Wistron)	1,268	1.60%	189	1.97%
13	Taiwan Power Company	1	0.00%	0	0.00%

[22] The top 100 Taiwanese companies was ranked by their net operating revenues in 2020.

Rank	Company	ICT		Smart city	
		Patents	% of total	Patents	% of total
17	Inventec Corp.	728	0.92%	145	1.51%
21	Acer Inc.	692	0.87%	101	1.05%
22	WT Microelectronics Co., Ltd.	0	0.00%	1	0.01%
24	AUO Corp.	3,450	4.34%	82	0.85%
26	InnoLux Corp.	1,384	1.74%	13	0.14%
28	China Steel Corp.	5	0.01%	0	0.00%
31	Chunghwa Telecom Co., Ltd. (Chunghwa)	31	0.04%	14	0.15%
32	ASUSTeK Computer Inc.	537	0.68%	94	0.98%
33	Formosa Plastics Corp.	1	0.00%	0	0.00%
35	NanYa Plastics	2	0.00%	0	0.00%
38	Mediatek Inc. (Mediatek)	4,118	5.18%	687	7.15%
44	United Microelectronics Corp. (UMC)	3,071	3.86%	155	1.61%
45	Lite-on Technology Corp.	954	1.20%	99	1.03%
46	Micro-Star International Co., Ltd. (MSI)	80	0.10%	26	0.27%
47	Morrihan International Corp.	0	0.00%	0	0.00%
48	World Peace Industrial Co., Ltd.	0	0.00%	0	0.00%
50	Advanced Semiconductor Engineering, Inc.	411	0.52%	7	0.07%
51	Qisda Corp.	206	0.26%	31	0.32%
53	EDOM Technology Co., Ltd.	0	0.00%	0	0.00%
57	Inventec Appliances Corp.	98	0.12%	15	0.16%
58	Siliconware Precision Industries Co., Ltd.	233	0.29%	1	0.01%
60	Wiwynn Corp.	31	0.04%	6	0.06%
62	Cheng Uei Precision Industry Co., Ltd.	64	0.08%	6	0.06%
63	Walsin Lihwa Corp.	409	0.51%	0	0.00%

Rank	Company	ICT		Smart city	
		Patents	% of total	Patents	% of total
65	ChiMei Corp.	610	0.77%	32	0.33%
66	Chang Gung Memorial Hospital, Linkou	2	0.00%	0	0.00%
67	Simplo Co., Ltd.	1	0.00%	0	0.00%
69	Foxconn Technology Co., Ltd.	533	0.67%	76	0.79%
70	Far Eastone Telecommunications Co., Ltd. (Far Eastone)	4	0.01%	5	0.05%
74	Catcher Technology Co., LTD.	1	0.00%	0	0.00%
75	Novatek Microelectronics Corp.	800	1.01%	117	1.22%
76	Taiwan Mobile Communication	2	0.00%	2	0.02%
77	Giga-byte Technology Co., Ltd.	107	0.13%	15	0.16%
83	Wistron NeWeb Corp.	168	0.21%	59	0.61%
84	Largan Precision Co., Ltd.	188	0.24%	6	0.06%
90	Chang Chun Petrochemical Co., Ltd.	1	0.00%	0	0.00%
94	Nanya Technology Corp.	515	0.65%	4	0.04%
95	Toshiba Electronic Components Taiwan Corp.	0	0.00%	0	0.00%
96	Accton Technology Corp.	66	0.08%	46	0.48%
98	Delta Electronics, Inc.	627	0.79%	124	1.29%
100	Unimicron Technology Corp.	73	0.09%	1	0.01%
	The sum of top 100 companies	41,261	51.92%	3,614	37.59%

(Source: 中華徵信所企業股份有限公司 (2019) and this research)

Table 29 Hardware- and software-centric ICT and smart city patents owned by the top 100 companies in Taiwan

	Hardware-centric		**Software-centric**		**All**	
	Patents	**% of total**	**Patents**	**% of total**	**Patents**	**% of total**
ICT	25,489	58.50%	15,772	43.93%	41,261	51.92%
Smart city	1,199	37.24%	2,415	37.76%	3,614	37.59%

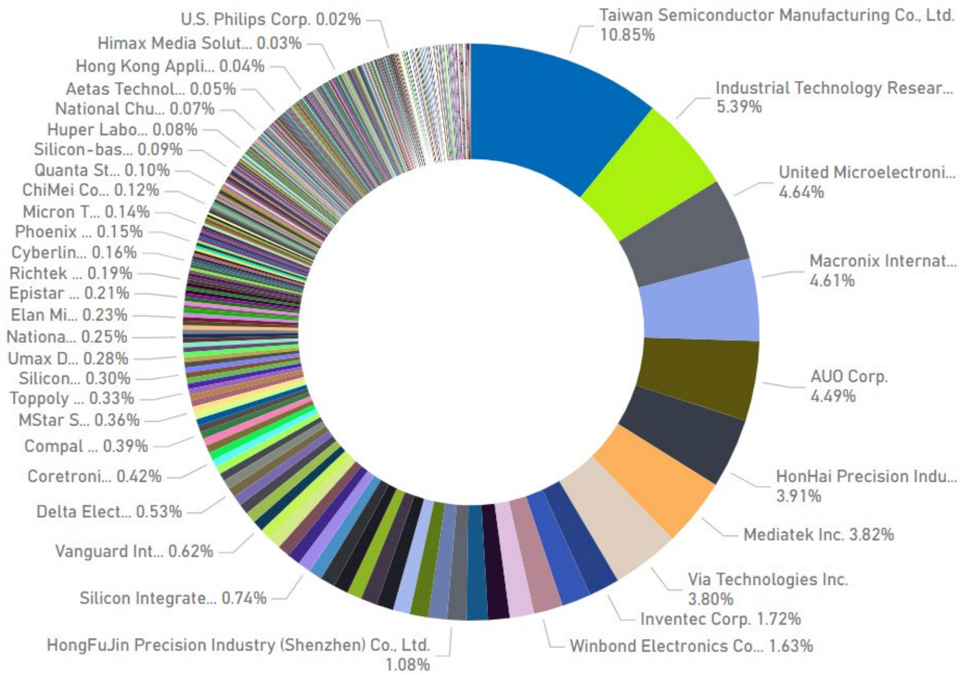
(Source: author's own compilation)

The following three subsections analyse the assignee composition through two approaches: 1) the predominant assignees and 2) the assignee organisation.

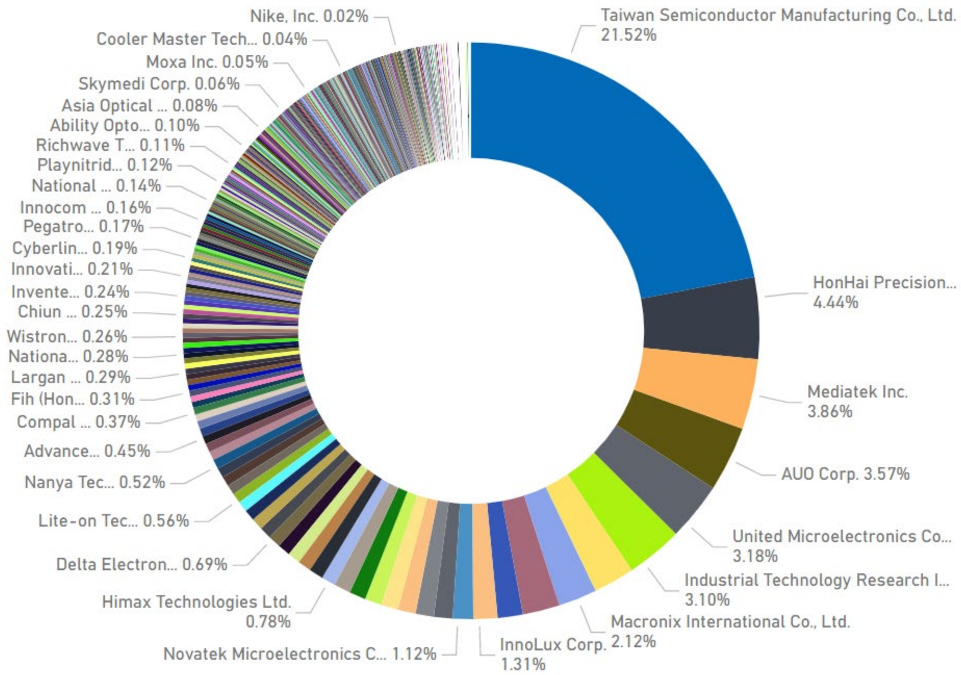
5.3.1 The analysis of changes in predominant assignees

The most prominent patent owners of the two technology sets can further reveal their radical differences. The changes in the top five patent assignees and total patents they owned between the traditional ICT and smart city industries were divergent. Between 2001 and 2010, for both ICT and smart city technology, over 29% of patents were owned by the first five assignees (see Figure 23 and Figure 24). However, the proportion of ICT patents owned by the top five assignees in the following decade increased to 37%. At the same time, the number of smart city patents reduced to 26%. In other words, the top five assignees of ICT patents became more dominant, contrasting with smart city patents' more diversified assignees.

The biggest ICT patent assignee in the first and second decades was TSMC – Taiwan's most significant semiconductor manufacturer. The proportion of ICT patents owned by this company doubled (from 10.85% to 21.52%) in the latter decade compared to the first. Namely, one-fifth of ICT patents in Taiwan were owned by TSMC in 2011-2020. TSMC also help the most smart city patents, accounting for 9.30% in 2001-2010, but was replaced by a research institute, the Industrial Technology Research Institute (ITRI), with a proportion of 7.42% in 2011-2020. This difference shows two distinct natures of ICT and smart city technology. In the ICT industries, a few lead firms became central to technology development, while for the smart city industries, the research institute's contribution to innovation can rival lead firms, though smaller shares of each. Clearly, the changes in the organisation of smart city firms between the two decades did not follow the ICT firms' path.



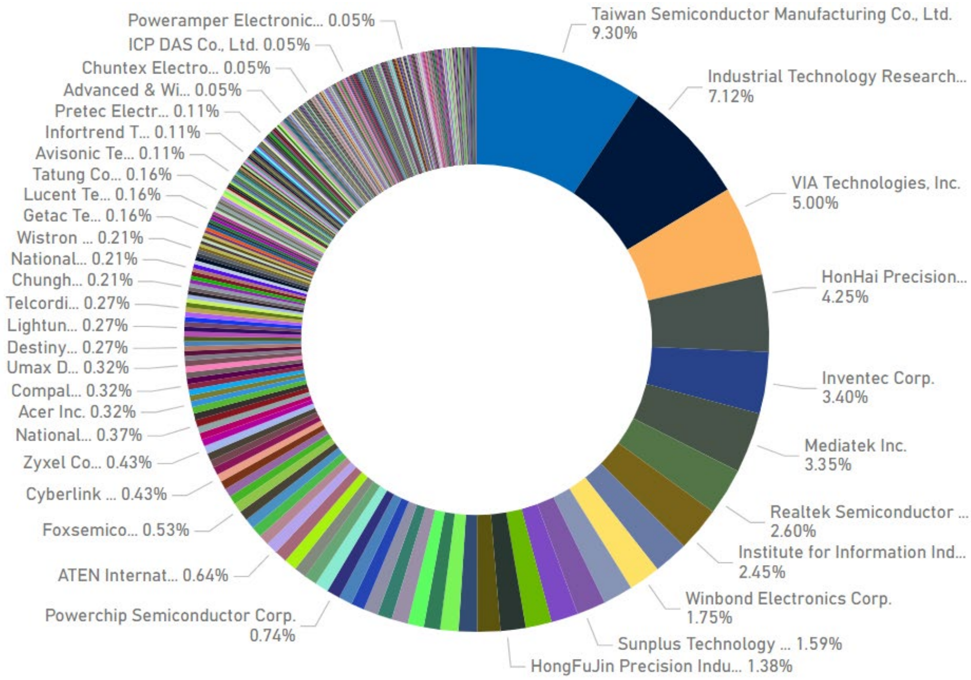
2001-2010



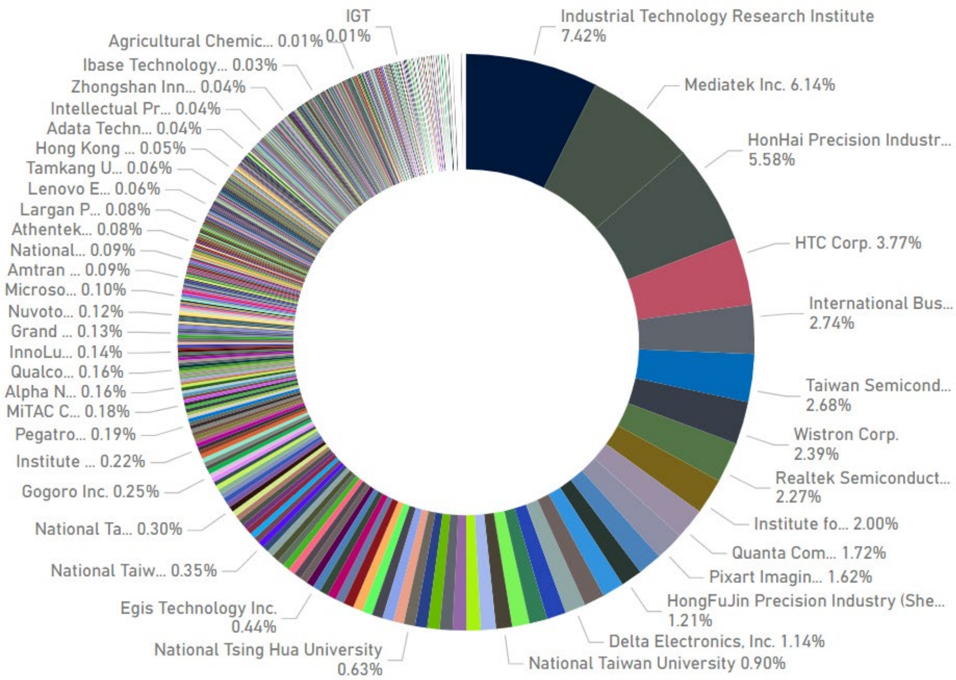
2011-2020

Figure 23 Changes in the ICT patent assignee percentage

(Source: author's own compilation)



2001-2010



2011-2020

Figure 24 Changes in the smart city patent assignee percentage

(Source: author's own compilation)

5.3.2 The analysis of changes in the patent assignee organisation

Since high-tech industries were established in Taiwan in the 1980s, hardware manufacturers have dominated traditional ICT industries. They are skilled at developing hardware technique but in the smart city industries, which combine both hardware and software, they must collaborate with software startups or become capable of producing software themselves. Either way leads to the same result: the ratio of firms owning software patents in smart city industries exceeding those in ICT industries. Thus, the compositions of entities owning ICT and smart city patents can differ.

5.3.2.1 The patents owned by ICT and smart city assignees

I first analysed what patents were owned by assignees of the two technology sets to reveal if there was a distinction between ICT and smart city industries. Over the 20-year period (2001-2020), assignees owning hardware-centric ICT patents accounted for 54.82%, nearly 10% higher than the software-centric assignees' proportion (45.18%) (see Table 30). The changes in the percentage of either hardware- or software-centric ICT patent assignees between 2001-2010 and 2011-2020 were insignificant, with less than a 4% rise or drop.

However, this composition contrasted with that of smart city patent assignees. Over the two-decade period, the smart city assignee proportion of hardware- to software-centric patents was 33.49% to 66.51%, a gap of over 30%. Although assignees owning software-centric smart city patents declined 10% from 76.01% in 2001-2010 to 66.51% in 2011-2020, which led to a corresponding rise in hardware-centric smart city patents, the total numbers of both categories increased. As explained in previous sections, smart city technologies are application- and service-driven, which accords with the result of the two times higher number of companies owning software-centric smart city patents compared to hardware-centric in the later decade. The above analysis of the compositions of industrial actors owning hardware-centric and software-centric patents provides an overview of innovation activities conducted by ICT and smart city firms and proves a radical difference between ICT and smart city industries.

Table 30 Assignee numbers of hardware- and software-centric ICT and smart city patents between 2001 and 2020

	Hardware or software-centric	**2001-2010**		**2011-2020**		**2001-2020**	
ICT	Hardware-centric	9,101	51.90%	34,469	55.65%	43,570	54.82%
	Software-centric	8,433	48.10%	27,472	44.35%	35,905	45.18%
	Total	17,534	100.00%	61,941	100.00%	79,475	100.00%
Smart city technology	Hardware-centric	451	23.99%	2,769	35.80%	3,220	33.49%
	Software-centric	1,429	76.01%	4,966	64.20%	6,395	66.51%
	Total	1,880	100.00%	7,735	100%	9,615	100.00%

(Source: author's own compilation)

5.3.2.2 The types of ICT and smart city assignees

The assignees of hardware-centric and software-centric patents for both technology sets can be further decomposed into three groups: 1) biggest companies[23], 2) research institutes[24], and 3) smaller companies[25]. For hardware- or software-centric ICT patents, the biggest companies were the most significant assignees. ICT patents owned by the biggest companies increased from 46.90% in 2011-2010 to 54.62% in 2011-2020, while the proportions of research institutes and smaller companies had corresponding drops (see Table 31). The group of research institutes, below 10% in both periods, had a mere 0.5 % decrease, while smaller companies declined from 44.71% to 37.49%.

[23] The group of biggest companies is Top 100 and plus global top 500, overseas only, companies (G500).
[24] The group of research institutes here includes universities.
[25] The assignees excluding those biggest firms, i.e. Top 100 and G500, and research institutes are counted as smaller companies in this research.

When singling out the hardware-centric ICT patents, the ratio owned by the biggest companies was even higher, rising from 52.25% to 60.85% between the two periods. However, smaller companies' patents dropped around 7%, to 31.23%, in the second period. As a result, from 2011 to 2020, the proportion of bigger companies was nearly double that of smaller companies (see Figure 25). The biggest companies have been the most dominant hardware-centric patent assignees in the ICT industries. In terms of the software-centric ICT patents' assignee proportion, between 2001 and 2010, smaller companies (51.84%) were around 10% higher than the biggest companies (41.14%). But the gap between the two groups in the following decade became less than 2%; the smaller companies accounted for 45.35%, and the biggest companies accounted for 46.81% (see Figure 25). The importance of the biggest companies to software-centric ICT patents also increased in the second period.

Table 31 ICT patent assignees

	Assignees	**2001-2010**		**2011-2020**	
Hardware-centric	Biggest companies	4,755	52.25%	20,975	60.85%
	Top 100 companies	4,734	52.02%	20,755	60.21%
	Global 500 foreign companies	21	0.23%	220	0.64%
	Research institutes	879	9.66%	2,729	7.92%
	Smaller companies	3,467	38.09%	10,765	31.23%
	Subtotal	9,101	100.00%	34,469	100.00%
Software-centric	Biggest companies	3,469	41.14%	12,860	46.81%
	Top 100 companies	3,424	40.60%	12,348	44.95%
	Global 500 foreign companies	45	0.53%	512	1.86%
	Research institutes	592	7.02%	2,153	7.84%
	Smaller companies	4,372	51.84%	12,459	45.35%
	Subtotal	8,433	100.00%	27,472	100.00%
All	Biggest companies	8,224	46.90%	33,835	54.62%
	Top 100 companies	8,158	46.53%	33,103	53.44%
	Global 500 foreign companies	66	0.38%	732	1.18%
	Research institutes	1,471	8.39%	4,882	7.88%
	Smaller companies	7,839	44.71%	23,224	37.49%

	Assignees	2001-2010		2011-2020	
	Total	17,534	100.00%	61,941	100.00%

(Source: author's own compilation)

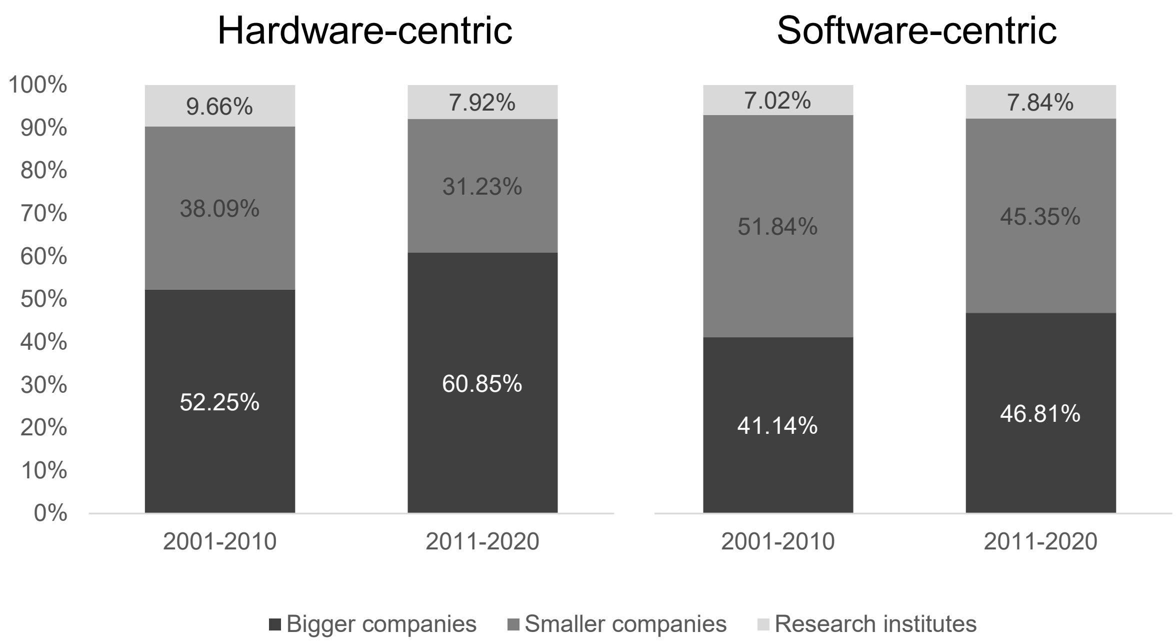


Figure 25 ICT patent assignees

(Source: author's own compilation)

In contrast to ICT, the numbers of the three smart city patent assignee groups were more balanced. Over the first ten-year period, the smart city patent assignee ratios of the biggest and smaller companies were around 41% and 45%, while research institutes contributed around 14% to the total (see Table 32). In the following decade, while the G500-owned patents increased slightly, the total proportion of patents owned by the biggest companies remained similar. Meanwhile, the proportion of research institute assignees rose to over 17%, and smaller company assignees slightly decreased to 41.53%. In other words, the proportions of the biggest companies and the smaller companies in the second period were nearly identical.

If we separate hardware- and software-centric patents, between 2001-2010 and 2011-2020, the research institute assignees' ratio declined for hardware-centric patents (from 24.83% to 19.75%) while climbing for software-centric patents (from 10.85% to 16.35%). We can see a shift in the focus of research institutes toward software technology in 2011-2020. In the first period, the proportion of hardware-centric patents owned by the biggest companies (34.59%) was lower than that of smaller companies (40.58%), which became the opposite in the following period (see Figure 26). Between 2011 and 2020, the biggest companies (43.34%) owned more hardware-centric smart city patents than the smaller companies (36.91%) did.

To some extent, this change demonstrates the biggest companies have regained their importance in hardware-centric patents for smart city technology. Regarding software-centric patents, the increase in research institute assignees in the second period was linked to an around 4% drop (from 43.11% to 39.55%) in the biggest companies and a 2% drop (from 46.05% to 44.10%) in smaller companies (see Figure 26). Still, the number of software-centric patents owned by the smaller companies was higher than that of bigger companies. These analysis results show that no single group of assignees grew to be more dominant for smart city patents.

Table 32 Smart city patent assignees

	Assignee	**2001-2010**		**2011-2020**	
Hardware-centric	Biggest companies	156	34.59%	1,200	43.34%
	Top 100 companies	151	33.48%	1,048	37.85%
	Global 500 foreign companies	5	1.11%	152	5.49%
	Research institutes	112	24.83%	547	19.75%
	Smaller companies	183	40.58%	1,022	36.91%
	Subtotal	451	100.00%	2,769	100.00%
Software-centric	Biggest companies	616	43.11%	1964	39.55%
	Top 100 companies	615	43.04%	1,800	36.25%
	Global 500 foreign companies	1	0.07%	164	3.30%
	Research institutes	155	10.85%	812	16.35%
	Smaller companies	658	46.05%	2,190	44.10%
	Subtotal	1,429	100.00%	4,966	100.00%
All	Biggest companies	772	41.06%	3,164	40.91%
	Top 100 companies	766	40.74%	2,848	36.82%
	Global 500 foreign companies	6	0.32%	316	4.09%
	Research institutes	267	14.20%	1,359	17.57%
	Smaller companies	841	44.73%	3,212	41.53%

	Assignee	2001-2010		2011-2020	
	Total	1,880	100.00%	7,735	100.00%

(Source: author's own compilation)

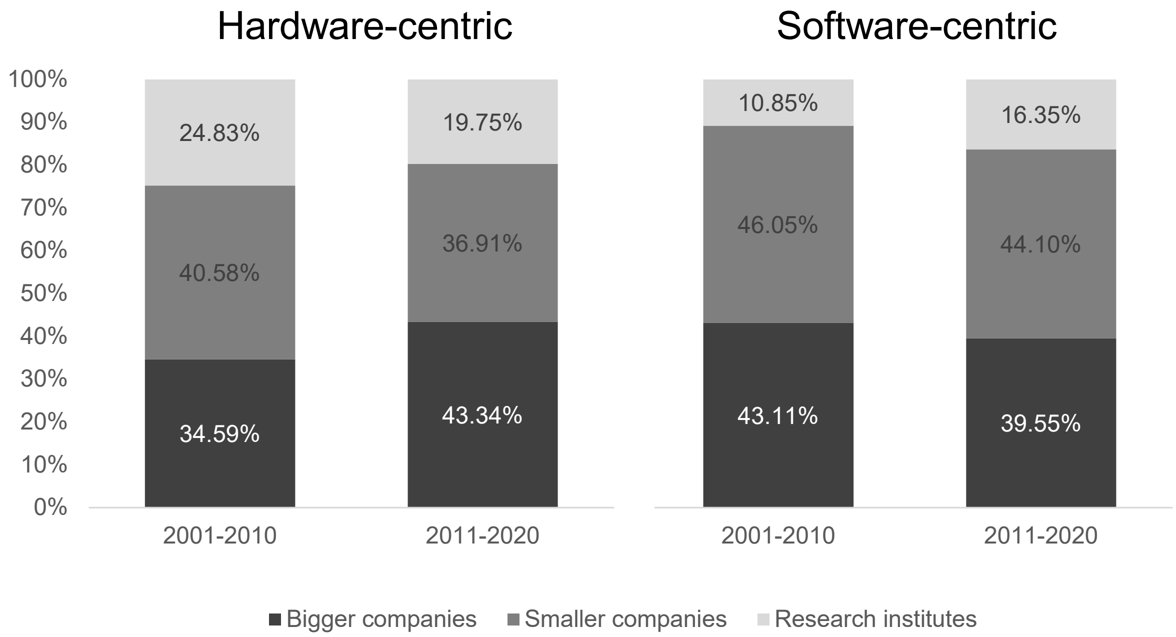


Figure 26 Smart city patent assignees

(Source: author's own compilation)

5.3.3 Summary: Increasing contributions from smaller companies and research institutes

The organisational differences in the compositions of ICT and smart city industries and their changes represent their distinct collaboration forms. In traditional Taiwanese ICT sectors, collaborations between industrial actors are centred around the biggest companies, especially ODMs and OEMs, such as TSMC, Mediatek, UMC, Wistron, etc. They are lead firms in local ICT industries, primarily producing electrical products of semiconductors, laptops or PCs. Each of these companies owned a significant portion of ICT, particularly hardware-centric, patents. Smaller companies involved in collaboration act as suppliers to these ODMs and OEMs (Yeung, 2022; Chen and Wen, 2013). Many of the biggest companies have corporation-based venture capital (VC) to encourage and facilitate startup growth because those startups play a supplementary role in their production network (Chen and Wen, 2013). The biggest-companies-dominated composition of ICT patent assignees can reflect this collaboration model. Moreover, the changes between the two periods show a consolidation of this model because of a strengthened significance of the biggest companies, e.g. TSMC.

However, in the smart city industries, the biggest companies did not have the same advantage as they enjoy in ICT, because hardware manufacturing has not been the focus of smart city technologies. Based on this section's analysis, the number of companies devoted to developing software-centric smart city patents was double that of hardware-centric ones. The biggest and smaller companies are more evenly engaged in the collaboration network of smart city industries. Meanwhile, research institutions play a non-negligible part in innovation in this collaboration network.

In terms of industrial actors, according to interviewees (IoT startup CEO, 2021; Construction consultant, 2021), key players in smart city industries include big hardware companies, telecommunication companies (telecoms), software companies, system integrators, and consultancies. Among them, system integrators play a critical role in interconnecting the technology sections of data collection, transmission, and accumulation use/application. Many smaller companies emerged to meet the strong demand for SI services (Construction consultant, 2021). Since they develop and provide software-centric services or products, these companies are mostly considered software companies.

