University of Southampton

Faculty of Environmental and Life Sciences

School of Geography and Environmental Sciences

Explaining Industrial Cluster Evolution: A Case Study of E-waste Clusters in China

by

Junwanguo Guo

orcid.org/0009-0003-0624-345X

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Abstract

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Since China's reform and opening up in the 1980s, a free-market environment coupled with policy guidance has led to the emergence of many industrial clusters. The e-waste industrial cluster is one example. It is widely acknowledged that e-waste is the fastest-growing type of waste, and this has been declared a 'global crisis'. Many e-waste industrial clusters are encountering numerous challenges in balancing economic viability and environmental concerns and are facing prolonged policy uncertainty. Numerous countries have implemented regulations to restrict the export and import of e-waste, exerting a significant influence on the entire industry. As a result, entrepreneurs, workers, and governments are searching for ways to achieve industrial upgrades and transformation. This research considers the evolution of e-waste clusters in China. Focused on Guiyu and Huaqiangbei, Shenzhen, it aims to explore the process of e-waste cluster evolution, the relations between socio-cultural context, networks, and politics, how external shocks disrupted industrial development paths, and how different clusters have adapted. These issues are discussed via empirical material from 85 in-depth interviews with workers and government officials. The thesis shows that the e-waste clusters in Huaqiangbei and Guiyu have followed two modes of formation and evolution with different evolutionary paths. It finds that Guiyu has been based on a disassembly mode of waste processing that has been associated with strong ties and closed networks. This has diminished the cluster's absorptive capacity and contributed to lock-in and fragmentation. Huaqiangbei, however, has followed a reassembly mode with much closer connections to related electrical product sectors. The thesis explains the implications of these differences for training, education, and technology and how these have changed in the development phases and mature stages. A well-educated workforce and human capital are necessary to maintain a cluster's innovation level and avoid possible decline or lock-in. Policy plays a crucial role in the development of industrial clusters in China. This research transcends the limitations of singular theoretical perspectives by constructing a multidimensional analytical framework that explores the factors influencing e-waste cluster development and examines their interactions with regulatory interventions and policy shocks. The study provides valuable insights for fostering more effective industrial development in less-developed regions. Through its integration of multi-level analysis and diverse research perspectives, this work not only enriches industrial cluster theory but also offers significant guidance for formulating targeted and effective regional development policies.

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Definitions and Abbreviations

EEG .... Evolutionary Economic Geography

ICT.................................. Information and Communication Technology

MTK .... MediaTek

CEIP .... Guiyu’s Circular Economy Industrial Park

Chapter 1 Introduction

This PhD research examines the evolution of electronic waste (e-waste) clusters in China as an example of the broader changes in the development of industrial clusters. According to the Global E-waste Monitor, e-waste encompasses all types of e-products and their components that have been discarded by their owner without the intention of reuse (Baldé et al., 2017). It includes nearly every household or commercial item with circuitry or electrical components powered by electricity or batteries (Parajuly et al., 2019). The research aims to investigate the developmental trajectory of the e-waste cluster and the factors influencing its growth, analyse the interactions among various stakeholders and examine the resilience and adaptability of different clusters in response to shocks, as well as their development pathways.

Industrial cluster refers to a geographic concentration of interconnected enterprises and institutions within a particular field, characterised by the sharing of complementary resources and the presence of common attributes (Porter, 2008; Shin and Hassink, 2011). Such clusters are defined by economic interactions along the value chain, cooperative competition, specialisation, strategic internal relationships, innovation and diffusion, as well as shared cultural contexts and explanatory schemes (Van de Ven and Poole, 1995). Industrial clusters play a crucial role in fostering collaboration, facilitating knowledge exchange, and promoting specialisation within specific industries. They provide a conducive environment for firm growth, stimulate innovation, and make significant contributions to regional economic development (Duranton and Puga, 2004; Liang and Goetz, 2018). Consequently, cluster development has become an essential strategy in navigating the tension between globalisation and localisation in the pursuit of local and national economic progress (Porter, 1998a). International organisations, alongside national and subnational governments, have increasingly prioritised and supported cluster development initiatives (Grillitsch and Sotarauta, 2020).