Apart from smaller companies, research institutions in Taiwan, particularly quangos of the ITRI and the Institute for Information Industry (III), play a pivotal role in propelling innovation in frontier technologies. Research institutions have been responsible for pioneering technique innovation when the government promotes the development of new technologies applied to smart cities. Once research institutions develop a commercialisation-ready technique, the development team will be encouraged to be spun off into a separate startup (IoT startup CEO, 2021). The distinct differences in the collaboration network between the ICT and smart city industries demonstrate that smart city technology is a radical innovation to Taiwanese traditional ICT industries because the organisation of actors involved has experienced a structural change.

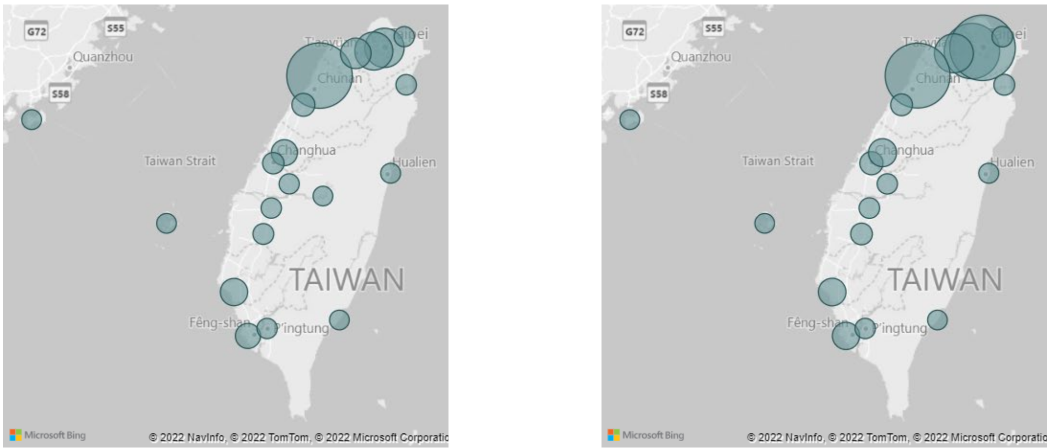
5.4 Locational Dimension

Locational proximity of industrial actors can reflect untraded interdependency in industries (Storper, 1997). The innovation activities for specialisation and diversification, i.e. traditional Taiwanese ICT production and smart city technology development, render different interdependencies embedded in regions. This section analyses ICT and smart city patent inventors' locations to reveal how they are located and clustered. When comparing the inventor locations between the two technology sets, we can find that the geographical centre of their production activities shifted from Hsinchu, where the semiconductor science park is, to Taipei metropolitan area, involving three cities with various high-tech firms and more comprehensive innovation capabilities (see Figure 27 and Figure 28). This distinction can be manifested in the different evolutional trajectories of hardware and software inventors' location cities between ICT and smart city technology.

As the industrial actors in the smart city industries are distinct from those in traditional ICT industries, there has been a radical difference in the sectors' location. The Taiwanese government established the first science park for electric product production in Hsinchu by 1980 (Lee and Yang, 2000). Since then, the Hsinchu has become the integrated circuit (IC) design cluster for traditional high-tech manufacturers, including semiconductor manufacturers, early established fabless companies, and their suppliers (see Figure 28) (Hardware company engineer, 2022). As a result, nearly 37% of conventional ICT patent inventors were based in Hsinchu between 2001 and 2020 (see Table 33). This number was higher than the next two cities combined, Taipei (15.63%) and New Taipei (14.70%) (see Table 33). Moreover, two-thirds of ICT patent inventors in Hsinchu developed hardware-centric techniques (see Table 34). In other words, most high-tech firms in Hsinchu are hardware producers.

Figure 27 Cities in Taiwan

(Source: author's own compilation)



ICT Smart city technology

Figure 28 Locations of patent inventors between 2001 and 2020[26]

(Source: author's own compilation)

[26] The bubble sizes represent proportions of inventor numbers in each city.

Table 33 Patent inventor numbers by cities

Cities	ICT		Smart city technology	
Yilan County	1,979	0.73%	182	0.69%
Keelung City	1,209	0.44%	143	0.54%
New Taipei	40,103	14.70%	5130	19.45%
Taipei	42,632	15.63%	6558	24.87%
Taoyuan	23,981	8.79%	2778	10.53%
Hsinchu	100,144	36.71%	6477	24.56%
Miaoli County	7,506	2.75%	326	1.24%
Taichung	14,171	5.20%	1212	4.60%
Nantou County	1,277	0.47%	105	0.40%
Changhua County	3,838	1.41%	511	1.94%
Chiayi	2,570	0.94%	300	1.14%
Yunlin County	1,610	0.59%	143	0.54%
Tainan	16,717	6.13%	1,148	4.35%
Kaohsiung	11,975	4.39%	1,100	4.17%
Pingtung County	1,502	0.55%	111	0.42%
Taitung County	166	0.06%	14	0.05%
Hualien County	460	0.17%	50	0.19%
Penghu County	215	0.08%	12	0.05%
Kinmen County	387	0.14%	24	0.09%
N/A	337	0.12%	47	0.18%
Total	272,779	100.00%	26,371	100.00%

(Source: author's own compilation)

However, in terms of smart city patents, Taipei had the highest number of inventors, rather than Hsinchu. 24.87% of smart city patent inventors are located in Taipei, slightly higher than Hsinchu's 24.56%, even though the prominent research institute – ITRI, one of the biggest assignees, is based in Hsinchu. The third place was New Taipei, accounting for 19.45% (see Table 33). We can tell from these analyses that inventors located in Taipei and New Taipei, nearly 45% in total, have formed a new cluster for smart city industries, contrasting with the traditional ICT cluster in Hsinchu (see Figure 28). As mentioned in the last section, the smart city industries comprise big hardware companies, telecoms, software companies, system integrators, and consultancies. The latter four groups of industrial actors were the professionals that the city of Hsinchu lacked. This nature of smart city innovation can be explained by the composition of smart city patent inventors. Between 2001 and 2020, over 60% of the smart city patent inventors worked at software-centric technologies (see Table 35). Besides, software-centric patent inventors accounted for about 55% and 64% of total inventors in Taipei and New Taipei.

Those software companies emerged to agglomerate around their primary clients, which are telecoms setting their headquarters in Taipei in the case of smart city industries. In Taiwan, telecoms are the core of smart city industries. This is because initially, the smart city scheme in the country was implemented by the government with telecoms to promote the application of 4G broadband (Thinktank associate director, 2021). The number of smart city patents held by telecom companies highlights the significance of smart cities as a key business focus for these firms. 0.2% of total smart city patents were owned by the two largest Taiwanese telecoms, Chunghwa and Far EasTone (see Table 28). While this figure was relatively small since telecoms were not keen on patent applications compared to high-tech companies, that was four times as many as they accounted for ICT patents (0.05%) (see Table 28). Meanwhile, many telecoms have SI subsidiaries also located in Taipei. As a result, telecoms and their close collaborators, i.e. system integrators and software companies, have gathered in Taipei and the nearby city of New Taipei, forming a smart city cluster.

Table 34 Inventor number of ICT by hardware- and software-centric patents

Cities	Hardware-centric		Software-centric		Total	
Yilan County	1,360	68.72%	619	31.28%	1,979	100.00%
Keelung City	654	54.09%	555	45.91%	1,209	100.00%
New Taipei	17,237	42.98%	22,866	57.02%	40,103	100.00%
Taipei	19,490	45.72%	23,142	54.28%	42,632	100.00%
Taoyuan	12,883	53.72%	11,098	46.28%	23,981	100.00%
Hsinchu	66,769	66.67%	33,375	33.33%	100,144	100.00%
Miaoli County	5,164	68.80%	2,342	31.20%	7,506	100.00%
Taichung	8,621	60.84%	5,550	39.16%	14,171	100.00%

Cities	Hardware-centric		Software-centric		Total	
Nantou County	876	68.60%	401	31.40%	1,277	100.00%
Changhua County	2,301	59.95%	1,537	40.05%	3,838	100.00%
Chiayi	1,645	64.01%	925	35.99%	2,570	100.00%
Yunlin County	986	61.24%	624	38.76%	1,610	100.00%
Tainan	11,747	70.27%	4,970	29.73%	16,717	100.00%
Kaohsiung	8,429	70.39%	3,546	29.61%	11,975	100.00%
Pingtung County	974	64.85%	528	35.15%	1,502	100.00%
Taitung County	119	71.69%	47	28.31%	166	100.00%
Hualien County	240	52.17%	220	47.83%	460	100.00%
Penghu County	153	71.16%	62	28.84%	215	100.00%
Kinmen County	155	40.05%	232	59.95%	387	100.00%
N/A	210	62.31%	127	37.69%	337	100.00%
Total	160,013	58.66%	112,766	41.34%	272,779	100.00%

(Source: author's own compilation)

Table 35 Inventor number of smart city technology by hardware- and software-centric patents

Cities	Hardware-centric		Software-centric		Total	
Yilan County	83	45.60%	99	54.40%	182	100.00%
Keelung City	55	38.46%	88	61.54%	143	100.00%
New Taipei	1,861	36.28%	3,269	63.72%	5,130	100.00%
Taipei	2,965	45.21%	3,593	54.79%	6,558	100.00%
Taoyuan	1,287	46.33%	1,491	53.67%	2,778	100.00%
Hsinchu	2,366	36.53%	4,111	63.47%	6,477	100.00%
Miaoli County	72	22.09%	254	77.91%	326	100.00%
Taichung	475	39.19%	737	60.81%	1,212	100.00%
Nantou County	51	48.57%	54	51.43%	105	100.00%

Cities	Hardware-centric		Software-centric		Total	
Changhua County	130	25.44%	381	74.56%	511	100.00%
Chiayi	97	32.33%	203	67.67%	300	100.00%
Yunlin County	51	35.66%	92	64.34%	143	100.00%
Tainan	281	24.48%	867	75.52%	1,148	100.00%
Kaohsiung	392	35.64%	708	64.36%	1,100	100.00%
Pingtung County	34	30.63%	77	69.37%	111	100.00%
Taitung County	4	28.57%	10	71.43%	14	100.00%
Hualien County	9	18.00%	41	82.00%	50	100.00%
Penghu County	7	58.33%	5	41.67%	12	100.00%
Kinmen County	19	79.17%	5	20.83%	24	100.00%
N/A	14	29.79%	33	70.21%	47	100.00%
Total	10,253	38.88%	16,118	61.12%	26,371	100.00%

(Source: author’s own compilation)

5.4.1 The analysis of changes in every city’s patent inventors

The two clusters of ICT and smart city industries have become more distinct from each other over the evolution. Hsinchu has consolidated its role as the biggest centre of ICT hardware inventors, while the Taipei metropolitan area has contained most of the smart city technology inventors and become their primary cluster as the two cities within this region (New Taipei and Taoyuan) gained comprehensive innovation capabilities. The cluster of ICT patent inventors has been consolidated in Hsinchu, which became more dominant in the second decade (2011-2020), while the proportion of Taipei decreased (see Figure 29 and Table 36), though the total inventor numbers of hardware- and software-centric patents rose in both cities. In Hsinchu, the number of inventors of hardware-centric patents outweighed that of software-centric patents, and the gap widened throughout 2011-2020 (see Figure 29).

However, when comparing the changes in the distributions of the smart city patent inventors, we can see they were gathering in Taipei, particularly significant in New Taipei and Taoyuan, from 2001-2010 to 2011-2020 (see Figure 30 and Table 37). This result shows that the Taipei metropolitan area has been the centre of the smart city industry cluster, and Taoyuan has also been involved in the cluster. Between 2001 and 2010, there were more inventors developing software-centric patents in three cities of the smart city industry cluster (see Figure 30). Then, in the following decade, the number of hardware-centric and software-centric patent inventors in Taipei and Taoyuan became roughly equal. New Taipei's software inventors of smart city patents still prevailed more than hardware inventors. This change in smart city inventor numbers between 2001-2010 and 2011-2020 shows that when the smart city industry was in its infancy, most inventors devoted resources to developing software-centric patents, while more hardware inventors emerged later. Although the ICT cluster in Hsinchu has also contributed greatly to the smart city industry, the core cluster of the smart city industry has been in the Taipei metropolitan area, which did not continue the traditional Taiwanese high-tech industry's path.

The above locational differences between ICT and smart city patent inventors are not because of the higher ratio of software- to hardware-centric patents for the smart city technology compared to that of ICT. The changes in the locations of hardware- and software-centric inventors were not parallel between ICT and smart city patents. ICT hardware inventors gathered more in Hsinchu (from 39.76% to 42.12%) in the second decade than in the first decade, while the proportions of their software inventors increased equally in New Taipei (from 17.66% to 20.88%) and Taoyuan (from 7.07% to 10.45) (see Table 36). It is worth noting a significant decrease in Taipei's proportion of total software ICT inventors between the two ten-year periods. However, inventors of hardware-centric smart city hardware patents became more concentrated in Taoyuan and New Taipei. The increases in the proportions for which they accounted were 7.38% and 5.24% (see Table 37). Like the ICT inventors, the clusters of software-centric smart city patent inventors grew around 3 to 4% in New Taipei and Taoyuan in the later decade, but the decline in the proportion of Taipei's software-centric inventors was minor.

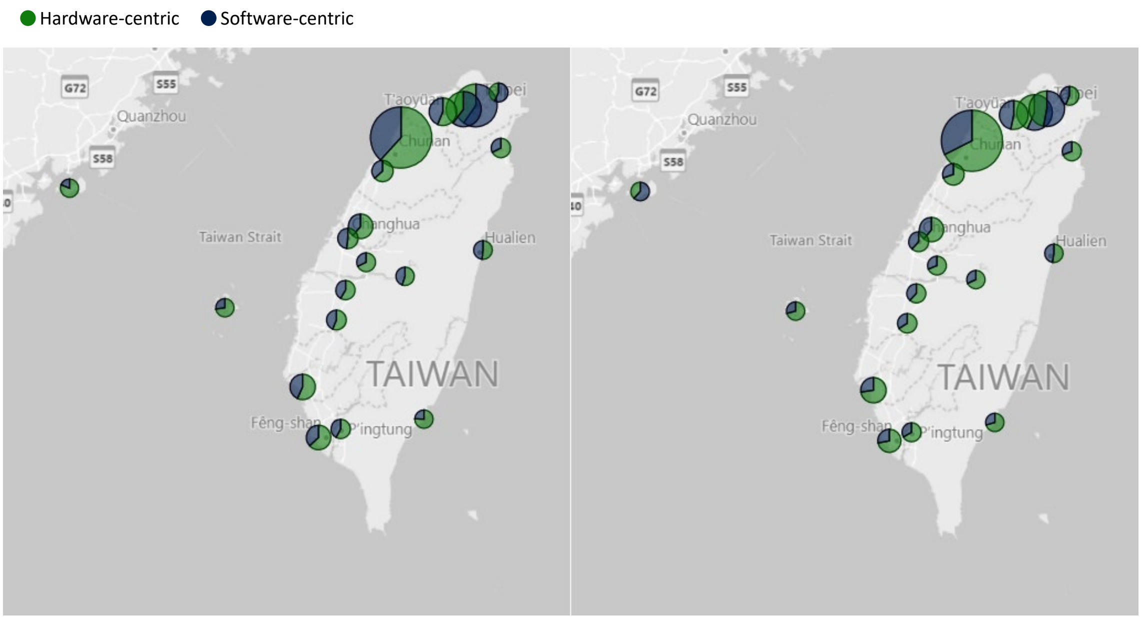


Figure 29 Locations of ICT patent inventors between 2001 and 2020

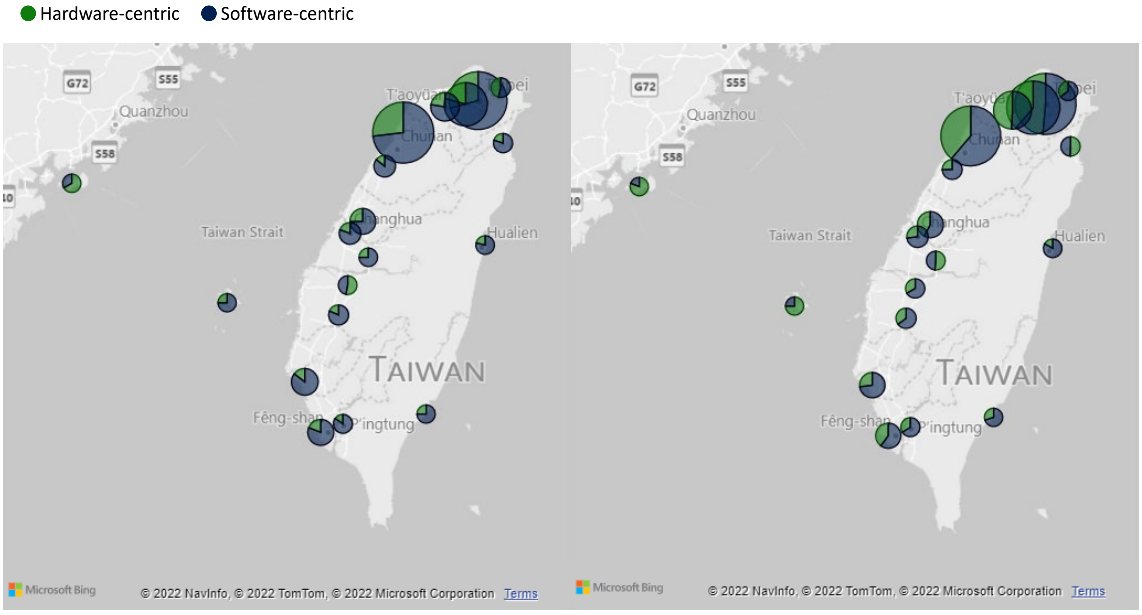
(Source: author's own compilation)

Table 36 ICT patent inventors by cities

Cities	Hardware-centric				Software-centric			
	2001-2010		2011-2020		2001-2010		2011-2020	
Yilan County	253	1.10%	1,107	0.81%	122	0.62%	497	0.54%
Keelung City	94	0.41%	560	0.41%	125	0.63%	430	0.46%
New Taipei	2,298	10.03%	14,939	10.91%	3,498	17.66%	19,368	20.88%
Taipei	3,383	14.76%	16,107	11.77%	5,009	25.28%	18,133	19.55%
Taoyuan	1,797	7.84%	11,086	8.10%	1,401	7.07%	9,697	10.45%
Hsinchu	9,112	39.76%	57,657	42.12%	5,642	28.48%	27,733	29.90%
Miaoli County	630	2.75%	4,534	3.31%	366	1.85%	1,976	2.13%
Taichung	1,319	5.76%	7,302	5.33%	842	4.25%	4,708	5.08%

Cities	Hardware-centric				Software-centric			
	2001-2010		2011-2020		2001-2010		2011-2020	
Nantou County	139	0.61%	737	0.54%	66	0.33%	335	0.36%
Changhua County	374	1.63%	1927	1.41%	345	1.74%	1,192	1.29%
Chiayi	211	0.92%	1293	0.94%	161	0.81%	615	0.66%
Yunlin County	181	0.79%	805	0.59%	129	0.65%	495	0.53%
Tainan	1,394	6.08%	10,353	7.56%	1,064	5.37%	3,906	4.21%
Kaohsiung	1,336	5.83%	7093	5.18%	779	3.93%	2,767	2.98%
Pingtung County	179	0.78%	795	0.58%	130	0.66%	398	0.43%
Taitung County	31	0.14%	88	0.06%	10	0.05%	37	0.04%
Hualien County	82	0.36%	158	0.12%	77	0.39%	143	0.15%
Penghu County	24	0.10%	129	0.09%	9	0.05%	53	0.06%
Kinmen County	13	0.06%	142	0.10%	3	0.02%	229	0.25%
N/A	68	0.30%	64	0.05%	35	0.18%	50	0.05%
Total	22,918	100.00%	136,876	100.00%	19,813	100.00%	92,762	100.00%

(Source: author’s own compilation)



2001-2020 2011-2020

Figure 30 Locations of smart city patent inventors between 2001 and 2020

(Source: author's own compilation)

Table 37 Smart city patent inventors by cities

Cities	Hardware-centric				Software-centric			
	2001-2010		2011-2020		2001-2010		2011-2020	
Yilan County	6	0.54%	77	0.84%	24	0.71%	75	0.59%
Keelung City	19	1.72%	36	0.39%	22	0.65%	66	0.52%
New Taipei	149	13.47%	1,712	18.72%	573	16.97%	2,696	21.16%
Taipei	333	30.11%	2,632	28.77%	808	23.93%	2,785	21.86%
Taoyuan	66	5.97%	1,221	13.35%	228	6.75%	1,263	9.91%
Hsinchu	332	30.02%	2,034	22.24%	901	26.68%	3,210	25.19%
Miaoli County	14	1.27%	58	0.63%	83	2.46%	171	1.34%
Taichung	55	4.97%	420	4.59%	162	4.80%	575	4.51%
Nantou County	3	0.27%	48	0.52%	9	0.27%	45	0.35%
Changhua County	19	1.72%	111	1.21%	80	2.37%	301	2.36%
Chiayi	10	0.90%	87	0.95%	44	1.30%	159	1.25%
Yunlin County	9	0.81%	42	0.46%	8	0.24%	84	0.66%

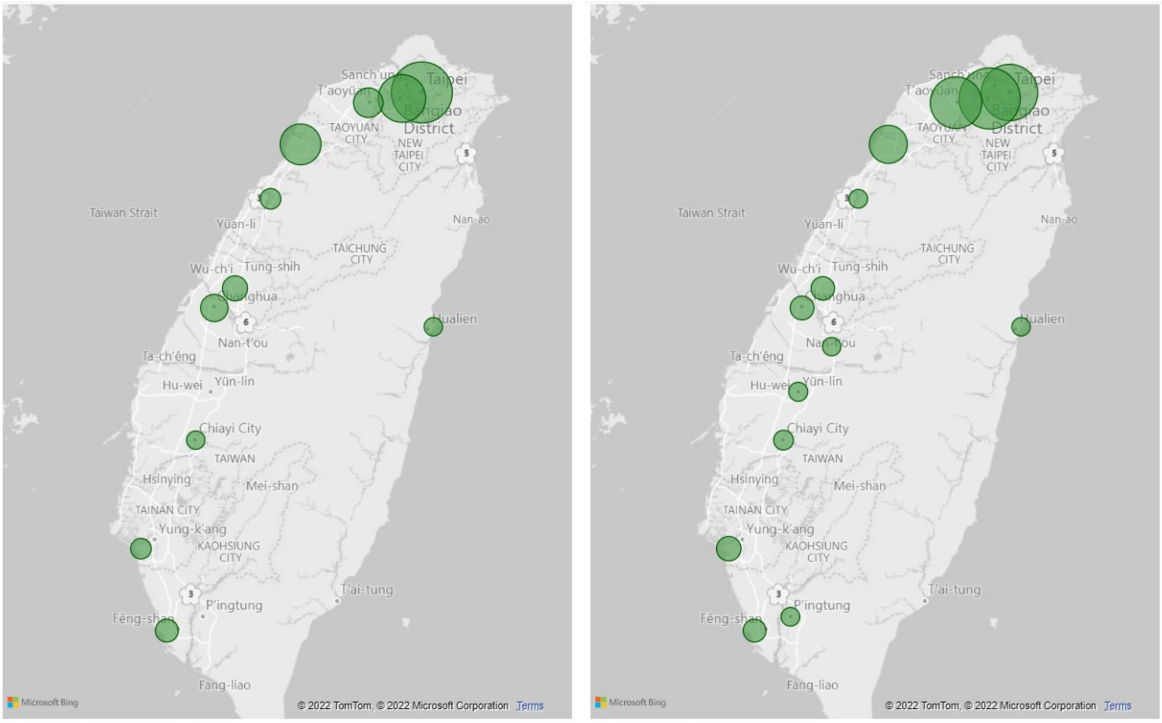
Cities	Hardware-centric				Software-centric			
	2001-2010		2011-2020		2001-2010		2011-2020	
Tainan	36	3.25%	245	2.68%	209	6.19%	658	5.16%
Kaohsiung	42	3.80%	350	3.83%	179	5.30%	529	4.15%
Pingtung County	3	0.27%	31	0.34%	17	0.50%	60	0.47%
Taitung County	1	0.09%	3	0.03%	3	0.09%	7	0.05%
Hualien County	3	0.27%	6	0.07%	11	0.33%	30	0.24%
Penghu County	1	0.09%	6	0.07%	3	0.09%	2	0.02%
Kinmen County	2	0.18%	17	0.19%	1	0.03%	4	0.03%
N/A	3	0.27%	11	0.12%	12	0.36%	21	0.16%
Total	1,106	100.00%	9,147	100.00%	3,377	100.00%	12,741	100.00%

(Source: author's own compilation)

The inventors for five non-ICT smart city patent classifications are further analysed to clarify how local interdependencies emerge or restructure for the new industry. Inventors of the four patent classifications relevant to the transportation domain gathered to similar places. Patent inventors for driving assistant techniques (G01C21 and G01C22) agglomerated in Taoyuan, New Taipei and Taipei in 2011-2020, though these inventors had not gathered to Taoyuan and New Taipei to form a cluster in the first decade (2001-2010) (see Figure 31). In terms of techniques used for a vehicle lighting system (B60Q1), in the first ten years, most patent inventors were located in Taipei and Taoyuan, but in the later decade, New Taipei became the centre of the cluster with the highest inventor number (see Figure 32). Lastly, the pathway of self-driving technology (G05D1) was slightly different. Its inventors were initially in Changhua because that city is where the Automotive Research & Testing Center was (see Figure 33). This government-funded research institute has developed techniques for self-driving cars since the industry was in its infancy. Then, after the industry started to bring self-driving technology to the market, the most inventors clustered in New Taipei in the period of 2011-2020.

Taipei has been the innovation hub of many ICT companies, especially for software technology or R&D, because there is no huge space for manufacturing in the capital city. Thus, Taipei can more easily cater to the software-centric smart city innovation than Hsinchu, Taiwan's biggest hardware manufacturing cluster. This locational shift reorienting interdependency in industries can be seen in the case of the driving assistant techniques cluster. Taipei has been substituted for Hsinchu as the cluster centre in the smart city industry. The inventors' locations for the three techniques above show New Taipei and Taoyuan also play an important role apart from the capital city, Taipei. Taoyuan's existing automobile manufacturing cluster, which was not one of the traditional ICT industries in Taiwan, started to take part in the smart city industry from 2011 onward.

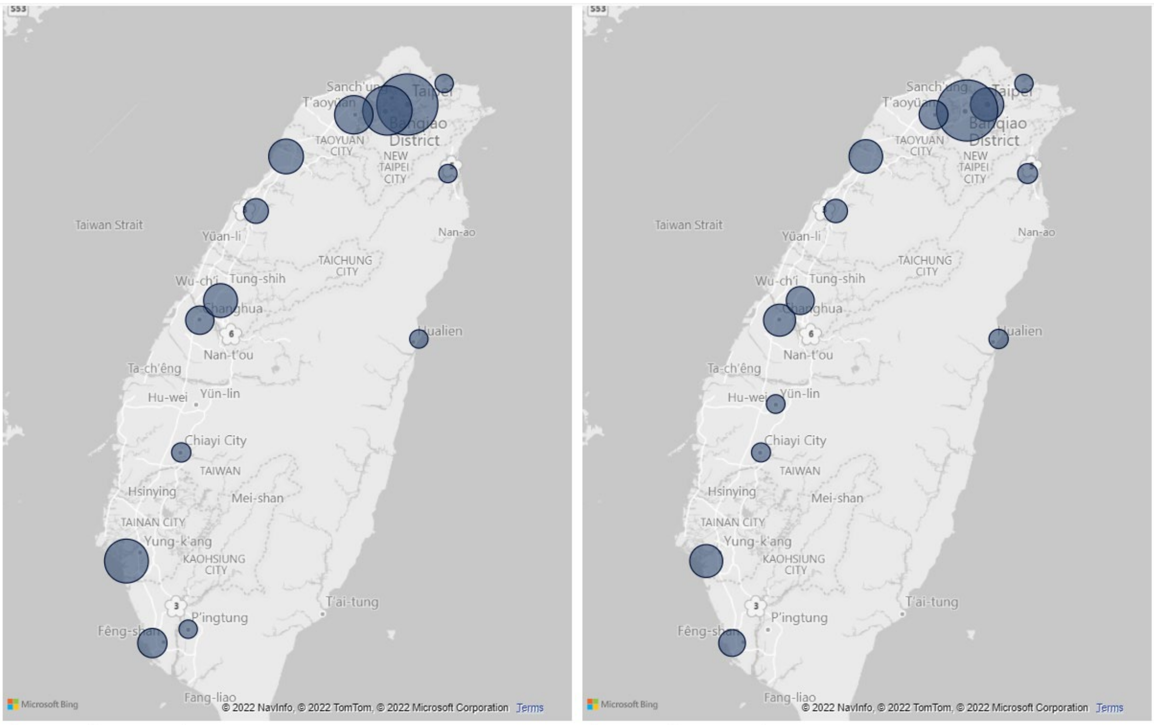
This sudden transformation shows a discontinuity in the development path and reflects a restructure in the interdependency in the industry. After the smart city innovation was brought to the city, the traditional automobile sector started developing new technologies to enter into the new industry. Meanwhile, New Taipei also gained more importance in the second decade, which was most noticeable for the self-driving technology (G05D1). The city has had an ICT cluster of electronics manufacturers, such as ODMs, ODMs and their suppliers producing consumer electronics like laptops or PCs. Contrary to Taoyuan, New Taipei represents the transformation of traditional ICT industries into a new phase that can be involved in the automobile industry.



2001-2010 2011-2020

Figure 31 Changes in inventors' locations of G01C21 (and G01C22)

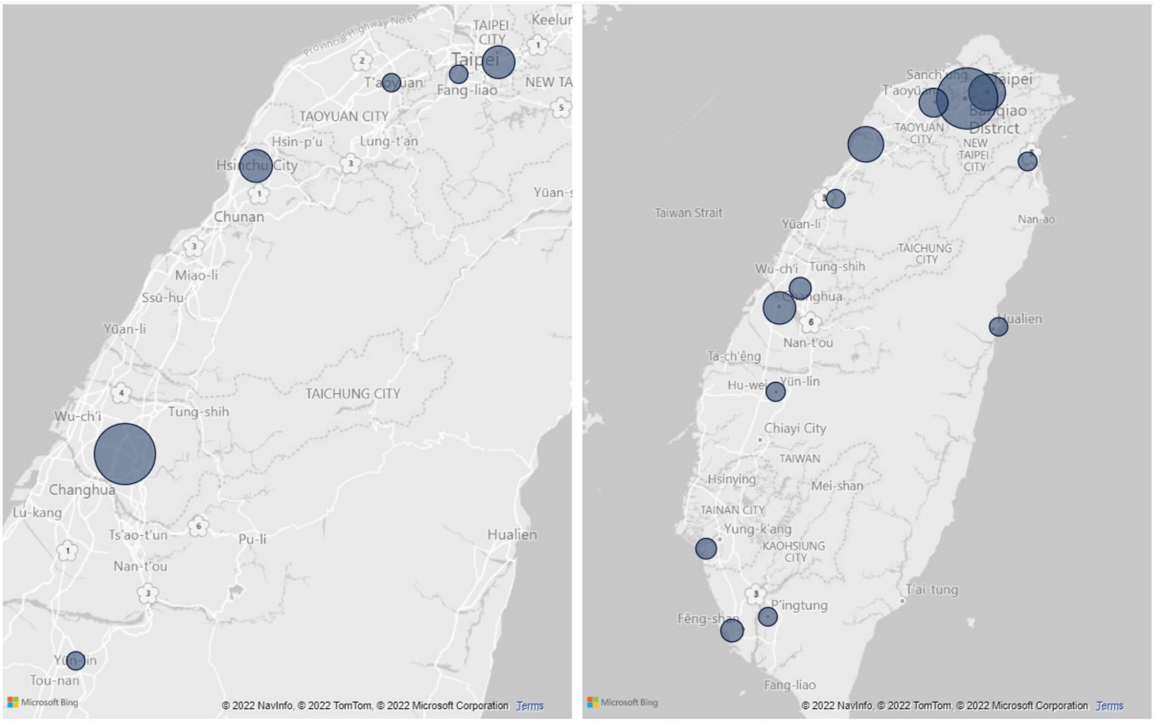
(Source: author's own compilation)



2001-2010 2011-2020

Figure 32 Changes in inventors' locations of B60Q1

(Source: author's own compilation)

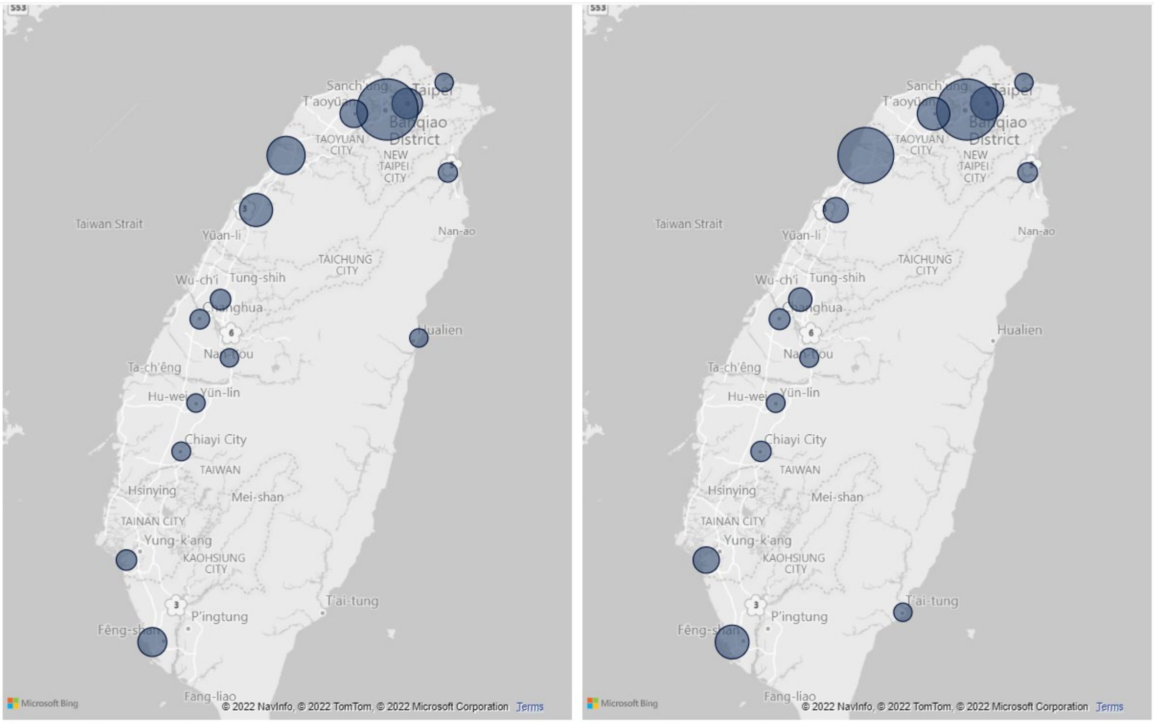


2001-2010 2011-2020

Figure 33 Changes in inventors' locations of G05D1

(Source: author's own compilation)

Innovation activities under the governance/surveillance domain show another development trajectory. Patent inventors of the technique set (F21V29) applied for smart lampposts were initially located in New Taipei, and the Hsinchu inventor cluster grew afterwards and co-existed with New Taipei (see Figure 34). As explained, New Taipei, the most significant cluster of smart lampposts between 2001 and 2020, has had large numbers of electronics manufacturers. In addition, this city is close to Taipei, where the key smart city industrial actors (i.e. telecoms) are located. Thus, this city can access the market in the early stages of the emergence of the smart city industry. Then, between 2011 and 2020, a cluster of smart lamppost innovation activities emerged in Hsinchu. This emergence is because the LED Lighting Industry is another significant sector in the traditional Hsinchu high-tech cluster, apart from semiconductors. Thus, those industrial actors were capable of developing smart lamppost technologies. Rather than being pioneers, innovation activities in Hsinchu followed the opportunities created by the radical innovation that earliest emerged in the Taipei metropolitan area to enter the smart city market. This smart lamppost case proves that smart city technology did not follow Taiwan's previous ICT development path, starting to gather in the most significant traditional cluster – Hsinchu.



2001-2010 2011-2020

Figure 34 Changes in inventors' locations of F21V29

(Source: author's own compilation)

5.4.2 Summary: Emergence of the new metropolitan cluster

It is evident that most industrial actors in the smart city industries are located in the Taipei metropolitan area (Taipei, New Taipei and Taoyuan). For those firms or relevant innovation activities, having large spaces for manufacturing is not their priority; rather, a close connection to the market or their collaborators is more important. Thus, they may prefer the Taipei metropolitan area, which aggregates various firms, to Hsinchu, which has lower land prices for factories and semiconductor lead firms. The three cities in the smart city industry cluster have different functions in the collaboration network. Taipei, where most telecoms and consultancies are located, acts as the software and R&D hub. Then, New Taipei's electronics manufacturers can produce the ICT components needed for smart city technologies. This city also developed software innovation capabilities over the two-decade period by virtue of the foundation of electronics companies' knowledge and experiences. Lastly, Taoyuan, accommodating most non-ICT manufacturers, plays a supplementary role in providing products used in smart city application domains. The development of the smart city industry has facilitated these three originally separate clusters to develop interdependencies. In an interview, a hardware company engineer (2022) mentioned that new fablesses, like Nvidia, developing application-based electronics are more likely to set up their offices in Taipei or New Taipei. The companies that did not originate from the traditional ICT industries' collaboration network, i.e. semiconductors, were not motivated to set up in Hsinchu.

The requirements of industrial activities for ICT and smart city innovation are different. Traditional Taiwanese ICT sectors are highly specialised, while smart city technology development needs diversified providers. This difference results in a radical change in the location of technology development and production.

5.5 Conclusion

Structural changes associated with smart city innovation in Taiwan's ICT sector are reflected in the emergence of new elements within its sectoral composition, supporting the hypothesis that there were triple transformations, and thus it was radical break from the path of incremental progress in Taiwan's ICT sectors. This is because smart city innovation in Taiwan has not emerged from mere improvements in the efficiency of ICT hardware manufacturing. The industrial actors involved in the smart city sector, along with their clustered innovation activities, demonstrate that these innovations do not follow the traditional path of Taiwanese ICT. The triple transformations of technology, organisation, and location are interwoven in high-tech sectors. Serial changes have been driven by the technological development and production activities involved in the smart city industries, which span multiple application domains and four technical sections. The application- and service-based technologies used for smart city development are more complex than general electronic products because they involve a broader range of fields. Smart city innovations go beyond hardware technologies and even ICT.

Technologically, the nature of smart city technology is characterised by diversification, which contrasts with the specialisation of traditional ICT products in Taiwan. Citation analysis reveals an increasingly diversified trend in the cited classifications of smart city patents, particularly for software-centric patents, which aim to develop new technology combinations, radically different from the hardware-centric technology development path. When developing software-centric smart city technologies, it is common to cite patents under non-ICT classifications. As a result, this emerging industry provides opportunities for new industrial actors, such as telecom companies, software firms, system integrators, and consultancies, to participate in the high-tech sector. On the other hand, local ICT sectors have been driven by radical innovation to evolve into a new phase that not only broadens technology applications but also enables local firms to address gaps in their technical capabilities, particularly in producing software technologies. These emerging actors and their activities have led to the growth and restructuring of new organizations for collaboration and geographic clusters, thereby creating a new development trajectory alongside the traditional Taiwanese ICT sectors.

The organisational aspect of smart city innovation presents a balanced collaboration network wherein the biggest and smaller companies evenly contribute, and which heavily relies on research institutes' innovation capability. As mentioned, smart city technologies are application- and service-based, so software techniques are critical to this technology set. Consequently, smaller companies and research institutes acted as pioneers of smart city innovation, complementing Taiwanese ICT lead firms' inefficient production of software technology development. In contrast, the ICT sectors have been dominated by big hardware companies, such as semiconductor, laptop and PC manufacturers.

Simultaneously, a territorial transformation in regional industries can be found in Taiwan, paralleling the emergence of smart city innovation. The new smart city industry has facilitated a restructuring of previously separated clusters in Taipei, New Taipei and Taoyuan. The interdependencies between these three cities, each of which functions differently, have been built for cross-field innovation. The smart city industry cluster in the Taipei metropolitan area contains Taipei as a software and R&D centre, a collection of electronics manufacturers and software startups in New Taipei, and a group of non-ICT manufacturers in Taoyuan. Due to the diversified needs for smart city innovation, Hsinchu's specialised ICT manufacturing cluster was incapable of fulfilling the requirements of this new industry.

In summary, the technological, organizational, and territorial differences between the ICT and smart city sectors demonstrate that these two industries are distinct from one another. Developing smart city technology in Taiwan did not stem from the traditional ICT industries aimed at improving production efficiency. Instead, it brought radical innovation and created a new path in the evolution of the industry, driven specifically by the emergence of new technological systems. This exogenous element-driven evolution began in the capital city, where key clients and multiple industrial actors played a crucial role in the early stages. As the foundation of the new industry was established, existing industrial actors in nearby cities mobilised relevant resources to join and contribute to the industry's growth. These transformations in regional industries reflect the formation of a new system for technology production in Taiwan.

Chapter 6: State Industrial Policy

6.1 Introduction

The shift in technical focus for developing smart city technologies marks a departure from the original evolution path of Taiwanese high-tech sectors, due to the transformations in sectoral composition discussed in the previous chapter. This chapter focuses on the unique role of the state in leveraging industrial policies to facilitate innovation and addresses the research question: Did the state play an important role in driving such structural change? By primarily analysing policy documents and supplementing them with interview data from individuals involved in government smart city projects, this chapter reveals the institutional context of the Taiwanese case in the evolution process.

Understanding the Effects of State Industrial Policies on Regional Evolution through an Upgraded EEG Theoretical Framework

The country's high-tech industry development history is unique because of its developmental state legacy, embedded in different level institutions that permeate industry activities. Those institutions involve a range of collaborative relations and networks, policy-making and -implementation mechanisms, and cross-sector consensus. Over the industry development process, the state of Taiwan played a vital role in the transformation of the high-tech industries into the smart city phase.

The Taiwanese institutional model supporting technology industry development has been moulded since the 1960s under the elite consensus to catch up with developed countries (Greene, 2008; Wade, 2018), during which the state had the power to control and utilise public and private resources for national economic goals. For example, the National Council for Long-Range Science Development (國家長期發展科學委員會), a ministry-level authority, was established in 1959, following the launch of the Long-Range Science Development Program (國家長期發展科學計畫綱領); by the late 1960s, this council started promoting science and technology development, becoming more determined in 1970s (Greene, 2008).

After the 1980s, the state was pressured to reconfigure its steering model (Chu, 2021), but it is still influential in determining the trajectory of industry evolution.

Specifically, the government transferred significant parts of the state's power over technology industry development to multiple levels of agencies (explained in Chapter 1) to match required resources is critical to developing the smart city sector. Those agencies maintain the government-business relations and networks that help consolidate the power structure, facilitating industry development.

Operationalisation of the Theoretical Framework

In the institutional context explained above, the smart city industry emerged with a division of labour between central and local governments of twenty-two administrative divisions (hereafter termed cities). Governments at both levels worked closely with quango agencies and businesses to realise the smart city industry development goal. Although the development of smart city technology is a radical innovation to local high-tech industries, the country's institutional endowments facilitate industry restructuring and enable existing sectors to evolve into a new phase. The Taiwanese case can help reveal certain structures of the industrial environment, which can enable a higher potential to seize a window of locational opportunity and help demonstrate the unique role played by the state in the evolution of industries. In this chapter, I will explore three aspects of the institutions: 1) high- and low-level governmental agencies' maintenance of government-business relations and networks, 2) developmental consensus between government and business, and 3) modes of intervention in the market, to explain how institutions can shape industry evolution.

The following sections explain what agencies across multiple levels have done to facilitate the industrial transformation. In the next section, I first give an overview of the 'Smart City Taiwan' policy's background and the influence of the developmental state legacy on this policy. Then, the third section analyses the state's policy-making and implementation structures and processes for the development of high-tech sectors. The fourth section reveals local governments' efforts to facilitate the development of smart city technologies either under or apart from the central government's smart city policy.

6.2 'Smart City Taiwan' under the Developmental State Legacy

Before unravelling the country's industrial development and evolution, we first need to understand the policy-making mechanism from the highest government level. The structural transformation of the high-tech industries to develop smart city technologies in Taiwan has unfolded in the context of the developmental state. The legacies of the developmental state continue to influence the state's behaviour in its economic and technology development policies (Wade, 2018). The Taiwanese government's mindset remains like a developmental state (explained in Chapter 3). Specifically, the central government still sets the nation's industry development directions and prioritises resources to facilitate the growth of specific sectors. For 'Smart City Taiwan' ('智慧城鄉'), the main policy to develop the smart city industry in Taiwan followed the developmental state perspective and measures. The primary objective of the 'Smart City Taiwan' policy is to upgrade the hardware production-centred Taiwanese information and communications technology (ICT) sectors to be capable of developing software technology.

Since the 1990s, the Taiwanese government has strived to enable local firms to develop domestic software and service-led technology products. The 'Five-year Scheme for the Development of Software Industry' ('軟體工業五年發展計畫') implemented by the Industrial Development Bureau (IDB) was considered to be the earliest and most comprehensive policy for this objective (今周刊, 2000). The goal of catching up with this technology frontier became a consensus among elites and thus has been followed by government agencies when making industry upgrade policies since then. As a result, this consensus has helped form an institutional effect guiding the direction of national technology development. However, until recent years, most Taiwanese companies' software products had not been competitive to achieve economies of scale (Think tank associate director, 2021).

But in the case of smart city technology development, the uniqueness, i.e. localisation needs and security issues of public data, drives the government to foster locally-developed technologies. In an interview, a senior telecom manager (2021) mentioned international software companies like Microsoft or Google could hardly customise their products to adapt to the local context and resolve data privacy concerns, which spurred the development of local solutions. This emerging demand in the domestic market echoes the goal of pre-existing software technology and is, therefore, relatively easy to mobilise public and private support.

Around the 2010s, the central government expected developing smart cities with domestic technology solutions was an excellent strategy to not only solve urban problems but advance high-tech industries. A series of policies, such as the ‘Smart Living Technology & Service Program’ [27] (‘智慧生活科技運用計畫’), ‘4G Smart Broadband City Application Scheme’ (4G Scheme) (‘4G 智慧寬頻應用城市補助計畫’) [28], ‘Digital Nation & Innovative Economic Development Program’ (DIGI+ Program) (‘數位國家•創新經濟發展方案’)[29], and ‘Smart City Taiwan’[30], have been implemented over the past two decades for this objective (Government official, 2021). Coincidentally, many local governments actively pursued smart city development during that period. This trend in smart city development aligns with the widespread global policy discourse across cities, nations, and continents. From an economic point of view, the emergence and prevalence of smart city discourse meant the market for the smart city industry was promising. The Board of Science and Technology (BOST) predicted that by the year 2025, the scale of the domestic market for the digital economy could reach 6.5 trillion NT$ (IDB, MOEA, 2018). However, developing the hardware-software combined smart city technologies is a new phase for Taiwanese high-tech sectors since Taiwanese firms have long relied on international big technology companies’ software solutions. Accordingly, the state has undertaken a series of strategies to transform the local ICT sectors, which have been hardware manufacturing dominated, and upgrade its capabilities to develop smart city technologies.

Against this background, the central government proposed the smart city industry development policy. Then, local governments were requested to engage in the policy implementation processes. The next two subsections explain the division of labour between the central government and local governments following the government-business consensus on industry development vision in making and implementing the ‘Smart City Taiwan’ policy.

6.3 Central Government’s Role

The central government was interested in the structural transformation of the nation’s high-tech industries. The Taiwanese state has been known for setting out the country’s industrial development blueprint (Wade, 1990). Regarding the smart city industry, the

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[27] The programme duration is between 2010 - 2013.
[28] The scheme duration is between 2015 - 2017.
[29] The programme duration is between 2017 -2025.
[30] The programme duration is between 2017- 2025.

two agencies of the central government in charge of policies for the high-tech sectors, i.e. 1) the BOST, under the highest executive branch – the Executive Yuan – and presided over directly by the Premier, and 2) the Ministry of Economic Affairs (MOEA), played big parts in proposing and implementing the promotion of smart city industry. Of the two, the BOST, as a high-level steering body, sets up the overall direction of policies related to technology development. The BOST was established in 2012 to succeed the 1980s-created Science and Technology Advisory Group (STAG)[31], which was responsible for scrutinising the new initiative proposals for national technology development. This reconfiguration continues the developmental state effects while enhancing the participatory networks by involving representatives from industries, academics and governmental agencies in decision-making processes. Based on the BOST's national technology development scheme, the Executive Yuan makes the related programmes, allocates the budget and assigns the MOEA or other ministry-level authorities to implement policies.

'Smart City Taiwan' policy has been implemented under this structure. The current policy can be seen as a continuation of the 4G Scheme (Government official, 2021) which was also implemented by the MOEA intending to complete the digital infrastructure of the whole country. The following 'Smart City Taiwan' pays increasing attention to applications, extending broader possibilities of technology uses. Both the current and previous smart city policies are under the MOEA's supervision, so their ultimate goals are relevant to industry development (Think tank associate director, 2021; Research institute associate director, 2021). The later policy was proposed in 2017, at the beginning of Dr Tsai Ing-Wen's presidency, under the three newly implemented national-level programmes, DIGI+ Program, 'Forward-looking Infrastructure Development Program' (FIID Program) ('前瞻基礎建設計畫') and 'Program for Promoting Six Core Strategic Industries' ('「五加二產業創新計畫」六大核心戰略產業') (IDB, MOEA, 2018). The Executive Yuan has directly supervised all three programmes. Among them, the FIID Program, proposed by the Executive Yuan in 2017, and the DIGI+ Program, proposed by the BOST in 2017, are most relevant to 'Smart City Taiwan'. These two Programs, serving as a guide, outline the objectives

[31] The STAG was the first high-level government agency set to help boost national R&D capacity. This agency was established before the power of the developmental state was weakened.

and strategies of the 'Smart City Taiwan' policy and specify the required budget amount and which authorities are in charge (IDB, MOEA, 2017).

Over the policy-making and -implementation processes of 'Smart City Taiwan', the *intervening in the market* strategy, inherited from the developmental state, constitutes the key component of this industrial policy. In the policy-making stage, the high-level steering group plays a critical role in building a consensus between the government and businesses for a future national industry blueprint. Then, in the policy-implementation stage, low-level quangos directly participate in innovation activities because their networks with industries help efficiently involve industrial actors in projects under the 'Smart City Taiwan' policy. The next two subsections present my analysis of what has been done by the central government for smart city industry development regarding the policy-making and -implementation processes.

6.3.1 Policy-making process

Under the aforementioned steering structure and the policy framework, the BOST further made more detailed and tailored policies for practices to transform local high-tech industries. Although smart city technologies applied in Taiwan can still partly incorporate those external solutions, the government requests domestic companies to lead such technology development projects and gradually produce in-house products. According to a senior telecom manager (2021), the central government has usually invited a few big local firms to be involved in flagship smart city projects to develop relevant technologies such as cloud services. Furthermore, the Taiwanese government plans to use the domestic market as a testbed to develop smart city technologies (Telecom director, 2021; Think tank associate director, 2021). Then, when any technology achieves minimum economy of scale, the market in Southeast Asian countries becomes their prior export target in accordance with the 'New Southbound Policy' ('新南向政策'). The government aims to enhance those products' economies of scale because both the government and high-tech firms are aware that the domestic market is too small to make enough profits (Telecom director, 2021; Construction consultant, 2021). This was also echoed by a government official in a 2021 interview:

> *Taiwan's ICT sectors have mostly relied on incomes from export, so if the domestic [clients] are their only market for [ICT] applications, the scale is too small. For*

example, the most prevalent smart city product in Taiwan is YouBike, owned by the Giant Group, … it takes over the maintenance jobs… But parts of their incomes are shared with the EasyCard Corporation, so the profit is not enough for the Giant Group. Thus, it sold the same system in Malaysia. (Government official, 2021)

Against giving priority to efficiency, this approach inherits the 'picking winners' tradition of the developmental state and makes extra efforts to mitigate risk for early-stage innovation activities. The innovation activities to develop smart city technology were nurtured in Taiwan in an institutional environment with elite consensus and government intervention. While the government makes industrial development policies partly based on the capabilities of local industries, the elites also have power to conceive an industry development goal that can catch up with the technology frontier. In other words, sometimes that means those new technologies are beyond a continuation of what local industries can produce. Setting the export orientation to be the long-term goal is also a mindset passed down from the developmental state. This Taiwanese case demonstrates that apart from local firms' technology capabilities, decisions and interventions made by the state are a powerful force in industry development, which should not be disregarded in EEG.

Consequently, BOST has proposed a policy approach to ushering high-tech industries into a smart city phase through the DIGI+ Program, which couples technology R&D with industries (Government official, 2021). It should be noted here that the BOST's decisions are not purely bureaucratic. As discussed by Evans (1995), in the South Korean context, there is always communication with the private sector, which is the same as the Taiwanese case. In the current structure of the BOST, such communication was formalised in the form of committees. Concerning smart city industries, there are several relevant committees and subcommittees, such as 'Digital Innovation & Governance Initiative' (DIGI+) committee ('數位國家創新經濟推動小組'), 'Technology and Talent' subcommittee ('科 技 及 人 才 分 組'), 'Infrastructure' subcommittee ('基礎建設分組'), 'Coordinated Implementation' subcommittee ('協調推動分組協調推動分組'), 'Digital Nation' subcommittee ('數位國家數位國家分組分組') and 'Digital Economy' subcommittee ('數位經數位經濟分組濟分組') where prominent members of the business community (e.g. Morris Chang, the founder of Taiwan Semiconductor Manufacturing Company (TSMC), Tzu-Hsien Tung, the chairman of

Pegatron, Eunice Chiu, the vice president of NVIDIA etc.), academics along with civil servants played a big part. Through discussions in committee meetings that involve voices from the public and private sectors, a consensus about the national industry development goal has been formed.

The DIGI+ committee, among all committees, is directly responsible for the DIGI+ Program. It has seven implementation pillars, one of which, 'Smart City and Regional Innovation,' is responsible for developing smart city technologies within high-tech sectors. While the state still has control, this decision-making mechanism allows for combining top-down and bottom-up perspectives (Wade, 2018). Key industry players' opinions are critical to the government's future policy on high-tech industries. Since the establishment of the BOST in 2002, there have been fifteen major strategy meetings that gather committee members to discuss overall technology industry development. The DIGI+ committee has had five meetings specifically for the DIGI+ Program. The BOST at the high governmental level plays a critical role in maintaining government-business relations, bridging the consensus gap between the two sides. Then, the BOST's blueprints based on the conclusions of these meetings serve as a guideline for related policy implementation ministries.

The blueprint for the DIGI+ Program outlines each implementation pillar's objectives, key strategies, budget amounts and relevant authorities (BOST, Executive Yuan, 2017). This Program was also used to guide the Executive Yuan in drawing up a national infrastructure upgrading policy – the FIID Program. In the FIID Program, the objective of developing smart cities is under the 'Digital Infrastructure' pillar. Accordingly, parts of implementation tasks in the DIGI+ Program have been included in the FIID Program (BOST, Executive Yuan, 2021). The relationship between these two Programs shows that the local infrastructure development plan strongly ties up with the national industry development goal. As a result, the 'Smart City Taiwan' policy has been guided by the DIGI+ Program and the FIID Program.

When the central government drafts policies relevant to the development of high-tech sectors, the two quangos, the Industrial Technology Research Institute (ITRI) and the Institute for Information Industry (III), play the role of a government think tank to further develop those blueprints into evidence-based policy frameworks with more details (Research institute associate director, 2021). ITRI focuses on knowledge of hardware technology, while III focuses on software technology (IoT Startup CEO, 2021). After the ITRI or the III conducts comprehensive surveys and helps the central government finalise policies with evidence, the Executive Yuan formally launches programs. These two low-level quangos have built networks with industries since their establishment in around 1980 and thus have access to first-hand information about Taiwanese high-tech sectors. Moreover, their networks can enlist the support of key players in relevant industries and later help mobilise their private collaborators to take part in policy implementation.

Both the DIGI+ Program and the FIID Program were launched in 2017. Finally, ministry-level authorities follow those policy frameworks to make plans and implement policies. In these two Programs, the implementation of the 'Smart City Taiwan' policy was assigned to the IDB, an agency of the MOEA, by the BOST and the Executive Yuan. Therefore, we should understand the development of high-tech industries in Taiwan under this policy implementation structure. And to transform the high-tech sectors into the smart-city phase, or broadly the IoT phase, is an outcome of the state's deliberate and formal decision.

6.3.2 Policy-implementation process

In addition to policy-making, the BOST also has significant leverage in policy implementation, i.e. budget allocation and negotiation between different government sectors. While the BOST does not have direct power to decide what could be used and who should implement policies, the Executive Yuan is in the decision-making role in terms of budget allocation and task assignment. The Legislative Yuan scrutinises the Executive Yuan's budget bills and gives recommendations. Then, when the Legislative Yuan's review process is done, the Executive Yuan enacts policies based on the proposal and makes them published.

After the BOST and the Executive Yuan finalised the DIGI+ Program, the DIGI+ committee took over the coordination works to negotiate with related authorities (BOST, Executive Yuan, 2017). Three vice chairs of this committee held posts of ministers without portfolios. Those related authorities could be at either the central or local level. Accordingly, the DIGI+ committee has established a cross-agency negotiation platform involving local governments to discuss local needs, test sites and usable resources (IDB, MOEA, 2018). Under this collaboration structure, the cross-departmental smart city policy can be delivered by different governmental authorities at multiple levels. Local governments' engagement is compulsory. The state intervenes in the market by requesting local governments to be smart city companies' initial clients, regardless of local administrative priorities. As a result, under this collaboration structure, the cross-departmental smart city policy can be implemented by different governmental authorities at multiple levels.