In terms of economic geography, Krugman (1980; 1991) conducted an analysis of the factors contributing to industrial localisation, focusing on production and technology dynamics. Specifically, he explored the concentration of specialised labour, the agglomeration of supporting industries, and the exchange of knowledge and information. According to his argument, when a concentration of economic activities forms in a particular region, it generates additional benefits or advantages. One significant factor in this process is the spillover of information, which enhances the efficiency of production within clusters compared to individual enterprises. However, the formation of clusters is a complex and dynamic process that unfolds over time. The mechanisms and impacts of various factors differ across stages of cluster development, with these influencing factors evolving alongside the cluster (Boschma and Lambooy, 1999).

Therefore, it is crucial to understand industrial clusters from a dynamic and evolutionary perspective, considering their historical context and the ever-changing nature of the forces shaping them (Boschma and Lambooy, 1999). Key questions arise, such as: How do clusters form? Why do certain industries emerge in specific regions? Why are some industrial clusters able to develop more rapidly and exhibit greater adaptability and resilience in response to external shocks, allowing them to restructure more swiftly and achieve transformation and upgrading? Are there common underlying mechanisms driving their formation? These questions must be thoroughly explored.

Economic geographers have integrated evolutionary economics, the theory of new industrial zones, and innovation system theory to introduce evolutionary perspectives into economic geography for analysing the spatial distribution and variation of economic activities (Martin and Sunley, 2011a; Boschma and Frenken, 2018). The focus of research on industrial clusters has shifted from studying the elements of cluster formation elements to analysing the processes of cluster formation. By rejecting the assumptions of rational individuals and equilibrium analysis methods of neoclassical economics, advocating biological evolutionary theory, complex science, and path dependence as the theoretical foundations, insisting on historical importance, emphasising temporal irreversibility and spatial heterogeneity, and conducting research on the laws of economic change in specific spatial and temporal contexts, evolutionary economic geography (EEG) has gradually become a vital theoretical framework for understanding the spatial evolution of industries and the formation of industrial clusters (Martin and Sunley, 2007;2015b).

Much of the existing research reflects the influence of Western free-market economic thinking, where the evolution of enterprises is primarily viewed as being driven by market-led, spontaneous behaviour (Van de Ven and Poole, 1995). However, China's economic development has differed significantly from that seen in Western capitalism (Bruton and Ahlstrom, 2003). China's economic model presents a distinctive form of 'socialist market economy with Chinese characteristics,' which transcends the simple binary opposition between market and planned economies, forming a multi-layered, multidimensional hybrid system (Naughton and Tsai, 2015). In this mixed system, the state is not only the creator and guardian of market rules but also an active participant and guide in economic development. The government actively participates in economic activities through industrial policies, financial instruments, and state-owned enterprises while also creating favourable conditions for the growth of market actors (Lin, Cai and Li, 1997). This contrasts sharply with the Western free-market economic model, which emphasises spontaneous market regulation and minimal government intervention.

In China's mixed economy context, the types and developmental pathways of industrial clusters exhibit diverse characteristics. First, government-led industrial clusters hold a significant position within China's economic landscape. These clusters typically emerge from the government's strategic planning and policy support, such as in high-tech, economic, and technological development zones (Zheng, 2016). The government actively fosters and guides the development of these clusters, including the provision of infrastructure, fiscal incentives, and talent policies (Liu, Yin and Sun, 2011). In contrast, market-driven industrial clusters are primarily shaped by entrepreneurial initiative and market demand, which usually form around local industries with comparative advantages and grow through market competition and inter-firm collaboration. Notable examples include the small commodity cluster in Yiwu and the electronics industry cluster in Dongguan (Wei, Li and Wang, 2007). Additionally, China's mixed economy has given rise to a distinctive type of 'government-guided, market-operated' industrial cluster. The electronics industry cluster in Shenzhen is a prime example. Initially planned and supported by the government, it later achieved rapid growth and innovation through market forces (Yang, 2014). The development of industrial clusters within China's mixed economy also displays strong regional characteristics. Coastal clusters tend to be more market-oriented and globally integrated, deeply embedded in global value chains. In contrast, clusters in inland regions rely more on government support and local resources, primarily serving domestic markets (Fan and Scott, 2003). However, industrial clusters in China's mixed economy also face challenges. Over-reliance on government support can lead to market distortions and resource misallocation. Additionally, issues such as local protectionism and redundant construction occasionally arise, hindering the healthy development of these clusters (Bai et al., 2004).