However, this implementation structure has a significant weakness. Although the DIGI+ committee is at a high governmental level and authorised by the Executive Yuan to coordinate policy implementation, this authority can neither use nor allocate budgets for most implementation plans. As a result, the coordination is sometimes inefficient. The outcome is determined by whether the collaborating authorities think implementation has political rewards or benefits. More than one interviewee (ICT consultant, 2021; Telecom director, 2021; Think tank associate director, 2021) suggested some city governments are more enthusiastic about being involved in the 'Smart City Taiwan' policy or have clearer objectives than others.

So far as I can tell, among the six special municipalities, probably Taipei and Taoyuan, then Tainan and Kaohsiung have relatively specific focuses of what technologies to develop. (Think tank associate director, 2021)

In other words, without the state's help, smart city innovation may have fewer market opportunities. It is still crucial to have this high-level authority to coordinate cross-domain policy implementation, like developing smart city industries. Interviewees who are consultants for smart city policies mentioned local governments are incapable of initiating and managing the cross-departmental collaborations of smart city projects because of the limitation of their authorities (ICT consultant, 2021; Policy consultant, 2021).

Many people think the development of smart cities is local governments' duty, but I disagree with that. Without the central government's support and help, many cross-domain systems cannot possibly be integrated. (ICT consultant, 2021)

The implementation of a smart city project usually involves the jurisdiction of different authorities (ICT consultant, 2021). For example, when a project concerns data from different agencies, only the National Development Council or similar level agencies, like the National Science and Technology Council (NSTC), have the authority to coordinate (Policy consultant, 2021). The National Development Council built the T-Road platform ('T-Road 跨機關資料傳輸服務') in 2020 to connect cross-departmental data in a secured environment. The NSTC[32] created a Civil IoT Taiwan platform in 2019 to integrate environmental data governed by seven different ministries. These two platforms gathering city data are fundamental to smart city development.

In addition, the consensus, achieved through BOST committee meetings to develop smart city industries, has been formalised as industry policies that the DIGI+ committee has overseen. These approaches form an institutional environment relatively friendly to the innovation in smart city technologies. Following the blueprint set by the BOST, at the bottom level of the central government, the IDB under the MOEA is directly responsible for the implementation of the plan of the 'Smart City Taiwan' policy. There have been two phases of this policy: the first was between 2018 and 2020, and the second was between 2021 and 2022. The function of IDB is not to conceive new concepts. Rather, it follows the plan. Thus, IDB needs to set practical and measurable objectives, i.e. key performance indicators (KPI), find suitable collaborators to deliver plans and monitor deliveries to ensure effective outcomes.

There are three main components of this policy. First, IDB uses part of the smart city budget for service procurement, outsourcing implementation work to the III to run a project management office to deliver related plans, i.e. selecting and subsidising smart city companies. Second, IDB also consults experts from ITRI for adjusting plans or their support to make decisions over the process of plan deliveries. Then, the third approach was implemented before the DIGI+ Program and the FIID Program while continuing after their launches to help meet these two Programs' objectives.

IDB has budgeted annually for the smart city exhibition since 2014. The Taipei Computer Association has helped IDB hold this exhibition over the past eight years through service procurement. The exhibition invites relevant high-tech companies to show their smart city products and gives awards to innovative technology applications. Low-level quangos are heavily involved in the policy implementation processes. On the one hand, their network with industries can help IDB easily find industrial participants. On the other hand, these networks, to some extent, could impede innovation. That is because with an aim to ensure the government can gain results to demonstrate the policy's success, the quangos tend to involve industrial collaborators

[32] This agency was previously named the Ministry of Science and Technology (MOST) until August 2022.

who have close ties with them or can provide safe solutions rather than the most innovative proposals with some uncertainties.

Under this division model, a governmental agency, like IDB, has commonly been criticised for overreliance on collaborators because the divisions are sometimes unclear. Under the service procurement contract, government agencies are buyers, so they tend to ask their collaborators to share some work they should do by themselves (Construction consultant, 2021). It is common to see private collaborators being asked to write the project plan and even procurement advertisements with implicit assurance that the collaborator will win the project (Construction consultant, 2021). This collaboration model, to some extent, has become a culture among most agencies. Such informal arrangements within a formal procedure might look like corruption, and sometimes is. In the majority of cases, however, the civil servants in charge of such a process are motivated by career advancement and therefore tend to use the informal arrangement to get things done and report to their superiors as their achievements, rather than pursue immediate pecuniary gains such as bribes.

Additionally, In most cases, those civil servants that have responsibilities in diverse policy areas do not have time to develop expertise in each project, so they cannot write up a project plan and project advertisement. With the lack of expertise and time within the government, making the collaborators do the work is an “efficient” way for the government to get things done. Over the process, civil servants only function to follow procedures to complete the paperwork and check the KPIs of plans. Consequently, the outcome of implementation plans could be the collaborators’ interpretation rather than the original intention of policies. This way of collaboration becomes an informal institution that ensures policies can be implemented, but could meantime cause a discrepancy between goal and result. For example, smart city solutions developed under such circumstances might be practical and reasonable, but not innovative.

The main objective of the ‘Smart City Taiwan’ policy is to support Taiwanese high-tech firms in developing smart city technologies based on the advantage of hardware manufacturing capability. A research institute associate director (2021) said that is because hardware manufacturing for ICT products is the strength of the Taiwanese high-tech sectors and accounts for an outstanding share of Taiwanese industries (explained in Chapter 1). A European Union (EU) report shows that in 2018, the ICT sector’s value-added number accounted for 16.7% of Taiwan’s total GDP, which surpasses all EU countries and major global economies (Mas *et al.*, 2021). Accordingly, the policy targets companies in this specific sector, hoping to help them expand the markets they can reach (Think tank associate director, 2021). The intention is twofold. On the one hand, the BOST recognises smart city development can bring enormous business opportunities to these companies because ICT hardware is fundamental to smart city technology. On the other hand, the MOEA plans to use the chance of developing smart city technology to upgrade hardware manufacturers' capability (Think tank associate director, 2021). The government thinks developing smart city technologies requires hardware-software combinations and thus can drive them to develop software technologies.

This policy is not the first time the IDB attempted to incentivise these firms to build domestic software products, but previous policies did not work well. A digital consultant (2021) said that industrial policies for high-tech sectors have long been fettered by the IDB's 'hardware' mindset. Software, or what we understand as technology applications, developed by domestic companies has always been less attractive to customers than those by big international companies. Microsoft and IBM have actively approached the Taiwanese government to sell their digital governance solutions, while under the 'Smart City Taiwan' policy's guide, local firms, such as ASUS, Acer and Lite-On, have begun to produce hardware-software integrated smart city products (Think tank associate director, 2021). Developing domestic software solutions has been regarded as a common mission between government and business, and thus largely supported by industrial actors, which can be seen as the effect of the soft institution. Apart from technology development, the policy is tended to encourage big companies to lead the project while collaborating with small companies to enhance small companies' capabilities (Think tank analyst, 2021).

Concerning policy implementation, IDB has a budget approved by the Executive Yuan, allocated to the MOEA to fund high-tech firms' R&D activities in developing technology products. The funded projects can be in the proof of concept (POC) or proof of business (POB) stage of product development. POC stage projects are mainly for advanced technologies, such as driverless vehicles (Think tank associate director, 2021). Funding is critical to high-tech firms during POC and the POB phases because of the high investment costs in new products. The government shares part of the innovation risks by funding POC and POB products. In terms of implementation, the III running the project management office helps execute the following work: 1) opening calls for proposals for smart city technology development project, 2) discussing with interested teams to form feasible proposals, 3) selecting competitive teams to fund, 4) monitoring project delivery and 5) presenting delivery outcomes. The intermediary role played by the low-level quango, III, is the key element to realise the industry development blueprint proposed by the high-level steering body.

In ‘Smart City Taiwan,’ there are two types of projects: locally driven bottom-up and centrally determined top-down innovation. Both need to work with local governments, but the difference is who is in the position to decide the project theme. Before high-tech firms submit proposals, they must achieve consensus on projects and sign official agreements with local governments, which is distinct from previous policies (Government official, 2021). A think tank analyst (2021) mentioned in the interview the ITRI helped the IDB identify a range of techniques that have the potential to become leading technology (e.g. AI, blockchain, edge computing, low-rank adaptation (LoRa), narrowband Internet of Things (NB-IoT), low-power wide-area network (LPWAN) etc.) as targets for top-down innovation. Later in this policy implementation process, the quango (i.e. ITRI) follows the high-level industry development consensus while further specifying what innovative techniques to develop. Institutions at both high and low levels connecting the government and industries heavily influence smart city innovations in Taiwan.

Then, the selected technology development project can receive subsidies up to 40% of the total cost, while the maximum for startups is 50% (IDB, MOEA, 2021). And the fund can only be used for R&D because the main policy objective is to facilitate the development of new technologies (Think tank associate director, 2021). During the selection process, the III needs to find external experts to form a jury to assess submitted proposals and decide which to fund. Those experts in a jury are usually selected from the III’s network. In other words, the network that the quango has can determine what kinds of innovation will be supported by public resources. Based on the DIGI+ programme (BOST, Executive Yuan, 2017), an ideal team to be funded is comprised of a big firm leading small startups to conduct a development project. According to a think tank analyst (2021), the IDB still prefers funding projects with big companies to those with only startups because the authority believes big companies are more capable of completing projects successfully and exporting their solutions.

6.4 Local Governments' Role

In the DIGI+ Program, local city governments in Taiwan are recognised as having a critical role in applying smart city technologies. Under the 'Smart City Taiwan' policy's implementation structure, local governments are required to collaborate closely with Taiwanese high-tech firms to develop smart city technologies. This model clearly shows the developmental state legacy still significantly affects industry development through an updated market intervention strategy. The state secured the initial clients, namely local city governments, of smart city companies. Apart from this policy, a few local governments have made extra efforts to utilise local resources or bid for special budgets from the central government for their smart city development, taking a proactive role in realising smart city development. In other words, they were actual clients for those smart city technologies if a free market. This section will explain these two approaches of local governments in realising the development of smart city technologies.

6.4.1 Under the guideline of the 'Smart City Taiwan' policy

Based on the public-private partnership (PPP) concept, local governments have been set as high-tech firms' initial clients in the BOST's high-level blueprint since 2018 (Think tank analyst, 2021). The intention is to develop smart city technologies with the local market, then sell them to the global market. The BOST considers developing technologies with local governments as an excellent opportunity for Taiwanese firms to experiment with new products (BOST, Executive Yuan, 2017). This strategy still adopts the developmental state's approach to intervening in the market, i.e. securing buyers for companies innovating smart city technologies with the state's institutional and financial back. Through the negotiation platform coordinated by the BOST committee, local governments need to decide projects used as the basis for open calls for proposals (IDB, MOEA, 2018). The selected projects proposed by Taiwanese firms can be funded for up to 40% or 50% of the total technology development costs. Apart from the financial support, this approach can resolve firms' common uncertainties: who to sell and how to improve prototypes. A digital consultant (2021) shared in the interview that most firms plan to sell smart city products to other cities after developing a minimum viable product and making improvements in the initial project funded by this policy.

This government fund investing in R&D activities of smart city technologies can help mitigate the risk of innovation. Additionally, collaboration between local governments and firms that were attributed to the state's intervention paved the way for further adoption of smart city technologies. For local governments budgeting for smart city projects can cause extra costs but is not necessarily rewarded. Therefore, the projects funded by the 'Smart City Taiwan' policy were equivalent to free trials offered to the local governments. This policy can help increase the willingness to take on new smart city solutions. The funding scales for products in the R&D phase and for those in the commercialisation phase differ significantly. Since 2021, the second phase of the 'Smart City Taiwan' policy has focused on the latter (Think tank analyst, 2021). In terms of project scales, the IDB set four levels of project budget scale: under NT$ 30 million, NT$ 30-60 million, NT$ 60-100 million and above NT$ 100 million (think tank analyst, 2021). In each project, 7% of the total budget should be used to enhance data security. After being involved in the 'Smart City Taiwan', some firms' products could become more ready for commercialisation. Then, local governments may further use their annual budgets for the infrastructure or service procurements to buy these products and enable smart city development. An IoT startup CEO (2021) said profits from procurements are usually higher than the funding that the 'Smart City Taiwan' policy can provide. Thus, the actual target of most firms is the later business opportunities directly offered by the local governments (IoT startup CEO, 2021). After the state's funding ends, firms earning local procurement of smart city technology supplies are those surviving from selections in the market.

However, maintenance and service play a critical role in smart city technologies, which means the purchases of these specific technologies are not one-off (Software startup CEO, 2021). In order to accommodate new forms of smart city technologies, some central agencies and local governments began to amend or discuss how to amend the procurement rules because the original rules were designed for hardware procurement (Think tank analyst, 2021). Consequently, more public procurements assess bidding proposals based on the 'Regulations for Evaluation of the Most Advantageous Tender' ('最有利標評選辦法'), which offer more room to realise innovative technologies (Telecom director, 2021). And in 2018, the 'Regulations for Priority Procurement of Innovation Products or Services by the Ministry of Economic Affairs' ('經濟部創新產品或服務優先採購辦法') was launched to make innovation a formal criterion in specific procurements. This institutional change shows how government rules can evolve with innovation activities and then encourage more technological innovation.

So far, there have been several rounds of open calls for smart city technology development proposals in each phase of the ‘Smart City Taiwan’ policy. A think tank analyst (2021) explained that the first round focused on the local market and the second listed an international sale plan as one of the criteria. In this case, local Taiwanese firms innovating smart city technology did not compete with international companies in a free market. Rather they developed new technologies and grew in a protected environment that blocked foreign competitors out, provided funds for their innovation activities and offered initial business opportunities. The ultimate goal of the MOEA is to enable Taiwanese high-tech firms to sell their smart city solutions to overseas markets in accordance with the export orientation strategy of a developmental state. The IDB is also responsible for helping Taiwanese firms explore overseas markets. Accordingly, one of IDB’s tasks is to hold or support Taiwanese firms to participate in exhibitions and business matching events in other countries (IDB, MOEA, 2020).

Under the goal mentioned above, local governments are assigned by BOST to propose urban problems they want to tackle. The purpose is to couple technology development with local needs, which previous policies failed to achieve, as mentioned by a government official (2021). However, the attitudes of local governments greatly influence the quality and outcome of projects, and every city’s requirements and environment for smart city technology development are different. In fact, before the IDB implemented the ‘Smart City Taiwan’ policy, a few cities such as Tainan and Taipei had already started promoting smart city development. These city governments have more explicit ideas about what they want to achieve and have higher expectations (Telecom director, 2021). Active local governments mainly drive what technologies are developed in the country. Those cities which were less enthusiastic about smart city development also followed the policy to work with industrial actors to innovate in technological solutions that they had seldom done before. For example, Hsinchu (City) won the award granted by the TCA-held smart city exhibition in 2021 for the first time with its disaster management technology that was developed with the funding of the ‘Smart City Taiwan’ policy. The case in Yilan was similar. The first time this city being awarded at the exhibition was in 2018 for its smart healthcare system, which was developed by a smart city firm, Netown Corporation, for four 'Smart City Taiwan' policy-funded projects in Keelung, Taitung and Hualien. To some extent, this duplication of one solution in multiple cities shows that some cities tend to adopt ready-made solutions rather than innovate for tailored solutions for most needed solved local problems.

Furthermore, some local governments could provide extra funds to support selected firms' technology development because they want better achievements (ICT consultant, 2021). Those results could help convince citizens that governments, i.e. city mayors and their teams, have done good jobs (Government official, 2021; ICT consultant, 2021). The purposes behind it are political, namely, to win the next elections. Six cities, Taipei, New Taipei, Taoyuan, Taichung, Tainan and Kaohsiung, have higher public budgets because they are Special Municipalities. Consequently, these cities have made more investments in smart city projects. When the DIGI+ committee requests they propose local needs of smart city development, those cities less interested in smart city development or with fewer resources may duplicate some ideas previously realised in other cities before (Digital consultant, 2021). The state's strategy to ease the innovation risk can help increase the survival rate of local firms pioneering smart city technology development. Then, the needs proposed by the active local governments later shape the technology innovation trajectory.

Generally, civil servants of local governments tend to follow a routine, so delivering local plans like smart city development requiring breakthrough or cross-departmental work cannot be a priority unless that becomes their obligation (Construction consultant, 2021). With the state's intervention, the institutional environment became less restrictive for smart city technology innovation. Local governments must designate a few sites in cities for technology experiments because the development of these technologies requires using public spaces for testing (IDB, MOEA, 2018). Local governments' legal support can help simplify the negotiation processes that high-tech firms previously spent much time and effort on. For example, the Taipei government allowed a bus lane in the central city to test autonomous buses at night, when most citizens do not use them, for about a year. This type of project can hardly be delivered without the local government's strong support. The 'Smart City Taiwan' policy's implementation structure set by the DIGI+ committee effectively facilitates smart city development in most cities. As a result, every city has smart city projects, whether or not local governments are enthusiastic about smart city development.

6.4.2 Other local-led smart city technology development schemes

Only four Special Municipalities, which are Taipei, Taoyuan, Tainan and Kaohsiung, (out of six Special Municipalities) among all cities in Taiwan have allocated additional budgets for smart city development. From the bottom up, these local governments collaborate with local firms to proactively determine what technology solutions they aim to develop for smart cities. First, the capital city makes the extra effort to develop to become a smart city. Apart from the ‘Smart City Taiwan’ policy, the Taipei city government established the Taipei Smart City Project Management Office for its smart city development. Three other Special Municipalities, Taoyuan, Tainan and Kaohsiung, obtained special budgets from the Executive Yuan to build technology test sites. Taipei and Kaohsiung have clearer goals for their smart city development: ‘Open Government’ and ‘Net Zero Emissions’ (Chang, Jou and Chung, 2021; National Development Council, 2023). In addition, Taoyuan, Tainan and Kaohsiung identify specific technologies, the artificial intelligence of things (AIoT), green technology and 5G, on which they aim to build smart cities.

In Taipei, the Taipei Smart City Project Management Office is responsible for inviting high-tech firms to propose smart city ideas, helping negotiate with relevant authorities and managing approved projects (Industry association consultant, 2021). The cases of Taoyuan, Tainan and Kaohsiung are similar to each other. Their plans for smart city development are made together with national-level schemes, which means these cities can have more financial support. For example, the ‘Smart City Technology Application Pilot Project’ in Taoyuan is one of the main plans in the ‘Asia Silicon Valley Development Agency’ scheme. The Taiwan CAR Lab in Tainan for the development of autonomous vehicles is a part of the ‘Shalun Smart Green Energy Science City’ scheme. Lastly, in Kaohsiung, the ‘Asia New Bay Area 5G AIoT Innovation Hub’ scheme aims to establish a cluster for high-tech firms or startups to create 5G-based technologies, while one of its main objectives is to develop 5G technologies used for smart city development. Although some might argue mayors in the same political party as the ruling party have a higher chance of gaining these special budgets, these three local governments and the capital city are, in general, more active in smart city development. In contrast, other cities were passively involved in the projects under the 'Smart City Taiwan' policy. This difference in local governments' attitudes leads to an asymmetric power relation among local governments and smart city companies, i.e. some are more influential than others, which can shape the trajectory of technology development.

The national-level scheme is guided by the central government following the developmental state approach, which means export orientation. The sites in Taoyuan, Tainan and Kaohsiung are used to experiment with different technologies for smart city development, i.e. green technologies, driverless vehicles, smart lampposts and 5G applications. The site in Tainan was designated to develop green technologies, especially driverless vehicles. One of its main objectives is to build a laboratory and site for testing components of driverless vehicles and their verification and validation (Taiwan Car Labs, 2021), with the ultimate goal to commercialise these components and qualify them for international industrial standard for overseas markets.

Despite the endeavours above, the central and local governments still conceive the development of these test sites with the mindset they used to construct a science park, which is the typical model the developmental state. Namely, a large portion of the budget is used to build the sites and subsidise the operations of the related companies within them. It has been criticised that the governments do not allocate a sufficient budget that can directly benefit R&D activities of these firms (Construction consultant, 2021). Evidently, the developmental state legacy does not always help create favourable conditions for innovation.

Another problem is that local governments usually do not have clear plans or roadmaps for technology development (ICT consultant, 2021), even though the goals of which technique to develop are clear. The president of an ICT hardware company (2021) mentioned high-tech companies spend much time figuring out what specific technologies the locals need and even sorting out how to establish a technology development standard. These issues show the soft and hard institutions embedded in the government can sometimes hinder smart city development. Some of the long-lasting models and regulations used to take hold of high-tech sectors are not very useful to smart city industries.

6.5 Conclusion

The state plays a significant role in enabling local industries to develop new technologies beyond their existing capabilities by fostering new innovation activities. This is achieved through market intervention and the established synergy between various public and private sectors, driving Taiwan's industrial evolution. This case supports the hypothesis that policy mechanisms and government-business relations within a developmental state have fostered innovation and contributed to improvements in the ICT industry.

Findings: State-Mediated Multi-Level and Cross-Sector Industrial Policy Mechanisms Enabling Radical Innovation While Limiting More Diverse Innovation Possibilities

The important role played by the local government in smart city industry policies clearly shows the legacy of the Taiwanese developmental state. In this case, we can see that both soft and hard aspects of the institution of this legacy have endured over the evolution processes. First, the central government has been consistently prominent since the ROC government's arrival in Taiwan and throughout the heyday of the Taiwanese developmental state. Although the background forming the developmental state has changed, the central government still believes planning for the high-tech industry's future is the state's responsibility. The BOST has, accordingly, been established directly under the highest-level governmental agency, the Executive Yuan, to make blueprints for promoting high-tech sectors. Through committee meetings, the BOST, as a high-level steering group, helps form a consensus about future industry development between the government and business.

In this governance structure, relevant government agencies are tasked with adhering to established blueprints and budget allocations. Since Taiwan's high-tech sectors have traditionally been hardware-focused, the BOST recognised that developing smart city technologies could serve as a natural extension of their existing capabilities, positioning it as a goal for industry upgrading. Based on this, the BOST launched the DIGI+ Program, from which the 'Smart City Taiwan' policy originated. Meanwhile, the FIID Program for upgrading national infrastructure also includes smart city development as a key pillar. This coordination between industrial and infrastructure development policies demonstrates how the state leverages local infrastructure development plans to support national industry goals. The evolution of Taiwan's industries has not been contingent but has instead been significantly influenced by the state. Developing smart city industries in Taiwan was a deliberate decision made by the BOST. In other words, the direction of innovation has been shaped in such a way that it limits the diverse possibilities for entrepreneurs' self-exploration, discouraging them from pursuing unknown but potentially high pecuniary gains. In this context, new, unknown, and less competitive markets—while sometimes offering equally good profits—may not be the primary driver for firms to decide whether to engage in radical innovation or determine the type of innovation they pursue.

Since the 'Smart City Taiwan' policy was launched by the BOST and the Executive Yuan, the state has intervened in the development of relevant industries through the following three approaches. First, the DIGI+ committee is in charge of coordinating agencies at multiple government levels to facilitate smart city development. Establishing this coordination platform prepares a favourable institutional environment for smart city technology innovation. Then, the two low-level quangos' (i.e. the ITRI and the III) are involved in the processes of shaping and implementing policy. Lastly, the IDB, MOEA, supported by the two quangos, works closely with firms to realise smart city projects. The ITRI and III's networks with industries significantly contribute to the success of delivering those projects because they help mobilise industrial actors to participate in the implementation of the 'Smart City Taiwan' policy.

More importantly, under this policy implementation structure, the local governments were designated as the clients, showing the Listian infant industry projection prevalent under the developmental states is still at work. Not every city government is active in developing a smart city, and the weights of smart city technology innovation is not distributed equally across local governments. Those active local governments play a crucial role in determining what technology solutions can be created. Still, under the central government's instructions, they are all requested to become clients of the firms producing smart city technologies. Under the DIGI+ Program, local governments must be involved in the development of the smart city industries. Without this intervention in the market made by the state, the actual clients of smart city companies would be fewer. The uniqueness of smart city development, i.e. a valid reason to improve city efficiency, allows the central government to utilise its power and public resources for related industry development.

Accordingly, the state can support the development of these new sectors with funds and market opportunities. While some challenges still remain when high-tech firms attempt to innovate to enter this market, to some extent, they have benefited from the ‘Smart City Taiwan’ policy that helps reduce entry barriers and risks.

Chapter 7: The Role of Key Industrial Actors in Structural Change

7.1 Introduction

In Taiwan, the smart city industry, developed with the state's support, has driven the high-tech industries to develop new systems and evolve. This evolution process involves significant changes in not only industrial actors' actions but also the structure of relevant sectors. This empirical chapter focuses on the final research question: did individual actors' choices and actions cause a structural change of Taiwan's ICT sectors? This question examines the role of these actors in altering the local sectoral composition, leading to the development of new technological systems for smart city innovation. Specifically, this research analyses the actions taken by industrial actors throughout the evolutionary process, using interview data from key participants in the industry, including individuals from smart city firms and government agencies, to understand industrial evolution.

Understanding Evolution Processes with an Upgraded EEG Theoretical Framework

EEG theory pays attention to the process of change because evolution is a course. In the relevant literature, despite various approaches, such as complexity thinking (Martin and Sunley, 2007), knowledge production (Lambooy, 2002) and relational perspective (Bathelt and Glückler, 2003), to explaining this process, we can find a common contention: the evolutionary course is a recursively interactive process between actors and the structure. Actors are explained as elements operating in systems within or among regions, such as firms, research institutions, and government agencies. The structure as institutions and social relations are embedded in spatial entities (Bathelt and Glückler, 2003; Martin and Sunley, 2007). This research focuses on firms as they are considered in EEG as the key drivers to innovate in terms of technology development (Bathelt and Glückler, 2003; Frenken, Van Oort and Verburg, 2007; Martin and Sunley, 2010; Stam, 2010; Kogler, 2015). These actors and the structure interact with each other, and this mechanism is fundamental to regional evolution (Lambooy, 2002).

Founded on EEG, this research further complements the above actor-structure framework with the structuration conceptions. The fundamental concept of the structuration theory is the duality of structure, which explains that the social systems' structural properties are 'both medium and outcome' of actors' practices that are recursively produced by the systems (Giddens, 1984). This contention clarifies the interrelationships between the structure and actors. In this chapter, I use the actor-focused analysis approach proposed by Giddens (1984) for the following two reasons. Firstly, a firm and its actions are critical to innovation and thus are among the key components that EEG argues can determine evolutionary trajectories. Secondly, industrial actors in Taiwan have adopted a series of strategies to transform the high-tech industries into the smart city phase. As explained in Chapter 3 (Section 3.3.3), the analysis focusing on changes in actors should also consider the related institutional changes.

Operationalisation of the Theoretical Framework

In terms of analytical operationalisation, the actions involved in the process of industrial evolution can be revealed through the four elements suggested by structuration theory. The first element is the episodes of change and the conjunction of events that lead to these changes. The second element is the reflexive monitoring of actors' conduct and their motivations. Next, I examined the systems' structural principles and properties, specifically institutionalised features, which industrial actors' actions are based on and which also reflect changes brought about by those actions. Lastly, based on the concept of regionalisation and time-space edges, I identified the systems and intersocietal systems of smart city industries in Taiwan.

In the case of Taiwan, with a view to pursuing the new phase of the high-tech industry, key industrial actors and the industrial structure have transformed in tandem in three ways: 1) changing the produced technology, 2) changing the collaboration network, and 3) changing the clustered region. The technological, organisational and locational aspects of changes, three elements in the holy trinity (Storper, 1997), can be representative of industrial evolution because they are fundamental elements forming the high-tech industry in Taiwan. Through the actions relevant firms took, the high-tech sectors in Taiwan have been reshaped into a new form, integrating more diverse technologies and firms than in the past.

In Chapter 5, I analyse the changes in the variety of technologies produced by these firms, the composition of the networks with which they collaborate, and the proximity of their locations. This chapter, on the other hand, focuses on analysing the processes behind these transformations. The following section for technological production focuses on the way industrial actors develop and produce technologies. Then, the subsequent collaboration network and cluster sections explain how they build connections and work with business partners and how companies relocate or establish new offices.

7.2 Technological Innovation

Technological innovation for smart cities has transformed the structures of Taiwanese high-tech industries. The changes in the structural properties and principles of the traditional ICT industry can reflect the evolution in the Taiwanese high-tech sectors caused by smart city innovation. While some of those actions for technological innovations done by hardware manufacturers only followed reflexive monitoring of industrial actors' conduct, parts of the ICT sectors' structural properties and even the principles have been challenged by the emergence of smart city innovations due to the need for system integration and data application in service- and application-based smart city technologies.

On the one hand, apparent shifts in the industrial actor at the leading role, the target client, and the driving force present opposite institutionalised features to the original structural properties of the Taiwanese ICT industry. The development of some technologies incorporated ICT elements into services or infrastructures used in cities, such as the bicycle-sharing system, smart lampposts, the driverless car platform, and the smart parking system. On the other hand, the innovation of new technologies, like smart electronic vehicles, transforms non-technology products into technology products. This type of technological innovation can break the structural principle based on the dominating role of hardware manufacturers in the ICT industry. The above transformations in structures have driven the industry to evolve into a radical new phase.

In order to produce technologies for smart city development, Taiwanese high-tech companies have innovated in different ways with the outcome of varying degrees of transformation. In contrast to traditional high-tech manufacturing in Taiwan, the application- and service-based smart city technologies are combinations of hardware and software for various applications (explained in Chapter 1). As mentioned in the literature review chapter, smart city technologies involve five application domains[33] and are composed of four technical sections[34]. According to an interview with the CEO of an IT company (2021), prior to 2018, that was the early phase of smart city technology development. During that time, the cloud and the Internet of Things (IoT) were the dominant concepts that drove the technological innovation of local high-tech companies (IT company CEO, 2021). These innovations focused more on hardware-centric technologies, such as devices and networks. Then, after 2018, data analysis techniques, e.g. artificial intelligence (AI), became commercially viable, which facilitated smart city technology development to leap into the later phase that synthesised the hardware and software technologies (IT company CEO, 2021). The technical sections of the platform and the tool, which are software-centric, have become the focus of technology development.

Against this background, the industrial evolution in Taiwan has not followed a smooth path. Making progress in the innovation of software-centric technologies has long been daunting for the Taiwanese high-tech industries. Therefore, in order to develop hardware-software combined smart city technologies, the relevant sectors have experienced a series of episodic changes in the companies' strategies for technology development. The origin of the episode in industrial evolution, moving from traditional information and communication technology (ICT) to smart city industries, was the new market opportunities created by the successful promotion of IBM's *Smarter Planet* initiative (Palmisano, 2008).

7.2.1 Structures of the traditional ICT industry

Aiming to develop the application- and service-based smart city technology, the system of the traditional ICT industry in Taiwan started to transform with the

[33] The five domains are transportation, energy, environment, governance/surveillance and city service.

[34] The four technology sections are devices or sensors for data collection, networks for data transmission, platforms for data collection, and tool for data analysis and application.

intersocietal systems in which the industrial system has been involved. Those intersocietal systems are connected to non-tech industries.

Conventionally, the Taiwanese ICT industry has been founded on a structural principle in which technology development and production primarily focus on hardware. Consequently, the industry is dominated by hardware manufacturers, namely original equipment manufacturers (OEMs) and original design manufacturers (ODMs). As a result, its structure exhibits five institutionalised features that shape the practices of industrial actors:

- Leadership in R&D: Big tech companies take the lead in research and development for new products, collaborating mainly with other hardware manufacturers.
- Client-Driven Technology: The technologies developed are primarily based on the needs of clients—often major overseas tech companies such as Microsoft and Dell.
- Market-Driven Product Development: Since the end customers are individuals and the technologies are mainly used in consumer electronics, product development is driven by market demand.
- Government Support: The central government supports tech firms' R&D activities through public funding.
- Role of Quangos: Government-funded organisations, such as the Industrial Technology Research Institute (ITRI) and the Institute for Information Industry (III), play a key role in facilitating industry innovation.

7.2.2 Structural transformations into smart city industries

Innovation in smart city technologies requires a combination of hardware and software techniques to collect, transmit, accumulate and use data. This need has initiated the evolution process of industrial actors to become comprehensive producers. The actions involved in the process for their transformations lead to different levels of changes in the industrial structures.

The structural transformations involved in this evolution episode can be categorised into 1) following reflexive monitoring, 2) changing structural properties, and 3) changing structural principles. They vary in intensity and the extent of changes. The highest level of transformation occurs when changes in structural principles are involved because that leads to a transition between societal types. By contrast, the lowest level of transformation is the category of following reflexive monitoring, which does not transform the structure of industries. In this subsection, I reveal the actions taken by the companies in the smart city industries to develop new technologies and explain how their actions can change the structures of industries at the three transformation levels.

7.2.2.1 Reflexive monitoring

Naturally, the development of smart city technologies in Taiwan has been seen as an extension of the strength of the Taiwanese ICT sector. In this case, existing industrial actors follow their previous practices (routines) based on reflexive monitoring of conduct. These actions are drawn on existing industrial structures, following the abovementioned structural principles and properties.

This group of tech firms began developing new hardware, such as electric devices or sensors installed in urban areas for signalling or detection. In other words, in the beginning, most traditional high-tech firms approached the smart city market by adapting their existing products to new uses for cities with minor changes. Firms that produce relevant components or facilities were some of the earliest participants in developing smart city technologies. For example, LEDs and IP cameras were used for smart lampposts (Senior telecom manager, 2021), and sensors and communication networks were used for river management (IoT startup CEO, 2021).

Following IBM's (Palmisano, 2008) promotion of the smart city concept (which is the origin of the evolution episode), many companies were eager to grab the new market opportunity. Meanwhile, the declining margins of electronic products motivated hardware manufacturers to expand their business, reaching the smart city market (IT company sales agent, 2021). However, the hardware used in cities must be installed over a wide range of space and be resilient to outdoor climates (IoT startup CEO, 2021), which is distinct from the existing electrical equipment used by individuals or factories. An IoT startup's CEO (2021) said that these technological developments were done mainly by redesigning the form of products or incorporating new materials rather than technologically innovating. Despite some small changes in their products being made, these actions mostly follow the routines of their technology production and thus did not transform the structures of the ICT industry.

7.2.2.2 Changes in structural properties

The second level of industrial transformations led to changes in the structural properties of the traditional ICT industry. When following the hardware-dominated principle and its structural properties cannot fulfil the requirement of smart city technologies, smart city innovations go beyond hardware because applications and services are crucial to this technology set, and only integrating the software can enable smart city technology to address urban issues. Accordingly, apart from a device, the technical sections of networks, platforms and tools used for data processing and system integration (SI) techniques also constitute the key components of smart city technology. Among these sections, the development of SI is the critical component of the restructuring between different technical sections (ICT consultant, 2021) and has catalysed a structural transformation in the Taiwanese high-tech industry. The actions taken by telecoms, hardware manufacturers, and software companies revealed below can explain how SI development changes the structural properties of the ICT industry's system in different ways.

i. Telecoms

The efforts made by telecoms could be most noticeable in Taiwan because they have been involved in the government's smart city projects early and extensively (Think tank director, 2021; IoT startup CEO, 2021; Government official, 2021). Similar to the rise of most smart city technologies, telecoms have followed this technology development trend since IBM's initiative (Palmisano, 2008). Due to the integration role telecoms played, they contributed significantly to the transformations of high-tech industries into the smart city phase, which was brought about at the conjuncture of the market saturation of the telecommunications industry (Telecom director, 2021) and the Taiwanese government's smart city policy. In the first industrial policy named with the keyword of smart city – the '4G Smart Broadband City Application Scheme' made in 2014 (see Chapters 1 and 6), telecoms were the most vital industrial actors involved in the policy implementation. That policy was made with the objective of applying 4G communication technology to the cities, and meanwhile, the government requested telecoms to include their smart city application ideas in their proposal for public spectrum auctions (Think tank director, 2021). The two smart city innovations, the bicycle-sharing system and the smart lampposts, analysed here are prevalent in many Taiwanese cities. They were developed under the telecoms' lead.

Bicycle-sharing system

Telecomes entered the smart city market by applying communication technology to smart transportation. In order to offset the shrinkage in revenue in the traditional mobile phone sector, telecoms enlarged their existing communications business by providing mobile network services beyond mobile phone data transmission. For example, sharing vehicle systems, e.g. YouBike and GoShare, installed FarEasTone Telecom's SIM cards on every bike and scooter. These bike/scooter networks enable those sharing vehicle companies to build data analysis platforms and manage sharing vehicles efficiently (Telecom director, 2021). While the communication technologies used for these systems are not new, the way they are applied is beyond data transmission. The application of data enabled by the platform has brought extra value.

With data collected from the sharing scooter system, Gogoro has developed a smart city energy system to power traffic signals (Telecom director, 2021; Gogoro, 2023). Apart from telecoms and vehicle companies, traditional hardware manufacturers have also participated in establishing sharing vehicle systems. The terminals at YouBike's docking stations were built and maintained by an industrial PC company, but the critical component of the systems is the data application and thus, traditional hardware manufacturers only play a supporting role in these sharing vehicle systems. This shows that telecoms are at the core of developing sharing vehicle systems because they are responsible for processing data. This reorients the market focus from big overseas tech companies' needs to local needs, marking the transformation of the structural properties of the traditional ICT industry being led by large companies for global clients.

Smart lamppost

Apart from the global trend, revenue decline, and policy tendency, the maturity in data analysis techniques also contributed to the conjuncture that furthered the ICT industry to transform into the smart city phase. Thus, many telecom firms took advantage of existing networks to connect data to establish new subsidiaries to approach SI business, enlarging the markets they can reach (Telecom director, 2021) and providing services for more smart city application domains. In the past, telecoms only acted as providers of communication and transmission channels but were barely in touch with the data they carried. Still, they are the industrial actor who understands how data connects most. However, only ensuring an end-to-end connection is not enough to enable application- and service-based smart city technology to function well. An ICT consultant (2021) stressed SI is indispensable to realising a smart city. He explained with a smart lamppost example.

'What can be done by LED manufacturers is nothing more than lighting; they consider themselves as hardware providers, so they cannot possibly provide SI services. They, at most, can only help build a unified control centre to monitor lighting. … Manufacturers are not SI companies, so they cannot realise the value of data. … in this case, smart lampposts are simply electronically controlled lampposts '(ICT consultant, 2021).

A pilot smart lamppost project in Kaohsiung was delivered by Chunghwa telecom with its SI subsidiary's profession. Chunghwa telecom established a smart connection platform that aggregates transportation and environment data collected from sensors and cameras on smart lampposts (Chunghwa Telecom, 2021). The platform can visualise the data and report lamppost conditions so that the city government can analyse urban issues and manage the facility. Based on its expertise in data transmission, Chunghwa Telecom integrates data in different formats from several devices together on the platform (Senior telecom manager, 2021). Then, the platform presents those data in meaningful ways.

The local government's aspiration to realise smart governance initiated the development of the smart lamppost. The lampposts' communication equipment was supplied by a hardware manufacturer, which was not in the role of leading the new technology development but rather passively supporting the innovation with its existing product. Thus, the innovation of this technology was local market-driven, not global firm-driven. The experience of developing smart lampposts did not accord with the Taiwanese ICT industry's structural properties, led by big hardware manufacturers and determined by big overseas tech companies and the consumer electronics market.

ii. Hardware manufacturers

Hardware manufacturers are another group of industrial actors trying to transform their practices to produce smart city technologies. The conjuncture that led these companies to transform their technology development was similar to that for telecoms' innovation but only with one different event: the decline in the gross margin of most hardware manufacturers. In terms of their strategies, there may not be a universal strategy for them to develop software and SI technologies. Despite the varied ways they endeavoured to innovate, their actions still drew on existing structures to some extent, and SI is a common target of their technological innovation. Two examples, the driverless car platform and the smart parking system, explain strategic actions taken by hardware manufacturers to innovate smart city technologies.

Driverless car platform

Acer's ODM, Wistron, grounded in its server manufacturing experiences, has further developed a SI platform for driverless cars. This platform was developed for use in the transportation domain. That innovation was based on a government-funded project that aimed to create a cloud service and SI platform incorporating high-definition maps (Wistron, 2021). The company's strength was producing electronic equipment for communication and data processing. Although those products had already been applied to automobiles, lack of data analysis know-how and techniques undermined its ability to produce application-based smart city products. Through that government-funded project, Wistron, responsible for building a cloud and SI platform, collaborated with the National Cheng Kung University and a smart environment startup, ThinkTron, to accumulate SI experience (Wistron, 2021). The university and the startup complement Wistron's SI platform with techniques of the high-definition map.

During the process of technology development, Wistron identified AI as the critical technology for the SI platform to anticipate traffic patterns. Consequently, the company further invested in operating a new research centre, inviting a team with AI labelling and AI prediction techniques at the National Chiao Tung University to join. The centre aims to improve the platform's computing capability to inform driverless vehicles of precise traffic information (Wistron-NCTU Embedded Artificial Intelligence Research Center, 2020). Without the establishment of a SI platform, an application-based smart city technology can hardly be realised. While the big tech company led the development of this platform, the innovation process involved other actors, i.e. universities and startups. This innovation was not driven by Wistron's previous clients, global laptop brands such as Acer and Dell, but was self-initiated because the company saw the enormous potential of the driverless car market. However, the big company's new technological innovation has still been supported by the government, and its target market has still been consumer electronics.

Smart parking system

As mentioned, smart city technologies cross five application domains, and their advance has been highly contingent on the maturity of data science. Thus, actors in the traditional ICT industry have been motivated to gain know-how from different fields and develop more complicated techniques. As a result, many tech firms invested in new departments, subsidiaries, acquisitions, or joint ventures (JV) and hired people with knowledge of the five domains and data analysis. Acer's subsidiary, Acer Intelligent Transportation System (Acer ITS), is an example of a hardware and electronics corporation that produces smart transportation technology through the acquisition approach. Its sales agent (2021) mentioned that although this subsidiary was founded in 2017, Acer has been developing e-ticket technology since 2004. The smart parking system was this subsidiary's first and most representative smart city solution (Acer ITS, 2021). Introducing the application-based platform distinguished the smart parking system from its previous e-ticket system.

The company took three critical actions to carry out this innovative solution. Firstly, Acer ITS incorporated the technique of a startup's parking service app into its parking system (Think tank director, 2021). The back-end platform behind the app accumulates real-time parking information data, analyses the best way to find parking spaces, and involves a mobile payment system (Think tank director, 2021). Then, apart from the e-ticket base and the app, the smart parking system further integrated the data collected from sensors and image recognition techniques to complete its roadside parking management service (Acer, 2017). Finally, the company collaborated with the Tainan University of Technology to borrow academic knowledge of transportation and used part of the campus as their testbed to optimise the system (Acer, 2017). These actions are unlike what Acer did before, which was to develop the e-ticket technology by itself, because the smart parking system requires hardware and software technology and transportation domain know-how.

Consequently, hardware manufacturers must collaborate with new business partners in those domains to participate in smart city projects[35]. The separation of Acer ITS from Acer, to some extent, shows that smart city transportation is a distinct sector from traditional electronic component production. In addition, the local government is the primary client of the smart parking system, though its users are the public. These features are different from the structural properties of the traditional ICT industry.

iii. Software companies

Software firms are the last active group of industrial actors facilitating the transformation of the ICT sector. An increasing number of new software firms have appeared in the markets as newcomers providing software solutions, usually incorporating SI services for smart cities (Software startup COO, 2021). The rising importance of data science brought another event to the conjuncture of industrial transformation. Since the open data policy launched in Taiwan and the entrepreneurial culture emerged, many startups have attempted to develop and sell their solutions to big firms involved in smart city projects (Think tank director, 2021; Construction consultant, 2021). The prevalence of open data initiatives and emphasis on data science contributes to the growth of these newcomers and enables more flexible SI solutions that not every hardware manufacturer is capable of developing.

Some startups are spin-offs of the quangos supported by the central government’s resources. For example, InSynerger, a startup developing a smart lamppost maintenance platform, was incubated under the III with public funding. Although the actions of these software startups mostly followed the hardware-manufacture-dominated structural properties of the traditional ICT industry, they have different end clients, which are the local governments in Taiwan instead of big global companies. In addition, the emergence of these software startups shows that software has started to gain more importance in the Taiwanese ICT industry.

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[35] The next section of this chapter will explain how these firms work with each other to develop technologies.

7.2.2.3 Changes in structural principles

Developing smart city technologies has transformed the ICT industry's structural principles, which is most profound transformation leading to the industry evolving into new systems. The actions facilitating radical innovation were mainly taken by non-tech firms. Along with the conjuncture of the abovementioned events facilitating smart city industries to emerge, the firms from the five domains have actively enhanced their technical capabilities. The strategies they adopt are similar to those of tech firms, i.e. starting new departments, subsidiaries, acquisitions or JVs or working with high-tech companies.

Smart electronic vehicle

The example of Gogoro can explain how a scooter manufacturer can be integrated into the high-tech industry. The electric vehicle (EV) company – Gogoro – revolutionarily changed the scooter market. In 2019, one-fifth of Taiwanese newly purchased scooters were EVs, which was less than 2% only four years ago (EV distributor, 2021). An EV distributor (2021) mentioned in the interview that the battery charging system has always been the biggest technical obstacle to commercialising electric scooters. Although Gogoro is a scooter manufacturer, its founder was determined to run this company as a tech firm and established a data science team to operate the battery exchange platform – Gogoro Network.

Gogoro Network was developed by information engineers, statisticians, geographical information consultants, and data analysts (Gogoro, 2021). With big data technology, the platform can compute data to identify the best locations for battery charging and exchange stations, manage the stations' electricity and inform users where to find batteries. This platform enables the efficiency of EV charging and contributes to the prevalence of EVs because charging is no longer a hindrance for their users. By developing data techniques, non-tech firms explored new opportunities in the non-tech market with ICT solutions. In the end, these firms became part of high-tech industries. They broke the routines of both tech and non-tech industrial actors. The two types of sectors were separated, and the tech sectors' innovation centred around hardware manufacturing.

The reflexive monitoring of the conduct in the traditional ICT industry cannot be used to explain the actions of the non-tech firm's innovation in smart city technology.

In the case of EV innovation, Gogoro brought data science to non-tech industries, making technology solutions integral to their products or services. Hardware has not been the core of this smart city technology. Instead, the data analysis system is the key component of its success in being widely used. The non-tech firm became the critical actor leading the technology innovation in smart city industries. These features are fundamentally distinct from the structural principles of the traditional ICT industry in Taiwan. In addition, this EV innovation was initially not funded by the government and was not incubated by quangos, which freed the firm from the previous hardware-focused institutional limitation.

Table 38 Categories of smart city industrial actors' actions

Actor	**Technology**	**Process**	**Action categorisation**		
			Following reflexive monitoring	**Causing structural property changes**	**Causing structural principle changes**
Hardware manufacturer	IoT devices (product)	Needing to improve products' durability	✓		
Telecom	Smart lamppost (solution)	Needing to build an operation platform		✓	
Telecom becomes SI	Sharing bike (solution)	Needing to build an operation platform		✓	
Hardware manufacturer becomes SI	Driverless car platform (solution)	Needing to build an operation platform		✓	
Tech firms with non-tech firms	Smart parking system	Needing to build an		✓	

Actor	Technology	Process	Action categorisation		
			Following reflexive monitoring	**Causing structural property changes**	**Causing structural principle changes**
	(solution)	operation platform			
Software startup	Smart lamppost (solution)	Needing to build an operation platform	✓		
Non-tech firms with tech firms	Electricity scooter (product)	Needing to establish a new charging system			✓

(Source: author's own compilation)

7.2.2.4 Summary

The need for technology to solve urban problems has driven the above innovation activities to thrive. They then formed new industrial sectors, the productions of which are distinct from the previous technology products in the traditional ICT industry. Formerly, the production of each technology section is relatively independent, but for smart city technology, the integration of different technology sections as a system is the core to enable this technology set to function. Over the technology development process, tech and non-tech firms must integrate various elements beyond the scope of traditional ICT to become solution-based products. Accordingly, SI plays a critical role in smart city industries (ICT consultant, 2021). As a consequence, many telecoms, hardware manufacturers, software startups and even non-tech firms have been motivated to acquire SI techniques.

We can see that the composition of industrial actors in high-tech industries has changed accordingly. Both high-tech and non-tech firms have undergone different levels of reorganisation, acquiring the capabilities to produce hardware-software integrated products for smart city development (see Table 38). These transformations led Taiwanese high-tech industries to depart from the original development path, enter a new phase and finally form new industry systems.

7.3 Collaboration Network

The collaboration between firms in the smart city industry has been distinct from that in the traditional ICT sectors in Taiwan because of the differences in their division models. The ICT industry's structural principle, which is hardware manufacturer dominating, has shaped its collaboration network, being familiar as the institutionalised feature of hierarchical subcontracting. This principle does not apply to collaboration for smart city projects or product and solution development. In their collaboration, any industrial actor who is capable of doing the system integrator job can play the leading role in the network. Besides, while the government still supports smart city industries with similar measures used for the ICT industry, the main clients for smart city technology are governments and its market is locally based, which is distinct from the ICT innovation model driven by big overseas tech companies. Instead, the operation of industrial associations for technical standardisation does not break the hardware-manufacturer-dominated principle while showing some discrepancies in structural features.

The smart city technology's nature (i.e. multi-section and cross-domain) has also facilitated the firms' collaboration network restructuring. As described in the last section, smart city industries' critical industrial actors involve tech and non-tech firms. Tech firms are composed of hardware manufacturers, telecoms, and software startups. According to the interview, they each could also function as a system integrator (IoT startup CEO, 2021). By contrast, non-tech firms from the five domains can be varied, but consultants with specific city know-how, e.g. transportation or construction, constitute an essential part of them (IoT startup CEO, 2021; Construction consultant, 2021). Besides, manufacturers producing products, such as EVs, used in the five domains can also be crucial. This diverse composition of industrial actors in the smart city industries is opposed to that in the traditional ICT sector. The innovation in smart city technologies is diversified, while the traditional ICT development in Taiwan is relatively specialised (see Chapter 1), and this distinction manifests in the labour division and collaboration network. Consequently, the Taiwanese ICT industry's structural principles can no longer explain the actor collaboration in the smart city industries, which shows that the new industrial system has emerged over the industrial evolution process.

7.3.1 Structures of the traditional ICT industry

Before analysing the actions of collaboration between various actors in the smart city industry, we must first understand the routinised collaborative model in the high-tech industries in Taiwan. Traditionally, hardware manufacturers played the dominant role in local high-tech industries, specifically the ICT sector, which constituted the basics of the industry’s structural principles and formed the five structural properties (explained in the last section). The reflexive monitoring of conduct for collaboration in the traditional Taiwanese ICT industry has been based on hardware-manufacturer-centred structures. Many leading firms are OEM and ODM (Telecom director, 2021), and thus, their primary collaborators or clients are local electronic component providers and big overseas tech companies. This form of collaboration is based on the hierarchical subcontracting division model. The top three Taiwanese companies, HonHai, Pegatron and Taiwan Semiconductor Manufacturing Company (TSMC), with the highest net operating revenues by 2020 (中華徵信所企業股份有限公司, 2019), are all famous as ODMs.

The vertical division of labour within the existing organisation of Taiwanese ICT sectors has been well structured and consolidated (Think tank director, 2021). The collaboration network of Pegatron is a good example. This company is a spin-out from ASUS, separated in 2008, focusing on the business of ODM. Apart from ASUS, Pegatron serves as an ODM for many global laptop brands; for instance, Pegatron once exclusively produced Microsoft Surface. Its vertically collaborated industrial actors for making a laptop include component manufacturers of motherboards, graphics cards, central processing units (CPU), random access memory (RAM), storages, power supply units (PSU), audio drivers, etc. (see Figure 35) (Taipei Exchange and Taiwan Stock Exchange, 2022). Their divisions are relatively independent. In other words, they can follow the component requirements to develop their own products.

7.3.2 Structural transformations into smart city industries

The collaboration network in smart city industries is beyond the tech or non-tech firms' previous production chains. Telecoms, software startups, and non-tech companies are new actors working with the traditional ICT industry, which was a significant event of the conjuncture transforming the collaborative network. These connections for new collaborations constitute intersocietal systems that bring transformations in the industrial systems. In the professional domains of those new actors, they can independently deliver most of their services, products or projects. But for smart city collaborations, they have to work or interact closely with their clients, i.e., citizens, companies in any field, or government agencies.

In addition, in the past, system integrators did not receive much attention in Taiwanese high-tech industries. They thus had been few in the country. Based on the experiences being involved in high-tech sectors, a think tank director (2021) mentioned in the interview:

> *'The division of labour in industries has been doing well in Taiwan. But once it concerns the development of technology integration that deals with the interface between [technologies], including standardisation, test, validation, and even service platform. These works are all not what the Taiwanese industry used to be good at.'*

However, in smart city industries, SI is the key component of incorporating hardware with software during the technology development process. The growth of SI firms out of the need for smart city technology development has connected the previously separated actors and radically transformed their relations in industrial systems. As a result, with the emergence of new industrial actors above, the collaboration model for developing smart city technologies is distinct from that of the traditional ICT sector.

In order to enter the smart city market, the industrial actors above need to invent new technique combinations and then set technical standards for production. The collaborations for the former purpose exist throughout the technology development and production process, while for the latter, the partnerships between all industrial actors relevant to specific products can emerge when those products have nearly reached economies of scale or have great potential. The composition of industrial actors in smart city industries brought about new practices. The collaborative actions for the two purposes have changed different parts of industrial structures in the traditional ICT sector and led to two levels of transformation, i.e. structural property (institutionalised feature) and structural principle levels. This subsection explains how collaborations between firms are organised and lead to changes in structural properties and principles with practical examples.

7.3.2.1 Changes in structural principles (technology development/production)

The new collaborative networks for developing and producing smart city technologies cannot be explained by the structural principles of the traditional Taiwanese ICT industry because, among those emerging partnerships, the industrial actors leading the collaborative work have shifted from hardware manufacturers solely to diversified actors. Hardware manufacturers do not have an absolute advantage over other industrial actors in smart city industries. Which actor, i.e. hardware manufacturer, telecom, software startup or non-tech firm, plays the central role in the collaboration process depends on what smart city technology they develop. Meanwhile, the way different industrial actors go into partnerships can be further sorted into two types by their intentions: cross-domain inclined and multi-section inclined collaborations.

The cross-domain inclined collaborations need to involve both consultants or any firms with domain knowledge and tech companies. Their partnerships are mainly project-based. In terms of the multi-section inclined collaborations, they are constituted by tech companies specialising in one or a few technical sections. Apart from typical tech firms (i.e. hardware manufacturers, telecoms and software startups), some nontraditional ICT tech firms (e.g. motor scooter manufacturers and electrical machinery manufacturers) actively apply new technologies to their products and become essential actors within the collaboration network. The multi-section inclined collaborations between these firms can be either product-based or solution-based.

The three parts below reveal what actions are involved in these three collaboration types, i.e. project-based, product-based and solution-based, between different industrial actors, leading to principle changes in the industrial structures.

i. Project-based

Non-tech and tech firms can work together on a specific development or infrastructure project implemented by government agencies through procurement. This type of partnership is project-based, driven by particular city construction or management projects, e.g. the Asia New Bay Area 5G AIoT Innovation Hub project in Kaohsiung or the smart transportation plan for the Taoyuan Aerotropolis (Construction consultant, 2021; Policy consultant, 2021).

In the past, high-tech firms could hardly have the chance to collaborate with consultants or non-tech firms, and vice versa. However, the early stage of these smart city development projects is usually co-led by a SI company and a consultancy, and then tech companies may be incorporated as supporting teams (see Figure 35) (Construction consultant, 2021). A construction consultant (2021) argued that the consultants' involvement is critical because those projects require their domain knowledge to conceive, design and plan how smart city development could be introduced to an area. In other words, consultancy and SI are indispensable to smart city development projects. Thus, in order to participate in these projects, tech firms began to build collaborator networks with SI companies and even consultancies to be involved in the planning stage of projects, which could ensure tech firms have a role in the infrastructure construction stage (Software startup COO, 2021). Then, together with tech companies, the led SI company and consultancy deliver projects for new infrastructure constructions or new system installations. After the construction work is completed, the SI company may work with a consultancy that has a facility management profession to help further operate facilities or systems (Construction consultant, 2021).

Apart from the change in the led firm in the collaboration, the primary clients of these projects are the local governments, which are different from those of the Taiwanese ICT sector, i.e. big global companies. In this case, the government agencies are clients to invest in smart city development through procurement, not the new technology innovation funder that they used to be in supporting the new technology development.