Understanding this mixed economic system is essential for analysing the development of clusters in China. It implies that we cannot simply apply Western theories but must instead construct a more complex analytical framework that considers the interaction of multiple factors, including government policies, market mechanisms, and institutional environments (Xu, 2011). Such in-depth analysis not only enhances our understanding of the operational mechanisms of China's economy but also provides a crucial theoretical and empirical foundation for exploring the differences in cluster development across various economic systems.

However, as previously mentioned, China's industrial clusters exhibit diverse types and development trajectories, making it difficult to study China as a homogeneous whole. Against this backdrop, this research selects the e-waste cluster as a case study, aiming to provide new insights and theoretical contributions to the study of industrial clusters in China. As an emerging and distinct research subject, the e-waste cluster offers several key advantages: Firstly, with the swift technological advancement in the electronic industries in both developed and some newly industrialised countries (e.g., China), e-waste has been identified as the fastest-growing waste globally (Baldé et al., 2017). According to the Global E-waste Monitor 2020, 53.6 million metric tons (Mt) of e-waste were produced worldwide in 2019 (Forti et al., 2020), with projections indicating a significant increase in the coming decades, potentially reaching 120 million tons per year by 2050 (Coalition, 2019). E-waste has become one of the fastest-growing wastes and has been declared a 'global crisis' by the United Nations Environment Assembly (Parker, 2019). Numerous regions, especially in developing countries, have become e-waste hubs, such as Guiyu in China (Davis, Akese and Garb, 2019).

While numerous scholars have conducted field investigations and research in these areas, their studies have primarily focused on topics such as global e-waste flows, labour conditions, cultural economies, and socio-environmental injustice (Iles, 2004a; Zhang, 2009; Gregson *et al.*, 2010; Brooks, 2012; Walters and Fuentes Loureiro, 2020; Wang, Qian and He, 2021;2022), with an emphasis on e-waste itself. However, these studies have largely overlooked the importance of examining e-waste as part of a complex industrial cluster system, particularly with respect to its formation, evolution, and resilience. As Davis, Akese and Garb (2019) highlighted, a notable research gap exists in perspectives concerning 'cluster evolution' in e-waste research. The e-waste cluster not only encompasses the collection and recycling of e-waste but also integrates economic, social, cultural, and justice-related aspects, which interact and influence each other. The issues caused by the e-waste industry, such as pollution, justice, and human rights, are essentially problems of cluster issues. Following the advocacy of certain international organisations and the subsequent establishment of e-waste management systems by many countries, various facets of local industry, economy, employment, and social stability have changed to differing extents, all closely linked to cluster development. Only by adopting a cluster perspective, deeply understanding the internal logic of e-waste cluster evolution and the impacts of the external environment, grasping its evolutionary process, and analysing the root causes of existing problems can we fully recognise the various challenges faced and formulate practical and feasible response strategies.

China is one of the largest producers and was once the world's leading recipient of e-waste, making it an excellent case for studying e-waste clusters (Gregson and Crang, 2019). According to the Global E-Waste Statistics Partnership, China generated 12,066 kilotons of e-waste in 2022 (Baldé *et al.*, 2024a). Although data on e-waste imports are limited, in 2002 alone, the United States exported 10.2 million obsolete computers to Asia, with the majority destined for China (Iles, 2004a). Numerous e-waste recycling and processing clusters have formed and agglomerated in China, bringing considerable economic benefits to local areas on the one hand but also causing severe environmental and social problems on the other. Tong and Wang (2004) even pointed out that since the 1990s, the primary source of pollution in many coastal areas of China has stemmed from e-waste recycling activities.

Among them, the most famous is the Guiyu e-waste cluster, once hailed as the largest e-waste cluster in the world (Glenday, 2013). Huaqiangbei, Shenzhen is renowned for its thriving second-hand electronics industry, boasting China's largest second-hand mobile phone resale market and famous for battery recycling efforts (Xu, 2023). However, they were severely polluted (Wang, Qian and Liu, 2020). For example, lead levels in the water sample from the Lianjiang River in Guiyu were found to be 2400 times higher than the World Health Organisation Drinking Water Guidelines (Guo *et al.*, 2009). As a result, the Chinese government has set regulations to ban e-waste imports and manage these clusters (Gregson and Crang, 2019). These top-down compulsory policy actions significantly influenced the path of evolution of the industrial cluster. The study of the most prominent e-waste clusters, especially how they evolve after the strict regulation, can provide inspiration for the development of other e-waste clusters.