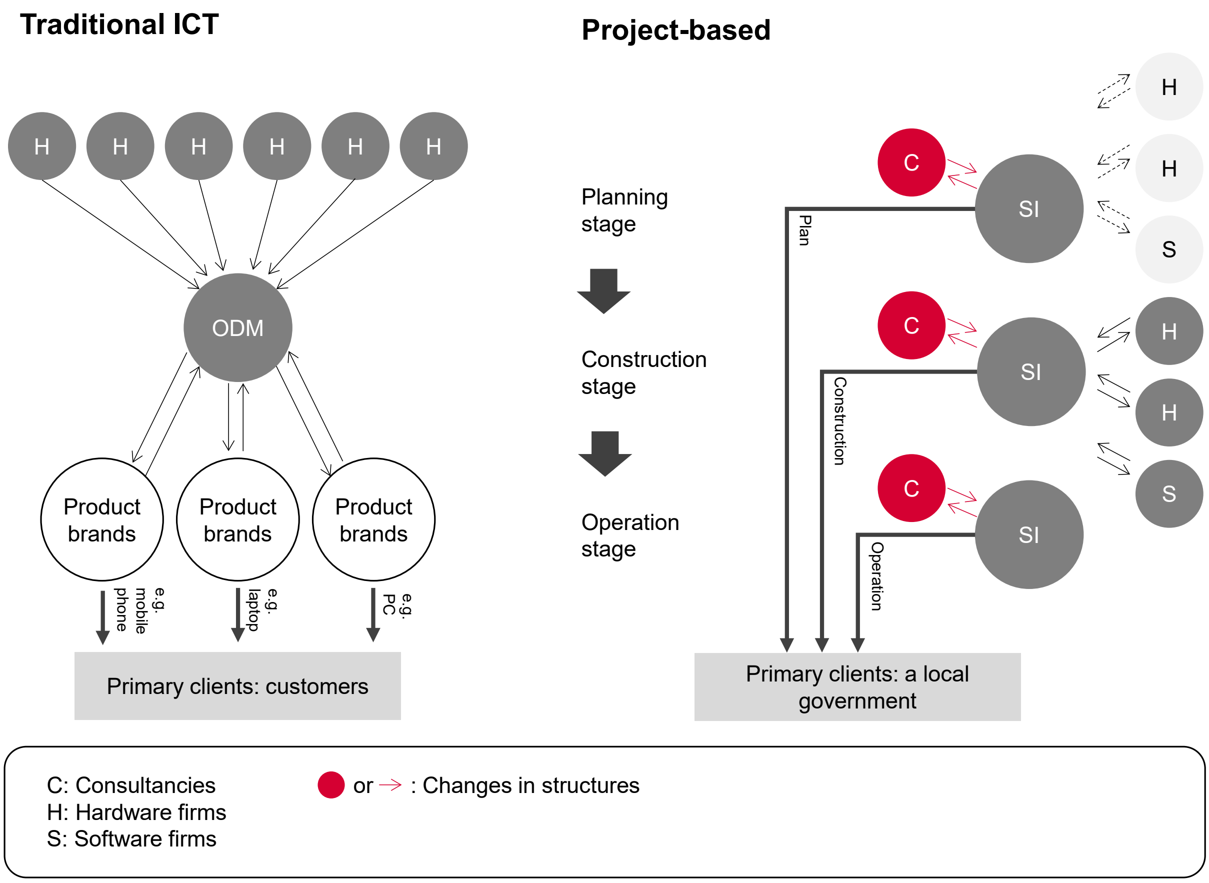

Figure 35 The collaboration network between firms developing traditional ICT and being involved in smart city projects

(Source: author's own compilation)

ii. Product-based

When a tech or non-tech firm attempts to develop a new product for smart cities, the innovation commonly requires techniques beyond its original capabilities. Thus, that company must find collaborators with complementary techniques to develop and produce or deliver the product or the service together.

Aeon's experience in developing a smart dashboard is an example of product-based collaboration. Aeon, an all-terrain vehicle manufacturer, has been endeavouring to invent new products to adapt to the changing market. On the one hand, products for smart electric scooters have been developed out of citizens' needs, as the demand for smart vehicles is considerable. An EV company's CEO (2021) said that Taiwan has the highest density of scooters in the globe, which means the country is an ideal site to experiment with smart electronic scooters. On the other hand, since the electronic scooter became prevalent under Gogoro's successful promotion, Aeon has been one of the earliest scooter manufacturers to innovate for smart scooters (EV distributor, 2021).

In order to enter the EV market, the company first decided to work with Gogoro to use its charging solution. Then, as a non-tech company, Aeon established a strategic alliance named CROXERA, inviting hardware and software tech firms to develop its Internet of Vehicles (IoV) products (see Figure 36) (EV company CEO, 2021). The alliance members' first new technology product collaboratively produced is a smart dashboard, i.e. a real-time traffic information system. Its display system has been developed with AUO Corporation, an optoelectronic solution company, and the real-time map system is a mapping data company's (HERE) solution. Finally, the data communication and computation technique of this smart dashboard is supported by Taiwan Mobile while using Microsoft's cloud technology and Micro-Star International company's (MSI's) computer hardware technology.

Unlike the traditional ODM collaboration model, Aeon did not have the know-how to design the product, so collaborations with its business partners are not unidirectional purchases. Rather, Aeon co-develops the smart dashboard with tech firms and uses the product on its scooters. Over the product development process, as a non-tech firm, Aeon took the leading role in the collaboration between various actors involved while tech firms were supporting. This model is distinct from the ICT's collaboration network. The clients of this product are locally based. Moreover, as a scooter is not a typical technology product, Aeon's IoV innovation and collaborative development work is not supported by the government's funding for technology R&D but rather firm-initiated.

iii. Solution-based

Regarding solution-based collaboration, the example of Acer ITS's smart parking system can elucidate the actions involved. Acer ITS was initially separated from an electronics (laptop) company, Acer. Founded on Acer's know-how, this subsidiary reached a high level of competence in producing e-ticket equipment early. However, although Acer ITS had accumulated its SI experiences through developing the e-ticket, innovation in software was still beyond its expertise. Thus, Acer ITS acquired a smart parking app startup to gain its parking information platform and mobile payment technique (Think tank director, 2021). Then, based on the previously owned and newly acquired technique, Acer ITS creates a smart parking system.

After this solution has been proven commercially viable, the company plans to expand the service of this system by providing EV charging. Accordingly, Acer ITS has started working with AOpen, another Acer subsidiary responsible for computer components design and production, to develop the upgraded smart parking system. In 2021, AOpen helped a US EV infrastructure company, Volta Charging, produce equipment within EV charging stands to control and manage the power system (AOpen, 2020). Furthermore, the Acer group announced in early 2022 that they would incorporate the Taiwanese energy company (electrical machinery manufacturers) EVALUE as their local EV infrastructure collaborator to develop the upgraded system in Taiwan.

In this example, in order to develop the solution for the smart parking and EV charging system, Acer ITS has transformed itself from a hardware manufacturer into a system integrator, connecting all required techniques for the development of the system and providing the smart transportation solution. For this type of collaboration, any firm (e.g. consumer electronics brand, ODM, telecom or software startup) that has gained SI ability can act to lead technology innovation (see Figure 36). Then, the smart city solutions are directly sold to local authorities while benefiting citizens. The collaborative network for developing smart city solutions is distinct from the linear collaboration model, from the upstream of component manufacturers to the downstream of an ODM and finally to a product brand.

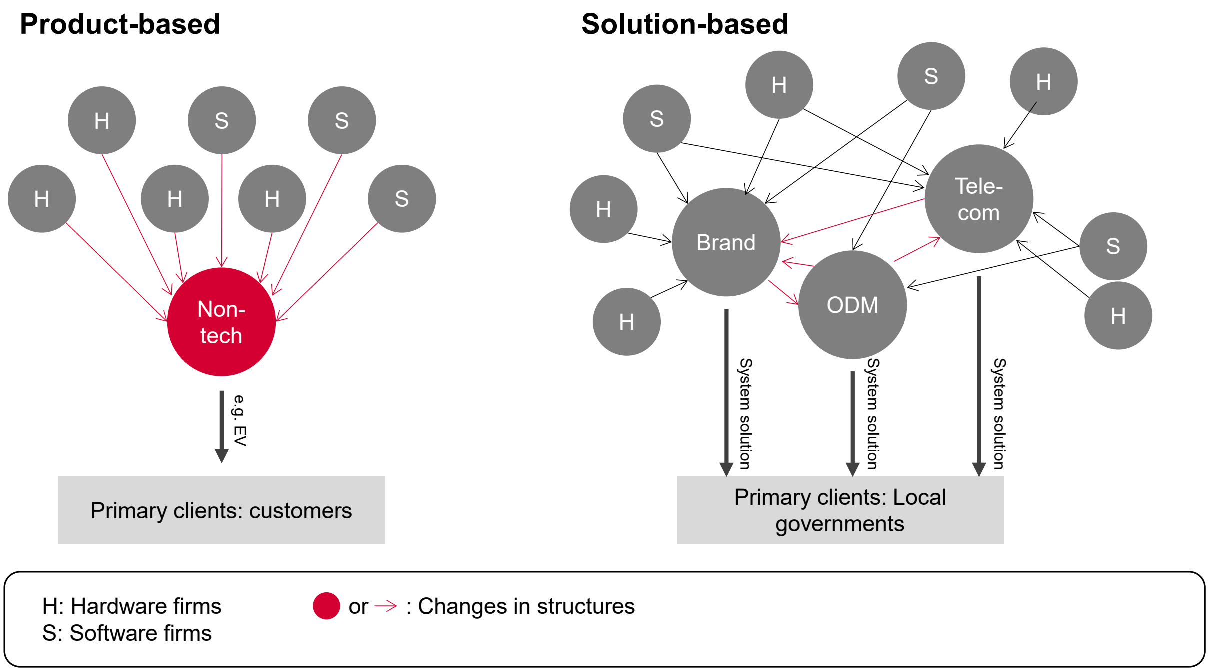

Figure 36 The collaboration network between firms developing smart city technology products and solutions

(Source: author's own compilation)

7.3.2.2 Changes in structural properties (technology standardisation)

Regarding collaboration for technology standardisation, the actions taken by the industrial actors, however, accord with the traditional ICT industry's structural principles. The most profound institutions established upon those principles in the industry determined how the formalised rules and resources have been made and distributed. Accordingly, while the collaboration for smart city innovation can be led by various tech firms or even non-tech firms, hardware manufacturers are still in the lead position to set standards in smart city industries. In short, its collaborative network for technical standardisation is hardware-manufacturer-dominated.

When a new technology product becomes ready or plans for mass production, companies involved in its production will encounter the need for technical standardisation, especially for smart city solutions and products. Thus, industrial actors relevant to their target products or solutions have to collaborate to achieve this objective. Since smart city technologies involve multiple technical sections, their technical standardisation is critical for technology integration. As a result, leading tech firms or industrial organisations initiate the establishment of industrial associations that invite relevant firms to work on formulating industry standards for specific technologies, such as driverless cars or smart lampposts. How industrial associations for solutions or products are organised is analysed below. This research uses the examples of industrial associations for developing smart lampposts and driverless cars to explain the types of solution- and product-based associations.

Smart lamppost

Firstly, the associations for innovation in smart city solutions work closely with government agencies and quangos or think tanks responsible for technology development and technique standardisation. This link between the industry and the government is because the government has been the primary client of smart city solutions. Accordingly, the involvement of the government in this type of association can ensure the solutions the relevant companies develop fulfil the government's needs and requirements. Meanwhile, the members of these associations are composed of firms producing different technical sections.

In an interview, an ICT consultant (2021) emphasised the example of the 5G Smart Pole Standard Promotion Alliance that was initiated by Mr Tzu-Hsien Tung, the chairman of Pegatron, while supported by the Bureau of Standards, Metrology and Inspection (BSMI), Ministry of Economic Affairs (MOEA). This association, established in 2021, with its forty-three members, endeavours to form a unified standard for a smart lamppost's components [36] (Science & Technology Policy Research and Information Center, 2022). Those members are all local firms. Based on the BSMI's requirement for the technical standard draft, the association has three committees: 1) standard establishment, 2) verification and data security, and 3) testbed requirement and demonstration, to be responsible for relevant preparation of technology standardisation. In this association, one or two companies have led each committee. Then, based on the draft the association proposed, the statutory technical standard for smart lampposts – *5G Smart pole system technical specification* – was published by the BSMI in September 2022. After establishing this standard, all smart lamppost component production must follow its requirements.

[36] These components include pole structure, power safety system, 5G and wireless communication module, information interconnection and management system, information security, application development.

In short, the collaboration for standardising the production of smart lampposts has been led by hardware manufacturers and greatly supported by the government, which meets the structural properties of the traditional ICT sector. However, this solution does not mainly sell to big global companies.

Driverless car

The other example of the industrial association for product standardisation is the Mobility in Harmony (MIH) Consortium, founded by Foxconn in mid-2021. This Consortium operates an industrial alliance aiming to create an open ecosystem for EV driverless car developers, facilitating collaborations between firms in relevant sectors and lowering the entry barrier for them (MIH Consortium[a], 2021). Compared to smart lampposts, EV development and production are much more complex because of the more sophisticated technologies involved. By 2022, there have been 2,532 members all over the world joining the association.

With the clear objective of developing reference designs and standards, the MIH Consortium is relatively top-down and well-structured. HonHai, the biggest Taiwanese hardware manufacturer, appointed the Consortium's CEO and initial members of the board of directors (MIH Consortium, 2021). There are two committees under the MIH Consortium for its operation. One is the technological committee building principles for technology development, and the other is the advisory committee setting out administrative, process, or organisational policies. The CEO appoints heads of these two committees (MIH Consortium, 2021). In other words, HonHai primarily leads the MIH Consortium. The government's participation in this organisation has been limited because the technology development of driverless cars has been highly market-oriented, and the main clients of the relevant products are international automobile or EV brands.

7.3.2.3 Summary

In sum, active actors in the collaborative network in emerging industrial systems are hardware manufacturers, telecoms, software startups, non-tech manufacturers and consultancy firms. Among the above three different types of collaboration, we can find a common feature: their primary clients shifted from big global companies to local governments or consumers. Meanwhile, the government's and quango's role in shaping the innovation network has changed to become to support, not determine, how the new industrial systems develop. The non-tech firm's innovation in a smart city product radically transforms the industrial landscape. New industrial systems crossing tech and non-tech sectors have been formed over the process of these collaborations.

When smart city products/solutions scale up production, they must standardise the required techniques. Whether they have the potential for reaching economies of scale is determined mainly by the expectations of clients and the market demand, i.e. the government and product users (citizens), for smart cities. The industrial associations for smart lampposts and driverless vehicles in Taiwan have made better progress in technical standardisation, but the reasons are not the same. The demand for smart lampposts grows as many local governments plan to install these facilities on a large scale. An IoT startup CEO (2021) highlighted the government's role in supporting the development of the smart city industry. Government procurement is the primary funding source for companies to develop smart city technologies (IoT startup CEO, 2021) and innovation in smart lampposts has been the case. In terms of driverless vehicle technologies, their development has combined the government's support in R&D and the primary hardware manufacturer's effort to build an innovation ecosystem. The central government launched a series of plans to facilitate the development of their relevant industries. For example, a think tank analyst (2021) mentioned that his team has acted as an external consultant for the 'Smart City Taiwan' policy to identify which cutting-edge technologies should be the priority to fund, and innovation in driverless cars is one of the priorities to develop. Meanwhile, the market potential of driverless cars has attracted HonHai to invest in establishing and operating the industrial association.

The former industrial association for standardising smart lamppost solutions has local-based members, while the latter product association includes more global members. This difference in the composition of their members is because of the different markets they target, selling to the local city governments or general consumers in any country. Thus, these associations are steered by contrasting factors. As a result, the government's involvement in the two associations also has varied levels. Based on the analysis of these two examples, the firms' practices of these two industrial associations mostly drew on the traditional ICT sector's structural properties, which demonstrates that the system of the traditional ICT industry mainly determines the collaboration network for technology standardisation.

7.4 Cluster

The transformations in the geographical cluster show the structural principle of the traditional ICT industry is not applicable to the smart city industries. The geographical distribution of innovation activities for the smart city industries reflects a series of actions taken by firms to change their locations. High-tech sectors shifted and multiplied production activities and functions from hardware manufacturing centres in Hsinchu to the Taipei metropolitan area (see Figure 37). The locations of smart city firms link to their activities for technological innovation and their collaboration network. The diversified innovation activities are located in several cities and involve different forms of collaboration networks to fulfil the need to produce multi-section and cross-domain smart city technologies.

Figure 37 Cities in Taiwan

(Source: author's own compilation)

7.4.1 Structures of the traditional ICT industry

The traditional ICT industry in Taiwan has clustered in Hsinchu since the state established its first science park in 1980. Prior to its establishment, the ITRI quango was founded in this city in 1973 (see Chapter 1). In the infancy of the Taiwanese ICT industry, the ITRI acted as the prime mover in innovating frontier technologies with the state's administrative and financial support (Wade, 2018). The most famous Taiwanese semiconductor company, TSMC, was one of the spin-offs of the ITRI. After 1980, small companies sprung out as offshoots of big companies' spin-offs and startups (Hsu, 2004; Yang, Hsu and Ching, 2009). The Hsinchu Science Park has accumulated ICT hardware manufacturers for specialised production, e.g. integrated circuits (IC), personal computers (PC) and related electronic components (Hsu, 2004). Specifically, firms in this cluster are mainly semiconductor manufacturers, early-established fabless companies, PC manufacturers, and their suppliers (Hsu, 2004; Hardware company engineer, 2022). Local customers and suppliers in Hsinchu interact dynamically, forming a collective learning process and enabling technical exchanges (Hsu, 2004). As explained in the last section, the centres of the networks between these firms are ODMs and OEMs, producing consumer electronics for big global tech companies. As a result, many small companies gathered in the city to stay close to their primary clients, i.e. ODMs and OEMs. These local relationships that are founded on the structural principle of the hardware manufacturer dominance enhance the significance of the Hsinchu cluster in the traditional Taiwanese high-tech sectors.

7.4.2 Structural transformations into smart city industries

However, the system of interactions between industrial actors in smart city industries is distinct from that in the traditional Taiwanese ICT industry. Accordingly, the locational transformations in high-tech industries following the emergence of smart city production activities present a new landscape that contrasts with the spatial formation founded on the hardware-manufacturer-dominated structural principle of the traditional ICT sectors. In other words, hardware manufacturers have no longer acted as the key driver in smart city industries. Rather, they are just one of the industrial actors along with telecoms, software startups and non-tech firms (IoT startup CEO, 2021; Software startup COO, 2021). Therefore, the cluster centred around the Hsinchu Science Park does not have a particular advantage in smart city industries, while the three cities in the Taipei metropolitan area (Taipei, New Taipei and Taoyuan) became the new home for smart city industries. The spatial formation of firms' locations in the three cities has represented different long-standing relations embedded in spaces. According to a construction consultant (2021), offices of government agencies, software startups and consultancies sit in central Taipei, while telecoms and tech companies requiring bigger spaces or lower rents for their offices are mostly located in the outskirt of Taipei and a few districts in New Taipei with good transportation connections to Taipei. Manufacturers producing electronic components and non-tech products set up their factories in a few less dense districts of New Taipei and in Taoyuan (Construction consultant, 2021). Companies in these three cities have begun to change their locations and build new relationships for the purpose of producing application- and service-based smart city technologies, which transformed the structural principle of the traditional ICT industry.

7.4.2.1 Changes in structural principles

There have been different reasons for firms to take action to make locational changes. Their motivations to change location are contingent on the needs of the production activities, ranging from hardware and software to system integration (ICT consultant, 2021). The relational interdependence built upon the space, which is hardware manufacturer dominant, can hardly benefit innovation in smart city technologies. As a result, new smart city firms and big companies' subsidiaries or branches exclusive to the business of smart cities have not been motivated to locate their offices in Hsinchu (Hardware company engineer, 2022). The subsection below reveals the strategic actions of industrial actors in setting up new offices to fulfil different needs, which have created new locational interdependencies in the Taipei metropolitan area. The cluster of the Taipei metropolitan area to produce smart city technologies has been structured by a polycentric network between related firms in industries because their developments and productions require diversified techniques from multiple companies. In this region, companies can find employees or collaborators with diverse skill sets, which enables these companies devoted to developing smart city technologies to become comprehensive providers.

i. Service need

In order to meet and serve clients in a timely manner, smart city companies whose businesses are mainly project-based are based in Taipei for two main reasons. First, the smart city firms' primary clients, i.e. government agencies, are domestic-based. The capital city is home to government agencies with the highest administrative power. Thus, the offices of their clients and their collaborators serving their clients are mainly located in Taipei. Second, as explained in the last section, when big companies attempted to enter the smart city market, they commonly invested in new departments, subsidiaries or JVs. Big companies' new departments or branch firms typically set offices somewhere close to their parent companies (IoT startup CEO, 2021), and most of those big companies have offices in Taipei to stay close to the market. Accordingly, the locations of a group of firms working on project-based smart city development mostly gather in Taipei.

The collaboration network of those industrial actors has been centred in the Taipei metropolitan area, which involves telecoms, their SI and consultancies in Taipei. Meanwhile, electronics hardware manufacturers, as one of the participants in smart city projects providing infrastructures or electronic devices, mostly have factories in New Taipei. These companies are remote from the traditional ICT cluster in Hsinchu. This reorientation of the market has broken the structural properties that high-tech sectors' innovation activities centre around hardware manufacturing, global companies' needs, and the state's investment in Hsinchu.

ii. Innovation need

The need for innovation activities in smart city products and solutions has driven companies running factories outside the Taipei metropolitan area to establish new offices in Taipei and New Taipei for R&D. These two cities accommodate companies in various fields. First, companies conducting R&D have gathered in the Taipei metropolitan area to stay close to their collaborators. Taking the innovation in the smart dashboard as an example, while Aeon's factory and headquarters remain in Tainan, the company runs a CROXERA project office in New Taipei, closer to its allies such as Microsoft and MSI (電腦王阿達, 2020; EV company CEO, 2021). The team in its New Taipei office only works on the smart dashboard innovation.

Regarding innovation in smart city solutions, companies in Taipei and New Taipei are more likely to take the lead than those in Hsinchu. The Hsinchu-centred spatial structure of the traditional ICT industry does not restrict the locations of relevant industrial actors because the multidisciplinary professionals they require are scattered among different clusters. The development team of Acer ITS's smart parking system is composed of people from multiple entities based in different cities. The lead firm, Acer ITS, similar to other R&D-oriented tech firms, set up an office in New Taipei, while its collaborators are located across three other cities, including a startup in Taipei, a non-tech manufacturer in Taoyuan and a university in Tainan (IT company sales agent, 2021). This network represents the formation of crossing-cluster collaboration systems, which is beyond Hsinchu's hardware manufacturer cluster and thus challenges the structural principle and properties of the traditional Taiwanese ICT industry because of the more diverse industrial actors involved.

iii. Manufacturing need

In terms of the need to manufacture smart city technologies, Taoyuan has been an ideal place for non-tech manufacturers and thus attracted new production-based firms. The experience of Gogoro's establishment in Taoyuan is a typical case of site selection for a non-tech company that relies on manufacturing to produce smart city technologies. Gogoro chose not to locate its smart scooter factory, which is also its headquarters, in Hsinchu or New Taipei, where the traditional ICT clusters are (天下雜誌，2020; EV distributor, 2021). Instead, this company is headquartered in Taoyuan, which has a non-tech manufacturing cluster. The predecessor of the Gogoro's factory in Taoyuan manufactured hand tools (天下雜誌，2020). By setting up in Taoyuan, Gogoro can build its production line in an existing factory space while staying close to the component suppliers. Although electronic components are critical to a smart scooter, hardware manufacturers have not dominated the collaboration network for its innovation and development. This production of smart scooters as a smart city technology draws on the relational interdependencies of a non-tech manufacturing cluster. The location of Gogoro is not determined by where most high-tech firms are clustered, which is radically different from the ICT industry's structural principle.

7.4.2.2 Summary

The cluster for smart city innovation has taken shape in the Taipei metropolitan area, which is underpinned by a polycentric network. The three cities in this region, Taipei, New Taipei and Taoyuan, have pre-existing clusters with different functions that can support production activities for diverse smart city technologies. However, the establishment of new smart city firms has transformed the relational interdependencies between these cities. The three cities' previously distinct industrial systems have been integrated through technological innovation activities and their collaboration network. The spatial features of the three cities can fulfil the diverse needs of firms developing different types of smart city technology. Setting up offices or factories in this region enables those smart city companies to become comprehensive providers because the diversity of firms in the Taipei metropolitan area can effectively complement them with techniques that a specialised cluster cannot provide.

7.5 Conclusion

Although the actions of industrial actors in the three aspects above led to varying levels of transformation in industrial structures, these changes demonstrate that the smart city industry extends beyond the original sectoral composition of local ICT and does not fully align with the institutionalised features of traditional Taiwanese ICT sectors. Instead, they represent a new set of features characteristic of emerging systems, which, while partly overlapping with traditional local ICT industries, are primarily driven by newly emerging innovation activities. This supports the hypothesis that the triple transformations driven by industrial actors have reshaped part of the original structure of Taiwan's ICT sector.

Findings: New Systems Generated by Emerging Industrial Actors in High-tech Industries and Their Impact on Institutionalised Features

The development of smart cities and related technologies creates opportunities for more tech firms—and, crucially, non-tech firms—to engage in the traditional Taiwanese ICT industry, as it requires multidisciplinary techniques, knowledge, and expertise. Products provided solely by hardware manufacturers cannot possibly meet current needs for developing smart cities, namely application- and service-driven solutions. New industrial actors, such as telecoms, software startups, consultancies and non-tech manufacturers, have emerged and formed smart city industries. Consequently, a series of reorganisations have occurred both within firms and between firms involved in innovation related to smart city development.

The above industrial actors have taken a series of actions to develop new technologies, i.e. products and solutions, for smart cities. Most industrial actors in tech sectors recognised the importance of SI in smart city technology. SI becomes a common ground when these firms plan to extend their business to the smart city. As a result, most industrial actors in smart city industries started undertaking SI work that is fundamental to smart city projects or technology product developments for others to join. Meanwhile, many tech or non-tech firms have established new departments, subsidiaries or JVs and gained new capabilities to develop smart city products. Although some hardware manufacturers still follow the reflexive monitoring of conduct to produce smart city products, the structural properties and principles of the traditional ICT industry have been broken by the new actions of emerging actors. The industrial transformations caused by technological innovation have brought new elements to structures.

On the one hand, the telecoms, hardware manufacturers, and software startups' actions for developing smart city solutions transformed the structural properties, while which parts of those properties have been transformed depends on which industrial actors are involved and what types of solutions are developed. On the other hand, non-tech firms' approach to developing smart city products can bring about the most significant transformations in the ICT industry, which challenge its hardware-dominated structural principles.

Hardware manufacturers are no longer the leaders of the collaboration network for innovation. In terms of inter-firm activities, new collaboration networks have been established strategically to incorporate complementary capabilities and standardise smart city technology productions. As smart city industries emerge, telecoms, software startups and companies from the smart city application domains (i.e. consultancies and non-tech manufacturers) become a part of Taiwanese high-tech sectors over the evolution process and challenge the structural principles of the traditional ICT industry.

Either tech or non-tech firms can lead the collaboration for smart city projects, products and solutions. Thus, the most dominant actors in the traditional ICT sector, hardware manufacturers, must extend their collaborative networks to telecoms, software startups and even non-tech firms, like electrical machinery manufacturers or consultancies, to gain the necessary techniques or knowledge and team with these firms to form new partnerships. Apart from these transformations in the Taiwanese ICT sector's structural principles, the contrasting primary client between the ICT and smart city industries is the most noticeable difference in the structural properties. The local governments have been the main clients of the smart city companies, rather than big global firms for hardware manufacturers. In contrast, the standardisations of the new smart city products and solutions do not change the principles of the ICT industry; they basically follow the long-standing institutionalised properties to formulate industry standards. All geographical transformations brought by smart city innovation have directly challenged the traditional ICT sector's structural principles. Establishing new companies and branches in the Taipei metropolitan area is mainly out of the need to stay close to clients for the service, locate close to collaborators for innovation and have suitable factories for non-ICT manufacturing. Evidently, the ICT hardware-manufacturing-dominated structural principle meets none of these features, and thus, the Hsinchu cluster can hardly be the prior option when smart city companies choose to locate their offices.

Still, due to the multidisciplinary nature of smart city innovation, the industrial evolution driven by smart city innovation marks the beginning of a parallel technological development trajectory within Taiwanese high-tech industries, distinct from traditional hardware manufacturing, characterised by radical innovation and the formation of new industrial systems in the country.

Chapter 8: Conclusion

This study aims to examine production-side research on smart cities, focusing on three key areas: 1) the outcomes of regional industry evolution driven by radical innovation, 2) the determinants, particularly state industrial policy, and 3) the processes shaped by actor-structure interactions. The research seeks to go beyond existing smart city literature, which predominantly focuses on the *use of technology* and examines the benefits and adverse effects of smart city technologies on a city's efficiency. Instead, this study explores the *production of technology* that is needed to build the smart city. By addressing these three aspects, the research makes empirical, methodological, and theoretical contributions.

Empirically, the unique sectors behind smart city technologies have not yet been studied collectively as a distinct industry type in regional studies. This research thoroughly explains the relevant production activities, which is a critical step before exploring the link between regional technological production capabilities and smart city development. The methodology based on patent analysis, developed in this research to delineate the specific scope of this technology set, can be applied to study smart city technology production in other regions and contexts, offering insights into the global landscape. This Taiwanese case is built upon the production capabilities of its regional industries. Using this methodology, we can further examine whether the window of locational opportunity (WLO), proactively created by smart city innovation in other regions and actively reshaping local conditions, leads to a trajectory similar to the one explored in this thesis. In terms of theoretical implications, the upgraded evolutionary economic geography (EEG) framework proposed in this research (see Section 8.2) will be valuable for examining other exogenous-driven radical innovations that have proven significant to regional evolution.

The next section begins with a discussion of the definition of smart city technology and the findings related to the three research questions. Following this, I offer my theoretical reflections on regional development literature. Next, I provide insights into production-side smart city studies. Sections four and five address the policy implications and research limitations of this thesis. Finally, I conclude with an outline for future research on smart cities and EEG theories.

8.1 Findings

8.1.1 The definition of smart city technology

Studying smart cities from the production side is essential, as examining the scope of smart city technologies helps establish a more specific definition. This definition can then be used for the operationalisation of smart city studies when investigating these technologies. This was achieved through a review of policy documents, supplemented by interviews. Based on the empirical results, this research defines smart city technology as a set of technologies designed to collect, transmit, accumulate, and use city data. These technologies are applied in the domains of transportation, environment, energy, surveillance/governance, and city services. They encompass multiple technical sections, including hardware, software, and system integration techniques, extending beyond ICT.

The definition highlights the distinctiveness of smart city technology, which, however, in existing literature, has mainly been represented by ICT (Caragliu, Del Bo and Nijkamp, 2011) or, in some cases, by specific techniques (Jo *et al.*, 2019; Sandoval, Garcia-Sanchez and Garcia-Haro, 2019; Jiang, 2021). Smart city innovation is radically different from previously developed technologies because its synthesis cannot be achieved by a single sector and, therefore, cannot be accomplished by merely improving production efficiency of existing sectors. Due to this complexity, the infusion of knowledge beyond local capabilities is essential for its development. As a result, this type of innovation is novel to local economic activities, as its development has introduced exogenous elements and initiated a series of changes in industries. Based on the analysis of the Taiwanese case, the production of smart city technologies has significantly transformed the development of existing regional high-tech sectors due to radical innovation and state industrial policies. The findings of this analysis are explained in the following subsection.

8.1.2 Smart city innovation-driven regional industry evolution

Smart city innovation in Taiwan has facilitated the evolution of its traditional ICT industry. This research sets out the analysis in the three empirical chapters with the framework developed from the EEG literature involving the aspects of innovation, institution, and actor-structure interactions, and theoretical elements borrowed from the 'window of locational opportunity' and 'developmental state' literature and the structuration theory. They can help address research questions related to whether changes in industries are radical and lead to transformations in the industrial structure, how the state influences these changes, and how industrial actors interact with the structure. The analysis of smart city innovation in two empirical chapters examines the outcomes (Chapter 5) and processes (Chapter 7) of the industrial landscape's technological, organisational and territorial transformation over the regional evolution. In addition, the analysis of the state's involvement in the regional evolution in Chapter 6 focuses on the changes in institutional environments for industry development. Their empirical findings are summarised below.

8.1.2.1 Radical innovation

The results demonstrate the discontinuity in the evolutionary path (Boschma, 1996) between the data sets of ICT and smart city patents over the period of 2001-2020. Specifically, their differences in the variety of technology (technology), the composition of firms (organisation), and the proximately located untraded interdependencies (territory) have been explored through 1) hardware-software ratio, classifications and citations, 2) hardware-software ratio, company sizes and types of assignees, and 3) hardware-software ratio and inventors' located cities. In addition, there are five classifications of smart city patents not under ICT patent classifications. These classifications were further separated from the whole smart city patents for analysis.

The analysis shows that the smart city industry constitutes a radical innovation from existing trajectory of Taiwan's ICT sector. The diversified nature of smart city technology contrasts with Taiwan's traditional specialisation in hardware manufacturing. The subsequent structural changes in regional industries are manifested in the emergence of software technology sectors, differentiating a new technological system from the traditional ICT industries in Taiwan. The difference between the ICT and smart city technologies is evident in their citation patterns. ICT patents followed fewer origins, while those of smart city patents were much more diverse. Either hardware- or software-centric patents followed this pattern. When comparing the changes between the two halves of the study period (2001-2010 and 2011-2020), this difference became more evident. The smart city patents cited more non-ICT classifications in 2011-2020. It is evident the development of smart city technology has brought new elements to the traditional Taiwanese high-tech industries that were highly ICT hardware-centric. As the analysis traces the citations of the five non-ICT smart city classifications, it was found they cover techniques used for products of smart electric scooters, self-driving vehicles, and smart lampposts.

Secondly, the transformation in the organisation of firms in industries can be seen from the rise of collaborative networks between big and small firms and research institutions. Particularly, the latter always played a big part in the network. This collaboration form is opposed to that of the existing Taiwanese hardware manufacturing. In its traditional ICT sectors, big companies, specifically OEMs and ODMs, have always been the centre of collaboration, which is based on the hierarchical subcontracting model. Over the 20-year period, the big companies gained more influence if we look at the ratio of ownerships for ICT patents, either for the hardware- or software-centric patents. However, this trend was not linked to the changes in the smart city patent assignees between 2001-2010 and 2011-2020. There was no single group of assignees that became dominant for smart city patents.

Lastly, the territorial transformation of regional industries led to a locational shift in clusters. A new cluster for smart city innovation activities has emerged in the Taipei metropolitan area, which sharply contrasts with the ICT cluster in Hsinchu. The Hsinchu city has consolidated its hardware manufacturing centre over the 20-year evolution for ICT innovation. A division in the smart city cluster in the Taipei metropolitan area's three cities has gradually taken shape. Initially, Taipei was the sole centre of this cluster, where most of the clients and collaborators in the smart-city-related industries are located. Then, early in the second decade, both hardware and software innovation activities for smart city technology emerged significantly in New Taipei and Taoyuan, which showed its close interrelationship with hardware innovation activities. The capabilities of electronics manufacturers in New Taipei and non-ICT manufacturers in Taoyuan enabled these two cities to complement Taipei as the R&D centre and play an indispensable role in the cluster.

Based on the analysis of the three dimensions above, it is clear that over the two decades of evolution in regional industries, the paths of smart city industries have not developed within ICT sector. Instead, the sector for smart city innovation has emerged as a separate system.

8.1.2.2 The state's role

Based on the studies on developmental states (Wade, 2018), three approaches should be taken into account when studying the Taiwanese case. Those institutional settings left by the Taiwanese developmental state as a legacy can be explored by analysing 1) governmental agencies, 2) developmental consensus, and 3) modes of intervention in the market. Firstly, in Taiwan, there are high- and low-level governmental agencies that maintain government-business relations and build networks with industrial actors. Being situated at the highest administration level of the Taiwanese government, the BOST has a good connection with key industry players. The BOST committee involves industrial actors and prominent academics as its members to collect their ideas for the draft of the blueprint for future industry development. This committee is the pivot of the government-business network. This communication channel in the central government has remained open for high-level decision-makers to reach industrial actors since the 1980s. At the practice level, the Industrial Technology Research Institute (ITRI) and the Institute for Information Industry (III), with abundant industry know-how, study the feasibility of policies for the government and enlist the firms from their networks to participate in projects for the development of new smart city technologies. The function of these networks between the government and industries is enabling. They do not directly contribute to R&D but help achieve requirements for innovation, i.e. involving capable industrial actors.

Secondly, the BOST has played a big part in building a development consensus between government and business. The BOST committee mentioned above is critical for forming a consensus. The voices of industrial actors and academics can be received through committee meetings and then reflected in the industrial policies. This approach ensures key industrial actors can back the policies made by the government and gain momentum to implement policies. Lastly, in order to encourage smart city innovation, the state intervenes in this new market through the industrial policy to assign local governments as initial clients of companies innovating related technologies. The ultimate goal of this policy is to export smart city products or solutions to overseas countries. The local market has been used as a testbed for innovative technologies in their infancy, and the government has also provided funds to invest in local firms' R&D of smart city technologies. These measures ease the risk of innovation and thus increase local industrial actors' willingness to innovate.

In sum, the legacy of the Taiwanese developmental state inevitably determines the evolution of the industry. The institutions established during the developmental state period have helped facilitate the local ICT to evolve into a new phase, while being a double-edged sword to technological innovation. The maintenance of networks between the government and industrial actors via high- and low-level agencies and the mechanism to protect innovation activities is an inflexible model broadly applied to all sectors and is inattentive to individual industries.

8.1.2.3 The actor-structure interactions

According to structuration theory, the smart city innovation-driven evolution process can be revealed by analysing the elements of episodes/event conjunctures, actors' conducts/motivation, institutionalised features, systems/intersocietal systems (Giddens, 1984). The first element indicates the beginning of an evolution course. Then, analysing the second and third points can help understand the interactions between industrial actors and structures. Structural transformations following evolution episodes have three levels: 1) following reflexive monitoring, 2) causing structural property changes, and 3) causing structural principle changes. The last element for analysis can reveal the structural dimension of changes responding to the emergence of smart city industries in Taiwan.

Over the evolution process, innovation activities combine tech and non-tech firms to develop service- and application-based smart city solutions. Technology integration, interdisciplinary collaboration, and new clustered relations have radically changed the traditional ICT industry's structural properties and principle, which are based on hardware manufacturers' dominance in technology development and production. Technologically, structural transformations involve actions at three levels, as explained above. The initial episode was a decline in the profit margin of ICT hardware products, but many hardware manufacturers developing smart city technologies still follow reflexive monitoring, i.e. they did minor modifications to existing hardware products. Then, combining the episode above with the events of the industrial policy to encourage and facilitate ICT sector upgrade and the government's promotion of open data, a conjuncture of evolution was formed to propel transformations in the structural properties. As system integration is the core of smart city innovation, hardware manufacturers no longer play the dominant role in the smart city industries, which thus causes structural property changes. Key actors involve not only hardware manufacturers but also telecoms and software companies. Their main clients are government agencies. Lastly, the most significant change in the structural principle has been made by the non-tech company-led product development. In this case, hardware manufacturers join the innovation activities only as suppliers.

Alongside the conjuncture explained above, organisational and territorial transformations in the structures of local industries happen in tandem with technological innovation. Organisationally, new collaborations between firms in the smart city industries have changed both the structural properties and principles. Industrial associations established for technology standardisation are still led by hardware manufacturers. However, the objective of those associations is to create a common standard to facilitate system integration, and thus, their members comprise firms developing techniques across multiple technical sections. They follow the traditional ICT sector's structural principle but still cause structural changes at the property level. Additionally, collaborations for the development of smart city projects, products and solutions involve new actors in the traditional ICT industry. Those non-tech firms have endeavoured to enhance technological capabilities and, to some extent, become a part of high-tech sectors. Their primary clients are local city governments and citizens. The leading firms for collaboration were determined by who was in the best position to coordinate the technology innovation. Hardware manufacturers are not necessarily dominating the collaboration, which is opposed to the structural principle of the traditional ICT industry in Taiwan.

Territorially, the transformations only happened at the structural principle level. The technology production cluster shifted from Hsinchu to the Taipei metropolitan area because of the need for service, innovation and non-manufacturing. New relations have been built in the new smart city cluster in the Taipei metropolitan area. The main clients and collaborators in the smart city industries are primarily located in Taipei. New Taipei and Taoyuan mainly function as hardware and software innovation and non-ICT manufacturing bases. As a result, the ICT hardware manufacturing centre, Hsinchu, has no advantage in attracting smart city firms to establish their offices in this city.

The strategic actions taken by newly emerging industrial actors with existing local tech firms have caused structural changes in the traditional ICT industry. They have acted as catalysts for opening access to exogenous elements during innovation activities.

8.2 Reflections on the Evolutionary Economic Geography

This research proves that a social scientific perspective is essential to a study on smart city technology production. The abundant theoretical arguments in the regional development literature focus on technological innovation (Krugman, 1979; Storper and Walker, 1989; Storper, 1997; Boschma and Martin, 2010; Pike, Rodríguez-Pose and Tomaney, 2016; Boschma and Frenken, 2018), which is thus suitable to be used to understand smart city innovation. Specifically, this research primarily borrows EEG's thinking to explain how technological innovation and regional development mutually interact and shape each other.

The findings show that industries in some regions have been restructured since the emergence of production activities for smart city technology. This empirical study on the evolution of the Taiwanese smart city industry reflects on the EEG's arguments regarding: 1) the *exogenous* elements in regional innovation activities, 2) the effects of the state on *institutions*, and 3) the role of actors in the process of regional *restructuring*. These elements are critical to understanding the regional evolution driven by smart city innovation. This section develops the theoretical understanding of the three research questions based on EEG.

8.2.1 Evolution after exogenous element emerging

As EEG literature explains, innovation plays a significant role in regional evolution (Lambooy, 2002), while local conditions, in turn, determine how innovation emerges within a region (Martin and Sunley, 2010). However, the concept of innovation as an endogenous element limits our understanding of smart city innovation, as its related sectors are new and do not stem from local industries. Storper and Walker's (1989) descriptions of the WLO provide insight into how we can identify innovation activities not linked to the local capabilities, which is considered discontinuous over the evolution process (Boschma, 1996). Combined with the 'holy trinity' structure (Storper, 1997), this approach operationalises the abstract concept of discontinuous development in industries by identifying the discrepancies between the traditional ICT industry and the emerging smart city industries in Taiwan. Specifically, it does so by analysing how radical innovation changes the sectoral composition, manifesting through technological innovation (technology), the networks between industrial actors (organisation), and locational relationships (territory).

Smart city innovation has opened the WLO in Taiwan. The cited classifications of smart city patents, which shifted from the ICT pattern and included multiple non-ICT origins, confirm that exogenous elements caused the regional industry's evolution, leading to the development of products beyond local technological capabilities. Organisational discontinuity was the external thrust brought by small companies and research institutes to regional industries. The last new cluster emerging in cities remoted to the traditional ICT production centre reflects that the new relations of spaces were built. These new elements have transformed the original local sectoral composition, leading to a structural change in regional industries.

It is important to note that the evolution of regional industries does not always challenge the established technological paradigm. Only a new system driven by radical innovation transforms sectoral composition and ultimately leads to structural change over time (see Figure 38). The Taiwanese ICT industry has primarily been centred around hardware manufacturing. Before the emergence of smart city innovation, local high-tech firms struggled for years to develop software technology solutions but were unsuccessful. Locally developed software solutions in Taiwan were not competitive in the market. The development of smart city technology in Taiwan has created a new technological system within local industries, enabling Taiwanese high-tech sectors to become comprehensive providers, offering both software and hardware solutions. Furthermore, the technological system of smart city innovation extends beyond the scope of ICT. The level of transformations in regional evolution should be understood in a stratified manner, rather than as the creation or locking of a single dominant path, as described in existing EEG. The dominant path may consist of multiple sub-paths, and its evolutionary trajectory is the result of either transformations within the dominant path or the accumulation of changes across several sub-paths. These findings provide insights into EEG by specifying how structural changes in regional industries occur after radical innovation emerges. This is done by comparing and identifying discontinuities in sectoral composition, advancing from theoretical discussions on history and local conditions to exploring potential evolutionary paths for the future. On the other hand, the evolutionary trajectory should be analysed in its component parts, which may consist of both endogenous and exogenous elements. In the Taiwanese case, the evolution does not involve a complete transformation of the dominant path but is shaped by multiple interwoven paths underpinned by different technological systems. This evolution has led to changes in Taiwan's ICT paradigm, expanding its original scope.

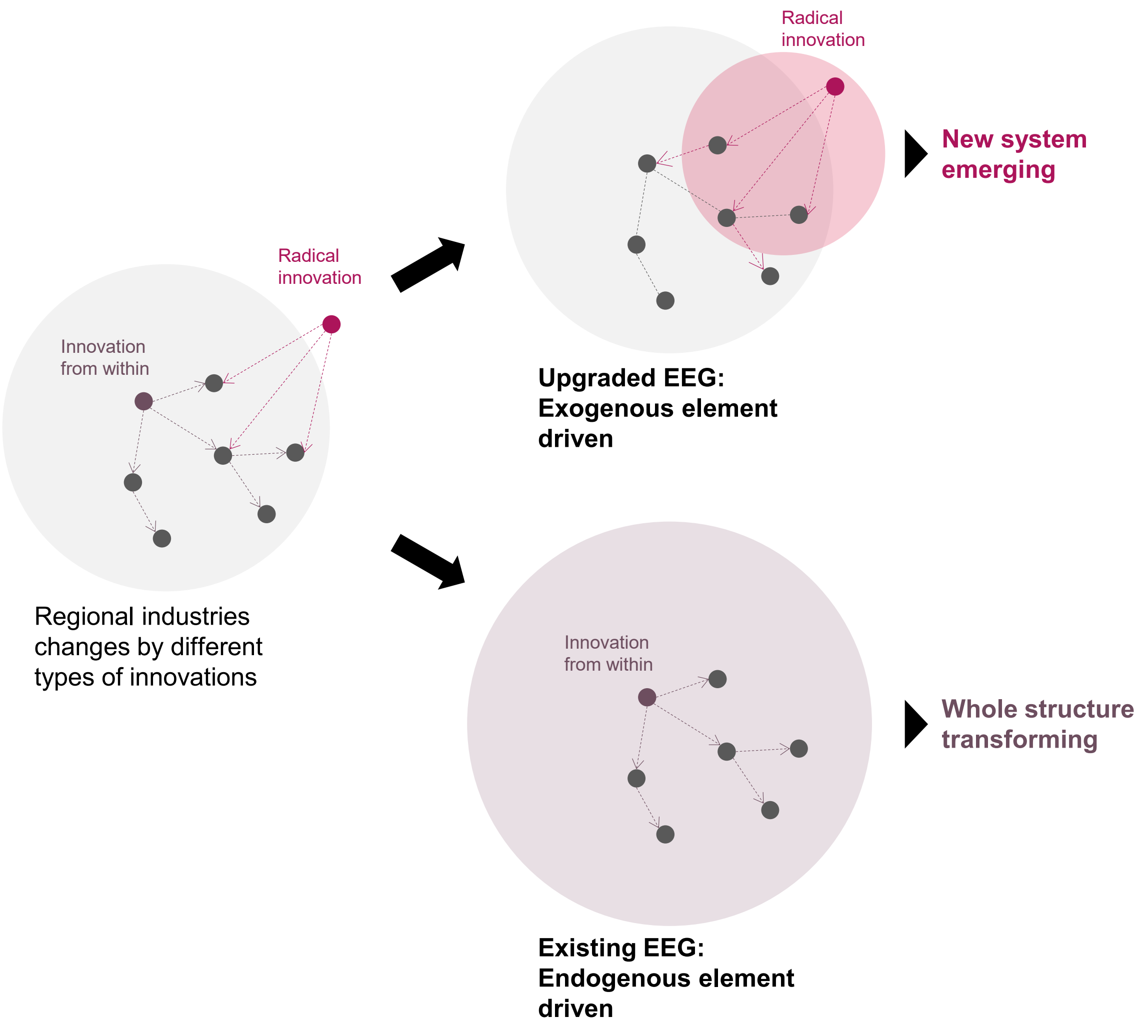

Figure 38 Regional industrial evolution trajectories caused by different types of innovation

(Source: author's own compilation)

8.2.2 Evolution under the developmental state institutions

In EEG, institutions are considered a critical element in shaping industry evolution (Martin and Sunley, 2006; Boschma and Frenken, 2009) and can co-evolve with changes (Nelson, 1995; Gertler, 2010). The second contribution of this research is to address the weakness of neglecting the state's role by enhancing the theoretical explanation of how the state can drive structural changes in regional industries through industrial policies. Developmental state literature elucidates the institutional arrangements that enabled East Asian countries to capitalise on the WLO and develop high-tech industries (Wade, 2018). The Taiwanese state has played a pivotal role in the development of the smart city industry, as government agencies have been the primary clients of smart city firms. This allows the government to harness public resources to facilitate smart city innovation and foster sector growth. The industrial policies enacted by the state are embedded within the industrial structure, incorporating institutions that sustain networks between government agencies at multiple levels and industries. This distinctive government-business relation contributes to the formation of a developmental consensus (culture) and, in some cases, manifests in government intervention in the market (capital). These institutionalised aspects of the industrial structure, embedded in the bureaucracy, shape how innovation activities emerge in regions and drive corresponding industrial evolution.

The institutions embedded in Taiwan, shaped by its developmental state legacy, were designed to promote economic development by facilitating government involvement in industrial development, particularly in high-tech sectors. Government-supported technological innovation is more likely to be realised, although the government's capacity may, to some extent, limit the outcomes of innovation. The central government's policy for smart city development, 'Smart City Taiwan', was introduced as a strategy to upgrade the local ICT industry. Most city governments have passively participated in projects funded by this policy. Due to these institutional endowments, the state's strategies have enabled the emergence of smart city innovation in Taiwan. The innovation activities involved in developing smart city technology are radically different from the hardware manufacturing capabilities of Taiwanese industrial actors in the ICT sector. A key factor in the evolution of local industries, which involves the generation of a new system for smart city innovation, is the successful mobilisation of industrial actors' participation. The policy-making and implementation mechanisms, formalised as institutions, play a pivotal role in facilitating this participation.

The WLO concept highlights that radical innovation is accompanied by uncertainties that can significantly alter the development pathway (Boschma, 1996). These uncertainties can also deter most firms from engaging in R&D during the initial stages. According to EEG, the development of radical innovation heavily depends on entrepreneurial culture; without a spirit of risk-taking, radical innovation cannot occur.

However, the institutional framework of a developmental state, materialised through industrial policies, acts as a pull force for technological innovation that drives changes in the industrial structure (see Figure 39), lowering the threshold for initiating certain innovation activities, which in turn lowers the needed level of risk-taking. Meanwhile, the market—which the government can leverage—plays a critical role in determining whether a new path can be successfully established. The unique market position of smart city technology has facilitated the evolution of Taiwan's ICT industries into a phase where they can develop software technologies.

By applying the concepts of a developmental state, and incorporating state-theoretical approaches in general, EEG can systematically illustrate the effects of each institutional factor and their roles in shaping the industrial structure. The unique institutional form, involving policy-making and implementation mechanisms, as well as government-business relations, could enhance EEG's explanation of how institutions enable or hinder innovation. Industrial actors draw on this structure and, through the relations underpinning it, proactively reshape the structure (see Chapter 7 for further analysis). Additionally, this developmental state case demonstrates that the institutionalised properties embedded in a region's governance and political structure are difficult to change, even with radical innovation that has led to structural changes (i.e., transformation of the sectoral composition).

8.2.3 Evolution through collective actions

Lastly, the concept of structural determinism hinders EEG researchers from explaining how actions taken by firms can change the structure. Although Martin and Sunley's (2006) path-dependence approach highlights the importance of agency, it does not provide a clear explanation of how firms' actions contribute to changes in the structure. This gap limits EEG's ability to describe the process, but it can be addressed through the concept of the duality of structures, as explained in the theory of structuration (Giddens, 1984). This concept moves beyond the tendencies of actor or structure determinism. Instead, Giddens' (1984) concept of duality sheds light on the evolutionary process of change by clarifying the interrelationships between actions and structures, which are constituted by institutionalised features. By incorporating theoretical elements such as conjuncture, reflexive monitoring, structural properties and principles, and intersocietal systems (Giddens, 1984) into EEG, we can make the abstract concept of interactive processes between actors and structure more concrete. This helps clarify the proactive role of firms in shaping evolutionary trajectories through their innovation activities, which act as push forces (see Figure 39).

Since the emergence of the smart city industries, new industrial systems have formed in Taiwan due to the participation of non-tech companies, including telecoms, software startups, and non-tech companies, in the traditional ICT industry. In the EEG literature, firms and their activities have always been a key focus when exploring how innovation significantly transforms regional industries and initiates a new course of evolution, as they are the primary actors in carrying out technological innovation activities (Boschma and Martin, 2010). The concept of the duality of structure explains how industrial actors (firms) draw on structures and how these structures are reproduced through their actions (Giddens, 1984).

Operationally, exploring the actions taken by industrial actors can reveal new institutionalised features that are overlooked by the framework of structure determinism. The analysis results (Chapters 5 and 7) support the hypotheses related to the research questions on structural changes, demonstrating that transformations driven by smart city innovation in Taiwanese industries are radical and have led to the restructuring of part of the traditional Taiwanese ICT industry. Specifically, in this case, the involvement of non-tech companies—and their actions, which differ from the routines of traditional tech companies focused on improving existing production efficiency—in the emergence of smart city innovation within regional industries can be seen as a critical stimulus for structural changes in the traditional ICT sector, shifting it away from its dominant hardware manufacturing tradition.

In addition, incorporating the concept of new systems from both structuration theory and the technological paradigm into EEG also provides valuable insights into explaining the proactiveness of industrial actors. New systems are generated when the actions of industrial actors become routinised practices, embedding a set of knowledge, skills, and experience. Consequently, industrial structures are transformed, manifesting new institutionalised features.

As explained in structuration theory, intersocietal systems—linked through non-tech companies to the existing ICT sector—catalysed the emergence of smart city innovation, facilitating the creation of a new technological system. The integration of two previously separate systems created space for radical innovation that did not exist locally before. In other words, the elements introduced into the traditional ICT production system through intersocietal systems are exogenous forces to the industry, as they were not part of the local capabilities previously equipped for production. Although local non-tech companies co-existed with tech companies in the same regions for a long time, the two systems did not integrate until the emergence of smart city technologies. This system integration enabled actors to engage in new activities beyond their routines, facilitating the opening of the WLO in the region, i.e., enabling the development of radical innovation that goes beyond merely improving existing technologies. The evolutionary process triggered by innovation in smart city technologies involves interactions between systems, new practices, and changes in structural properties and principles, demonstrating structural changes in local industries, even though these changes do not challenge the existing technological paradigm.

The explanation above, based on structuration theory, aligns with complexity thinking's understanding of intra- and intersystem interactions and path dependency's emphasis on accidents in EEG. However, it offers a more comprehensive and systematic approach to organising these critical components to depict the evolutionary process. This framework integrates exogenous elements into EEG's discussions of the transformation of local structures and actors in regional evolution. In this context, exogenous elements refer to actors who, whether inside or outside a region, were not initially integrated into the local industrial systems. Therefore, when considering local conditions in EEG, the distinction between exogenous and endogenous elements lies not in whether the element is non-local or local, but in whether it has been integrated into the system.

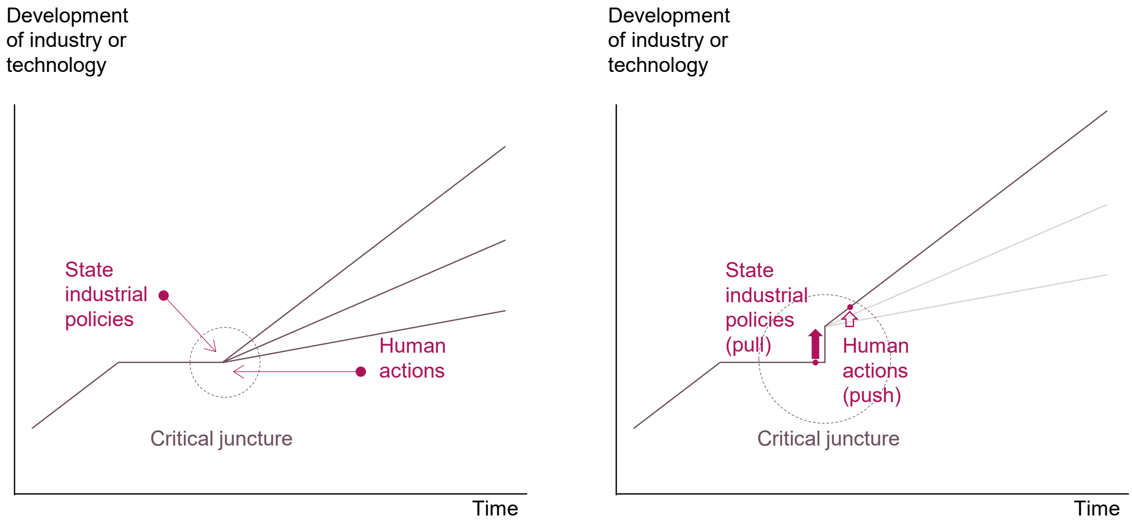

Figure 39 Regional evolution trajectory shaped by state industrial policies and industrial actors' actions

(Source: author's own compilation)

8.3 The Smart City Study from the Production Perspective

This research studies the technology production for smart city development to complement existing use-side inclined smart city literature. The significance of their production activities to city and regional development is no less than applying those technologies in urban areas. In regional development literature, we can find profound theoretical foundations exploring the interrelation between local conditions and technological innovation. Based on the EEG arguments and the findings of this research, it is clear that the need for smart city innovation might drive the production of this technology set, but, more importantly, the production capabilities of regional industries highly determine their production (Martin and Sunley, 2010; Boschma and Frenken, 2018). The developmental state institutions and local industrial actors have moulded how the smart city industry emerged and evolved in Taiwan with its ICT sectors. Although hardware manufacturers have not played a dominant role in this new industry, their participation has established a supportive environment for smart city innovation. Conversely, the innovation activities cause changes in the routines of industrial actors, which further involves structural transformations in social and spatial relations between those actors, entailing the network and cluster reorganisation for regions devoted to developing smart city technologies (Martin and Sunley, 2006, 2007). Approaching the research of smart city technology from this perspective can help give a more comprehensive understanding of the effects of smart city technology innovation on regional and city development.

Smart city technologies are used in varied application domains and comprise different technical sections. This complexity can result in divisions within smart city literature (Mora, Bolici and Deakin, 2017; Mora, Reid and Angelidou, 2019). This research provides a comprehensive understanding of the base technologies used for smart city development. The purpose is not to create an extra branch but to lay a foundation of a common definition for future debates. With the methodology used to identify smart city technologies, along with the definition and specific scope outlined in this research, studies on this topic can have a more precise direction to explore relevant innovation activities and advance the understanding of this technology set.