Given the consensus that e-waste possesses dual values—material recovery and equipment refurbishment/reuse—this study categorises the e-waste recycling industry into two primary sectors: the dismantling-oriented industry, focused on material recycling, and the reassembly-oriented industry, centred on equipment repair, refurbishment, and reuse. The cases of Guiyu and Huaqiangbei, selected for this study, exemplify two distinct e-waste processing clusters. This study conducts a cluster path development analysis of these two recycling models, including the influence of different factors on different development phases of industrial clusters, particularly networks and policies, and their response to the shocks in the face of the 'disruptive process' of economic and compulsory government control by studying industrial cluster evolution in a developing country. E-waste, especially the pollution caused by e-waste clusters, is a matter of concern at the central government level, with various attempts being made in recent years to regulate those in disarray. These attempts have resulted in varying levels of success in the environment, but, to some extent, these have disrupted the development paths of industry clusters. In recent years, the Chinese government enacted regulations prohibiting the import of e-waste. Concurrently, some Chinese cities with high pollution have imposed stringent rules on their e-waste industry. It seems clear that the e-waste industry in China has been forced to adapt.

1.1 Aims and Objectives

This research aims to generate robust empirical evidence on the underlying causes and determinants that shape the evolutionary trajectory of e-waste clusters. It seeks to explore the complex interactions, conflicts, and negotiations within these clusters over time, particularly in response to external shocks or disruptive forces. Specifically, this study examines why the Guiyu e-waste cluster became path-dependent and locked-in, whereas Huaqiangbei—benefiting from its location in a major city, associated externalities, and adaptive capacities—successfully underwent industrial upgrading and transformation.Concurrently, through extensive fieldwork, this study delves into the intrinsic tension between environmental concerns and economic imperatives, as the e-waste industry presents a paradoxical scenario – while generating substantial income for local communities, it also produces severe environmental pollution. In so doing, the research aims to broaden knowledge and comprehension of this field of study, provide empirical cases of how networks and policies affect the industrial clusters, how various agents in developing countries respond and provide ideas for cluster revitalisation.

Objective 1:

To identify diverse evolutionary trajectories within e-waste clusters, delineate key factors influencing e-waste industry development, and elucidate the challenges associated with industry upgrading and transformation.

Objective 2:

To explore the interplay between multi-level governance structures shaping e-waste clusters. To compare regional variations in response to central governance systems.

Objective 3:

To examine the varied perspectives on the e-waste industry among different agents and analyse their responses to economic and regulatory disruptions.

Objective 4:

To contribute to and advance the empirical and theoretical research within EEG. Furthermore, to propose innovative ideas and potential policies for facilitating cluster transition and upgrading.

To address the aims and objectives, this study employs various data collection methods, including archival and documentary analysis, participant observation, and interviews. Extensive fieldwork was conducted over eight months at two case sites (March to April 2021 in Guiyu, May to June in Guiyu, and August to November in Shenzhen), resulting in 85 interviews. The interviewees included local workers and government officials at both local and higher levels, ensuring enough and representative data collection.

1.2 Thesis Structure

Following this introductory chapter, the literature review and research methodology will be presented in Chapters 2 and 3, respectively. Chapter 2 provides a comprehensive review of the broader literature on industrial cluster theories and EEG, encompassing perspectives developed within and beyond the discipline of geography. This chapter is structured into four sections: a discussion of industrial clusters, an examination of EEG and cluster theory, an analytical framework,and a conclusion synthesising the key concepts.

Chapter 3 delineates the research methodology and fieldwork procedures employed in Guiyu and Huaqiangbei. This chapter serves as a bridge between the theoretical and contextual frameworks established in Chapters 1 and 2 and the empirical research that forms the foundation of this thesis. It begins by formulating research questions derived from the literature and provides a critical examination of the research process, covering several key aspects: an introduction to the two field sites, a detailed description of research methods and procedures, a reflection on researcher positionality and reflexivity, a discussion of ethical considerations encountered during the study, and an explication of the data analysis techniques utilised.

The main body of the thesis comprises four empirical chapters, encompassing a detailed overview of the e-waste industry in China, two detailed case studies, and a comparative analysis. Chapter 4 critically examines the global and Chinese e-waste landscape, providing a contextual framework for the subsequent case studies. Chapters 5 and 6 focus on empirical studies of Guiyu and Huaqiangbei, respectively. These locations were selected to explore distinct aspects of the e-waste industry: Guiyu's focus on e-waste disassembly and Shenzhen's reassembly processes. Guiyu, once recognised as China's largest e-waste cluster, serves as the subject of Chapter 5. This chapter analyses the developmental trajectory of Guiyu's e-waste cluster, proposing a life cycle model to illustrate its evolution. It elucidates the complex interactions among various stakeholders and examines how the cluster developed and responded to external shocks.