The brand of smart city development for many city governments is a measure to attract tech companies and build a vibrant technology-based region stimulating economic growth (Hollands, 2008; Carr and Hesse, 2022). When focusing on technology use, it tends to focus on the controversy of data privacy and the dominance of big global tech companies (Galdon-Clavell, 2013; Vanolo, 2016). But when approaching from the production perspective to studying the Taiwanese case, big global tech companies have not had a dominant role, and each technical section of smart city technology has been dealt with by a certain group of industrial actors. Rather, the role played by the local non-tech companies is critical because their domain knowledge and know-how are key components of smart city technology innovation. The involvement of these actors in smart city development can be decisive in a project's success. Also, the collaboration between tech and non-tech firms greatly contributes to radical innovation in regional development. Data is at the core of smart city technology, but a thorough understanding of the composition of smart city technology and how different technical sections are integrated can help recognise the structure of the data pipeline and what data sets can be involved. Smart city data come from not only personal data but also non-private or anonymous data. This production approach to revealing smart city technology can help situate issues in a broader context and shed light on the disputes over data use.

8.4 Policy Implications

This smart city research is of significance to national industrial policies and local smart city development strategies. The Taiwanese case shows that the development of smart city industries is closely linked with government policies, and there is a bias in favour of high-tech industries. While the long-standing model its central government uses to facilitate technological innovation indeed helps the new tech sector development in its infancy, some supplementary measures could be adopted to enable radical innovation to prosper and scale up. First of all, it is critical for policymakers to learn from the experience of non-tech firms' involvement in smart city innovation, leading to successful structural transformation in local industries. When assessing local conditions, apart from those of hardware manufacturers, more diverse actors should be taken into account. The high- and low-level governmental agencies could expand their network by reaching relevant non-tech companies as they launch new interdisciplinary initiatives, like smart city innovation promotion, and utilise their capabilities to realise the diversification of technology products and achieve more creative solutions.

Secondly, out of the developmental mindset, export is the primary goal of the second phase of the 'Smart City Taiwan' policy set by the Taiwanese government. The approach of building a network with international actors through cross-country collaborations might be more effective than the current strategy of promoting the products or solutions to overseas markets at international exhibitions. Developing smart city products or solutions requires multiple industrial actors and working with local governments. Encouraging Taiwanese firms to involve overseas collaborators in their technology development with industrial policies could be a stepping stone to approaching the global market. Lastly, the central government's 'Smart City Taiwan' policy has ensured every city's opportunity to adopt smart city technologies, not being left behind with less advanced infrastructures, but may result in some unfit adoptions. It could be more beneficial for the DIGI+ committee to hold meetings involving representatives from all local governments to propose collective strategies applicable to most cities than collecting individual demands from each local government.

8.5 Research Limitations

It is important to note that this study has three limitations regarding the definition and scope of technology, which are due to the data collected and the perspective adopted. First, since this research focuses solely on the case of Taiwan, it cannot fully represent the entire range of smart city technologies produced globally. The definition and scope of smart city technology in this research are based on the technologies developed within the Taiwanese context. Although the development of smart city technology is a radical innovation to the local ICT sectors, the conditions and capabilities of different regions still matter and can significantly influence what technologies are produced. The rapid progress in technology leads to the second limitation. Technology development is in a state of flux. Smart city technologies are the synthesis of existing techniques. The structure used for the definition, comprising the varied technical sections, may remain similar but can still be challenged when disruptive innovation is brought to the market. Finally, this research only focuses on production activities. While places producing smart city technologies are not necessarily where to use those technologies, the market may be one of the determinants of technological innovation in some cases. This study has not traced where the smart city technologies produced in those regions are sold for use and if the uses affect what technologies are innovated.

8.6 Avenues for Further Research

This research has established a foundation in a few different empirical, methodological, and theoretical ways, while leading to new avenues for future regional development research. Empirically, this research probes Taiwanese industrial policy to facilitate the processes of smart city innovation. Based on this research, two approaches can further explore smart city technology production and innovation policy. First, the production perspective provides another angle for researchers to review existing expectations of this technology set and smart city development. When discussing what kind of smart city we can build, we must consider regional technology production capability. Second, the study of Taiwanese smart city industry development, on the one hand, creates an opening for policymakers and researchers to review the effects of the developmental state legacy on technological innovation. On the other hand, this study uses a developmental state case with a unique condition shaped by a set of institutionalised properties offering market opportunities and cooperative networks to nourish the smart city industry. However, when the state does not make the same level of effort to facilitate smart city innovation, the results could be different. Thus, research on non-developmental state cases can be further conducted to explore other development trajectories under industrial policies made and implemented by different logic.

It is imperative for regional development theories and EEG to incorporate the exogenous perspective in this rapidly changing world. With my upgraded EEG and patent analysis methodology, this research provides a framework to understand how external elements are being introduced in regions and developed to become local industrial landscapes, such as electric vehicle battery technology development or the emergence of digital nomads in some regions. However, further efforts in theoretical discussions are required when considering more sophisticated issues. Many forces causing structural transformations in industries are above local and beyond regional. Among all the global challenges, such as the COVID crisis, global warming, wars and trade conflict (Kogler *et al.*, 2023; Yeung, 2023), I particularly highlight the uncertainties relevant to geopolitics. Geopolitics impacting regional development and industries is inevitable. Most regional development theories were built in the era of unobstructed globalisation and under a stable global political order. We can no longer count on these conditions in future studies. Accordingly, geopolitical considerations and their related exogenous impacts are critical in future regional development research.

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Abbreviation

4G Smart Broadband City Application Scheme (4G Scheme)

Acer Intelligent Transportation System (Acer ITS)

Artificial intelligence (AI)

Artificial intelligence of things (AIoT)

Board of Science and Technology (BOST)

Bureau of Standards, Metrology and Inspection (BSMI)

Central processing units (CPU)

Chunghwa Telecom Co., Ltd. (Chunghwa)

Digital Nation & Innovative Economic Development Program (DIGI+ Program)

Electric vehicle (EV)

European Union (EU)

European Patent Office (EPO)

Evolutionary economic geography (EEG)

Far EasTone Telecommunications Co., Ltd. (Far EasTone)

Forward-looking Infrastructure Development Program (FIID Program)

Geographical political economy (GPE)

Global production network (GPN)

Gross domestic product (GDP)

HonHai Precision Industry Co., Ltd. (HonHai)

Industrial Technology Research Institute (ITRI)

Institute for Information Industry (III)

Institutional economic geography (IEG)

Integrated circuits (IC)

Information and communication technology (ICT)

Intellectual Property (IP)

International patent classification (IPC)

Internet of Things (IoT)

Internet of Vehicles (IoV)

Japan Patent Office (JPO)

Joint ventures (JV)

Low-power wide-area network (LPWAN)

Low-rank adaptation (LoRa)

Key performance indicators (KPI)
Mediatek Inc. (Mediatek)
Micro-Star International company/Co., Ltd. (MSI)
Ministry of Economic Affairs (MOEA)
Ministry of Science and Technology (MOST)
Mobility in Harmony (MIH)
Multinational corporations (MNCs)
Narrowband Internet of things (NB-IoT)
National Science and Technology Council (NSTC)
New economic geography (NEG)
Original design manufacturers (ODMs)
Original equipment manufacturers (OEMs)
Pegatron Corp. (Pegatron)
Personal computers (PC)
Proof of business (POB)
Proof of concept (POC)
Public-private partnership (PPP)
Random access memory (RAM)
Relational economic geography (REG)
Science and Technology Advisory Group (STAG)
Science, technology and innovation (STI)
Smart City Summit and Expo (SCSE)
Storages, power supply units (PSU)
System integration (SI)
Taiwan Semiconductor Manufacturing Company/Co., Ltd. (TSMC)
Telecommunication companies (telecoms)
United Microelectronics Corporation/Corp. (UMC)
United States Patent and Trademark Office (USPTO)
Venture capital (VC)
Window of locational opportunity (WLO)
Wistron Corp. (Wistron)

Appendices

Appendix 1 The categorisation of ICT and smart city patent classifications

Hardware- or software-centric	Technology sections	ICT		ICT patent classifications	Smart city patent classification	
		Main areas	subareas		ICT	Non-ICT
Hardware-centric	Data collection	Area 4: Sensor and device network	Sensor network	G08B1/08, G08B3/10, G08B5/22-38, G08B7/06, G08B13/18-13/196, G08B13/22-26, G08B25, G08B26, G08B27, G08C, G08G1/01-065		G01C21, G01C22
			Electronic tag	H04B1/59		
		Area 11: Information communication device	Electronic circuit	H03B, H03C, H03D, H03F, H03G, H03H, H03J		
			Cable and conductor	H01B11		
			Semiconductor	H01L29-33, H01L21, 25, 27, 43-51		
			Optic device	G02B6, G02F, H01S5		
			Others	B81B7/02, B82Y10, H01P, H01Q		
		Area 12: Electronic measurement		G01S, G01V3, G01V8, G01V15	G01S13	
	Data transmission	Area 1: High speed network	Digital communication technique	H03K, H03L, H03M, H04B1/69-1/719, H04J, H04L	H04L12, H04L29	

Hardware- or software-centric	Technology sections	ICT Main areas	subareas	ICT patent classifications	Smart city patent classification ICT	Non-ICT
			Exchange, selecting	H04M3-13,19,99, H04Q	H04Q7	
			Others	H04B1/00-1/68, H04B1/72-1/76, H04B3-17		
		Area 2: Mobile communication		H04B7, H04W	H04B7, H04W4, H04W52	
Software-centric	Data accumulation	Area 6: Large-capacity and high-speed storage		G06F3/06–3/08, G06F12, G06K1-7, G06K13, G11B, G11C, H04N5/78-5/907		
		Area 13: Others	Computer input-output	G06F3/00, G06F3/05, G06F3/09, G06F3/12, G06F3/13, G06F3/18		
			Other related technique	G06E, G06F1, G06F15/02, G06F15/04, G06F15/08-15/14, G06G7, G06J, G06K15, G06K17, G06N, H04M15, H04M17	G06F15	
	Data use/application	Area 3: Security	Cyphering, authentication	G06F12/14, G06F21, G06K19, G09C, G11C8/20, H04K, H04L9, H04M1/66-665, H04M1/667-675, H04M1/68-70, H04M1/727, H04N7/167-7/171, H04W12		

Hardware- or software-centric	Technology sections	ICT Main areas	subareas	ICT patent classifications	Smart city patent classification ICT	Non-ICT
			Electronic payment	G06Q20, G07F7/08-12, G07G1/12-1/14, H04L12/14[37], H04W4/24[38]		
		Area 5: High speed computing		G06F5, G06F7, G06F9, G06F11, G06F13, G06F15/00, G06F15/16-15/177, G06F15/18, G06F 15/76-15/82	G06F9, G06F15	
		Area 7: Large-capacity information analysis	Database	G06F17/30, G06F17/40		
			Data analysis, simulation, management	G06F17/00, G06F17/10-17/18, G06F17/50, G06F19, G06Q10, G06Q30, G06Q40, G06Q50, G06Q90, G06Q99, G08G	G06F19	
		Area 8: Cognition and meaning understanding		G06F17/20-17/28, G06K9, G06T7, G10L13/027, G10L15, G10L17, G10L25/63,66,	G06K9	
		Area 9: Human interface		H04M1, G06F3/01-3/0489, G06F3/14-3/153, G06F3/16, G06K11, G06T11/80, G08G1/0962-0969, G09B5, G09B7, G09B9		B60Q1, G05D1, F21V29
		Area 10: Imaging and	Imaging technique	H04N, G06T1-9, G06T11, G06T13, G06T15, G06T17-19, G09G	H04N9	

[37] There are only three patents in total under the classification of H04L12/14, and thus the H04L12 is categorised as a hardware-centric classification.

[38] There are only six patents in total under the classification of H04W4/24, and thus the H04W4 is categorised as a hardware-centric classification.

Hardware- or software-centric	Technology sections	ICT		ICT patent classifications	Smart city patent classification	
		Main areas	subareas		ICT	Non-ICT
		sound technology	Sound technique	H04R, H04S, G10L		

(Source: Inaba and Squicciarini (2017) and this research)

Appendix 2 Smart city patent classifications with full patent titles

Classification	If it is ICT	Classification titles	Note
G01C21	No	Navigation; Navigational instruments not provided for in groups G01C 1/00-G01C 19/00	measuring distance traversed on the ground by a vehicle G01C 22/00; control of position, course, altitude or attitude of vehicles G05D 1/00; traffic control systems for road vehicles involving transmission of navigation instructions to the vehicle G08G 1/0968
G01C22	No	Measuring distance traversed on the ground by vehicles, persons, animals or other moving solid bodies, e.g. using odometers or using pedometers	
G01S13	Yes	Systems using the reflection or reradiation of radio waves, e.g. radar systems; Analogous systems using reflection or reradiation of waves whose nature or wavelength is irrelevant or unspecified	
H04B7	Yes	Radio transmission systems, i.e. using radiation field	H04B 10/00, H04B 15/00 take precedence

Classification	If it is ICT	Classification titles	Note
H04L12	Yes	Data switching networks	interconnection of, or transfer of information or other signals between, memories, input/output devices or central processing units G06F 13/00
H04L29	Yes	Arrangements, apparatus, circuits or systems, not covered by a single one of groups H04L 1/00-H04L 27/00	
H04Q7	Yes	Selecting arrangements to which subscribers are connected via radio links or inductive links	
H04W4	Yes	Services specially adapted for wireless communication networks; Facilities therefor	
H04W52	Yes	Power management	
B60Q1	No	Arrangement of optical signalling or lighting devices, the mounting or supporting thereof or circuits therefor	for lighting vehicle interior B60Q 3/00
F21V29	No	Protecting lighting devices from thermal damage; Cooling or heating arrangements specially adapted for lighting devices or systems	lighting fixtures combined with outlets for air-treatment systems F24F 13/078
G05D1	Yes	Control of position, course, altitude, or attitude of land, water, air, or space vehicles, e.g. automatic pilot	radio navigation systems or analogous systems using other waves G01S
G06F15	Yes	Digital computers in general; Data processing equipment in general	details G06F 1/00-G06F 13/00
G06F19	Yes	Digital computing or data processing equipment or methods, specially adapted for specific applications	G06F 17/00 takes precedence; data processing systems or methods specially adapted for

Classification	If it is ICT	Classification titles	Note
			administrative, commercial, financial, managerial, supervisory or forecasting purposes G06Q
G06F9	Yes	Arrangements for program control, e.g. control units	program control for peripheral devices G06F 13/10
G06K9	Yes	Methods or arrangements for reading or recognising printed or written characters or for recognising patterns, e.g. fingerprints	methods or arrangements for graph-reading or for converting the pattern of mechanical parameters, e.g. force or presence, into electrical signals G06K 11/00; speech recognition G10L 15/00
H04N9	Yes	Details of colour television systems	

(Source: author's own compilation)

Appendix 3 Smart city patents' cited classifications

Technology groups	Time	Cited classifications	Cluster	Repeated times	If it is ICT	Classification titles
Hardware-centric	2001-2010	G06F17	1	3	Yes	Digital computing or data processing equipment or methods, specially adapted for specific functions
	2011-2020	G06F3	1	3	Yes	Input arrangements for transferring data to be processed into a form capable of being handled by the computer; Output arrangements for transferring data from processing unit to output unit, e.g. interface arrangements
		G06F15		2	Yes	Digital computers in general; Data processing equipment in general
		H04N7		2	Yes	Television systems
		H04W4	2	1	Yes	Services or facilities specially adapted for wireless communication networks

Technology groups	Time	Cited classifications	Cluster	Repeated times	If it is ICT	Classification titles
		H04W24		1	Yes	Supervisory, monitoring or testing arrangements
		G01S5	3	1	Yes	Position-fixing by co-ordinating two or more direction or position-line determinations; Position-fixing by co-ordinating two or more distance determinations
Software-centric	2001-2010	H04B1	1	2	Yes	Details of transmission systems, not covered by a single one of groups H04B 3/00-H04B 13/00; Details of transmission systems not characterised by the medium used for transmission
		G06K9		1	Yes	Methods or arrangements for reading or recognising printed or written characters or for recognising patterns, e.g. fingerprints
		G06F17	2	3	Yes	Digital computing or data processing equipment or methods, specially adapted for specific functions
		G06F19		1	Yes	Digital computing or data processing equipment or methods, specially adapted for specific applications
		G06F15		2	Yes	Digital computers in general; Data processing equipment in general
		G06F3		3	Yes	Input arrangements for transferring data to be processed into a form capable of being handled by the computer; Output arrangements for transferring data from processing unit to output unit, e.g. interface arrangements
		G06F1		1	Yes	Details not covered by groups G06F 3/00-G06F 13/00 and G06F 21/00
	2011-2020	G06F17	1	3	Yes	Digital computing or data processing equipment or methods, specially adapted for specific functions

Technology groups	Time	Cited classifications	Cluster	Repeated times	If it is ICT	Classification titles
		H05K1	2	1	No	Printed circuits
		G06K7		1	No	Methods or arrangements for sensing record carriers
		H04B1		2	Yes	Details of transmission systems, not covered by a single one of groups H04B 3/00-H04B 13/00; Details of transmission systems not characterised by the medium used for transmission
		H04N5		1	Yes	Details of television systems
		H04N7		2	Yes	Television systems
		G06F3		3	Yes	Input arrangements for transferring data to be processed into a form capable of being handled by the computer; Output arrangements for transferring data from processing unit to output unit, e.g. interface arrangements
		H01L21		1	Yes	Processes or apparatus specially adapted for the manufacture or treatment of semiconductor or solid state devices or of parts thereof
		G03B21		1	No	Projectors or projection-type viewers; Accessories therefor
		G08B23		1	No	Alarms responsive to unspecified undesired or abnormal conditions
		G08B21		1	No	Alarms responsive to a single specified undesired or abnormal condition and not otherwise provided for
		H05K7	3	1	No	Constructional details common to different types of electric apparatus
		H05B37		1	No	Circuit arrangements for electric light sources in general

(Source: author’s own compilation)

Appendix 4 ICT patents' cited classifications

Technology groups	Time	Cited classifications	Cluster	Repeated times	If it is ICT	Classification titles
Hardware-centric	2001-2010	H04B1	1	73	Yes	Details of transmission systems, not covered by a single one of groups H04B 3/00-H04B 13/00; Details of transmission systems not characterised by the medium used for transmission
	2011-2020	H01L21	1	220	Yes	Processes or apparatus specially adapted for the manufacture or treatment of semiconductor or solid-state devices, or of parts thereof
Software-centric	2001-2010	G06F15	1	79	Yes	Digital computers in general (details G06F 1/00-G06F 13/00); Data processing equipment in general
	2011-2020	G06F1	1	184	Yes	Details not covered by groups G06F 3/00-G06F 13/00 and G06F 21/00 (architectures of general purpose stored program computers G06F 15/76)

(Source: author's own compilation)

Appendix 5 Patent titles of non-ICT smart city patents' top cited classifications

Classification	Cited classifications	If it is ICT	Cited classification titles
G01C21 (and G01C22)	G01C21	No	Navigation; Navigational instruments not provided for in groups G01C 1/00-G01C 19/00
	G01S5	Yes	Position-fixing by co-ordinating two or more direction or position-line determinations; Position-fixing by co-ordinating two or more distance determinations
	H04B7	Yes	Radio transmission systems, i.e. using radiation field
	H02J7	No	Circuit arrangements for charging or depolarising batteries or for supplying loads from batteries

Classification	Cited classifications	If it is ICT	Cited classification titles
	G06F7	Yes	Methods or arrangements for processing data by operating upon the order or content of the data handled
B60Q1	B60Q1	No	Arrangement of optical signalling or lighting devices, the mounting or supporting thereof or circuits therefor
	G08G1	Yes	Traffic control systems for road vehicles
	G03B21	No	Projectors or projection-type viewers; Accessories therefor
	F21V29	No	Protecting lighting devices from thermal damage; Cooling or heating arrangements specially adapted for lighting devices or systems
G05D1	G05D1	No	Control of position, course, altitude, or attitude of land, water, air, or space vehicles, e.g. automatic pilot
	B60R21	No	Arrangements or fittings on vehicles for protecting or preventing injuries to occupants or pedestrians in case of accidents or other traffic risks
	H04N1	Yes	Scanning, transmission or reproduction of documents or the like, e.g. facsimile transmission; Details thereof
	G06K9	Yes	Methods or arrangements for reading or recognising printed or written characters or for recognising patterns, e.g. fingerprints
	G01C21	No	Navigation; Navigational instruments not provided for in groups G01C 1/00-G01C 19/00
F21V29	F21V29	No	Protecting lighting devices from thermal damage; Cooling or heating arrangements specially adapted for lighting devices or systems
	G03B21	No	Projectors or projection-type viewers; Accessories therefor
	F21V7	No	Reflectors for light sources
	F21V21	No	Supporting, suspending, or attaching arrangements for lighting devices

Classification	Cited classifications	If it is ICT	Cited classification titles
	H01L33	Yes	Semiconductor devices with at least one potential-jump barrier or surface barrier specially adapted for light emission; Processes or apparatus specially adapted for the manufacture or treatment thereof or of parts thereof; Details thereof

(Source: author's own compilation)

Appendix 6 Hardware- and software-centric ICT patents owned by the top 100 companies in Taiwan

Rank	Company	Hardware-centric		Software-centric	
		Patents	% of total	Patents	% of total
1	HonHai Precision Industry Co., Ltd. (HonHai)	1,292	2.97%	2,038	5.68%
2	Pegatron Corp. (Pegatron)	26	0.06%	79	0.22%
3	Taiwan Semiconductor Manufacturing Co., Ltd. (TSMC)	12,768	29.30%	2,521	7.02%
5	Quanta Computer Inc.	131	0.30%	632	1.76%
6	Compal Electronics, Inc.	33	0.08%	269	0.75%
9	Wistron Corp. (Wistron)	209	0.48%	1,059	2.95%
13	Taiwan Power Company	0	0.00%	1	0.00%
17	Inventec Corp.	94	0.22%	634	1.77%
21	Acer Inc.	261	0.60%	431	1.20%
22	WT Microelectronics Co., Ltd.	0	0.00%	0	0.00%
24	AUO Corp.	1,811	4.16%	1,639	4.56%
26	InnoLux Corp.	865	1.99%	519	1.45%
28	China Steel Corp.	5	0.01%	0	0.00%
31	Chunghwa Telecom Co., Ltd. (Chunghwa)	20	0.05%	11	0.03%

Rank	Company	Hardware-centric		Software-centric	
		Patents	% of total	Patents	% of total
32	ASUSTeK Computer Inc.	135	0.31%	402	1.12%
33	Formosa Plastics Corp.	1	0.00%	0	0.00%
35	NanYa Plastics	2	0.00%	0	0.00%
38	Mediatek Inc. (Mediatek)	2,262	5.19%	1,856	5.17%
44	United Microelectronics Corp. (UMC)	2,583	5.93%	488	1.36%
45	Lite-on Technology Corp.	278	0.64%	676	1.88%
46	Micro-Star International Co., Ltd. (MSI)	7	0.02%	73	0.20%
47	Morrihan International Corp.	0	0.00%	0	0.00%
48	World Peace Industrial Co., Ltd.	0	0.00%	0	0.00%
50	Advanced Semiconductor Engineering, Inc.	396	0.91%	15	0.04%
51	Qisda Corp.	73	0.17%	133	0.37%
53	EDOM Technology Co., Ltd.	0	0.00%	0	0.00%
57	Inventec Appliances Corp.	37	0.08%	61	0.17%
58	Siliconware Precision Industries Co., Ltd.	231	0.53%	2	0.01%
60	Wiwynn Corp.	2	0.00%	29	0.08%
62	Cheng Uei Precision Industry Co., Ltd.	8	0.02%	56	0.16%
63	Walsin Lihwa Corp.	264	0.61%	145	0.40%
65	ChiMei Corp.	342	0.78%	268	0.75%
66	Chang Gung Memorial Hospital, Linkou	1	0.00%	1	0.00%
67	Simplo Co., Ltd.	0	0.00%	1	0.00%
69	Foxconn Technology Co., Ltd.	155	0.36%	378	1.05%
70	Far Eastone Telecommunications Co., Ltd. (Far Eastone)	3	0.01%	1	0.00%

Rank	Company	Hardware-centric		Software-centric	
		Patents	% of total	Patents	% of total
74	Catcher Technology Co., LTD.	1	0.00%	0	0.00%
75	Novatek Microelectronics Corp.	189	0.43%	611	1.70%
76	Taiwan Mobile Communication	1	0.00%	1	0.00%
77	Giga-byte Technology Co., Ltd.	18	0.04%	89	0.25%
83	Wistron NeWeb Corp.	128	0.29%	40	0.11%
84	Largan Precision Co., Ltd.	24	0.06%	164	0.46%
90	Chang Chun Petrochemical Co., Ltd.	0	0.00%	1	0.00%
94	Nanya Technology Corp.	407	0.93%	108	0.30%
95	Toshiba Electronic Components Taiwan Corp.		0.00%		0.00%
96	Accton Technology Corp.	36	0.08%	30	0.08%
98	Delta Electronics, Inc.	321	0.74%	306	0.85%
100	Unimicron Technology Corp.	69	0.16%	4	0.01%
	The sum of top 100 companies	25,489	58.50%	15,772	43.93%

(Source: author’s own compilation)

Appendix 7 Hardware- and software-centric smart city patents owned by the top 100 companies in Taiwan

Rank	Company	Hardware-centric		Software-centric	
		Patents	% of total	Patents	% of total
1	HonHai	190	5.90%	599	9.37%
2	Pegatron	8	0.25%	7	0.11%
3	TSMC	19	0.59%	385	6.02%
5	Quanta Computer Inc.	51	1.58%	102	1.59%

Rank	Company	Hardware-centric		Software-centric	
		Patents	% of total	Patents	% of total
6	Compal Electronics, Inc.	19	0.59%	75	1.17%
9	Wistron	52	1.61%	137	2.14%
13	Taiwan Power Company	0	0.00%	0	0.00%
17	Inventec Corp.	41	1.27%	104	1.63%
21	Acer Inc.	62	1.93%	39	0.61%
22	WT Microelectronics Co., Ltd.	0	0.00%	1	0.02%
24	AUO Corp.	20	0.62%	62	0.97%
26	InnoLux Corp.	1	0.03%	12	0.19%
28	China Steel Corp.	0	0.00%	0	0.00%
31	Chunghwa	7	0.22%	7	0.11%
32	ASUSTeK Computer Inc.	38	1.18%	56	0.88%
33	Formosa Plastics Corp.	0	0.00%	0	0.00%
35	NanYa Plastics	0	0.00%	0	0.00%
38	Mediatek	453	14.07%	234	3.66%
44	UMC	48	1.49%	107	1.67%
45	Lite-on Technology Corp.	15	0.47%	84	1.31%
46	MSI	2	0.06%	24	0.38%
47	Morrihan International Corp.	0	0.00%	0	0.00%
48	World Peace Industrial Co., Ltd.	0	0.00%	0	0.00%
50	Advanced Semiconductor Engineering, Inc.	1	0.03%	6	0.09%
51	Qisda Corp.	7	0.22%	24	0.38%
53	EDOM Technology Co., Ltd.	0	0.00%	0	0.00%

Rank	Company	Hardware-centric		Software-centric	
		Patents	% of total	Patents	% of total
57	Inventec Appliances Corp.	13	0.40%	2	0.03%
58	Siliconware Precision Industries Co., Ltd.	0	0.00%	1	0.02%
60	Wiwynn Corp.	3	0.09%	3	0.05%
62	Cheng Uei Precision Industry Co., Ltd.	1	0.03%	5	0.08%
63	Walsin Lihwa Corp.	0	0.00%	0	0.00%
65	ChiMei Corp.	14	0.43%	18	0.28%
66	Chang Gung Memorial Hospital, Linkou	0	0.00%	0	0.00%
67	Simplo Co., Ltd.	0	0.00%	0	0.00%
69	Foxconn Technology Co., Ltd.	0	0.00%	76	1.19%
70	Far Eastone	5	0.16%	0	0.00%
74	Catcher Technology Co., LTD.	0	0.00%	0	0.00%
75	Novatek Microelectronics Corp.	9	0.28%	108	1.69%
76	Taiwan Mobile Communication	2	0.06%	0	0.00%
77	Giga-byte Technology Co., Ltd.	2	0.06%	13	0.20%
83	Wistron NeWeb Corp.	55	1.71%	4	0.06%
84	Largan Precision Co., Ltd.	0	0.00%	6	0.09%
90	Chang Chun Petrochemical Co., Ltd.	0	0.00%	0	0.00%
94	Nanya Technology Corp.	0	0.00%	4	0.06%
95	Toshiba Electronic Components Taiwan Corp.		0.00%		0.00%
96	Accton Technology Corp.	38	1.18%	8	0.13%
98	Delta Electronics, Inc.	23	0.71%	101	1.58%
100	Unimicron Technology Corp.	0	0.00%	1	0.02%

Rank	Company	Hardware-centric		Software-centric	
		Patents	% of total	Patents	% of total
	The sum of top 100 companies	1,199	37.24%	2,415	37.76%

(Source: author’s own compilation)