Chapter 6 examines the evolutionary trajectory of Shenzhen's e-waste cluster. Renowned for its flourishing second-hand electronics industry, Huaqiangbei hosts China's largest secondary market for mobile phone resale. In contrast to Guiyu's focus on traditional e-waste dismantling, Shenzhen's industry emphasises repair and reuse processes, which can be characterised as reassembly. The Huaqiangbei cluster exemplifies continuous upgrading and adaptability, having successfully avoided stagnation. This chapter discusses the cluster's operational model, industrial chain, distinctive characteristics, and its interrelationships with related industries. Furthermore, it investigates the factors enabling the industry to circumvent lock-in effects and achieve incremental upgrading when confronted with external shocks and evolving contextual changes. The analysis encompasses the cluster's resilience and innovative capacity, providing insights into its sustainable growth within the dynamic e-waste cluster.

Chapter 7 presents a comparative analysis of the empirical evidence from the two case studies. This chapter investigates the factors underlying the divergent developmental trajectories observed in the e-waste industries of Guiyu and Shenzhen, characterised by lock-in and upgrading, respectively. Specifically, the research emphasises the influence of cluster diversity composition, networks, and types of innovation; industrial atmosphere, culture context, and learning skills; and the impact of policies on the development paths of industrial clusters.

Chapter 8 concludes the thesis by summarising the primary arguments, findings, and policy implications. It critically assesses the limitations of the current study and proposes recommendations for future research.

This thesis provides new theoretical perspectives for understanding the evolutionary dynamics of industrial clusters while offering empirical evidence for policy formulation to promote sustainable cluster development. The research not only focuses on the internal mechanisms of clusters, the interactions between multi-agents, and the influence of networks but also considers the broader institutional environment and policy framework impacting cluster development, thus constructing a systematic analytical framework. This approach is significant for deepening our understanding of cluster resilience and adaptability, especially in rapidly changing economic and policy contexts.

Through comparative analysis of cases of successful transformation and the one trapped in lock-in, this study aims to identify key influencing factors and potential policy intervention points, providing valuable insights for promoting the sustainable development of industrial clusters. This comparative research method not only reveals the critical elements of successful transformation but also helps us understand the potential risk factors leading to developmental lock-in, offering more in-depth and practical guidance for policymakers and industry participants.

One of the key features of this study is its focus on underdeveloped regions. Choosing China as a case study allows us to delve into the role of the state in shaping industrial growth, an aspect often criticised as under-researched in the field of EEG. As MacKinnon et al. (2019) point out, existing literature tends to overly focus on micro-level firms in regional development, neglecting the role of other key actors and institutions. Furthermore, this study examines the impact of economic and policy shocks, as well as conflicts and negotiations among various actors, including government entities, workers, and local communities. By exploring these interactions, the research provides a deeper perspective, considering different scales of political and relational networks. It also emphasises the importance of recognising grassroots demands, aiming to reduce discrepancies between top-down policies and local realities, policy requirements, and research focus.

Furthermore, this study's methodological choices carry significant theoretical implications. Firstly, it demonstrates the unique value of qualitative methods in explaining the complexity of industrial evolution, supplementing EEG with important research tools. Secondly, through its investigation of 'grey' industries and informal economies, this study expands the research boundaries of economic geography, offering new perspectives for understanding diverse economic formations in the era of globalisation (Coe *et al.*, 2017). Most importantly, this study showcases the value of qualitative methods in theory construction. Through in-depth analysis of specific cases, the research not only verifies the explanatory power of existing theories but also identifies their boundary conditions and potential directions for expansion.

Overall, this study offers valuable insights for achieving more effective industrial development in less-developed regions. By integrating multi-level analysis and diversified research perspectives, this study not only enriches industrial cluster theory but also provides important references for formulating more targeted and effective regional development policies.

Chapter 2 Literature Review

This chapter presents a critical overview of the relevant literature to establish the theoretical and conceptual background for the subsequent empirical analysis and identify the existing research gaps. The chapter is structured into four sections: industrial cluster debates, evolutionary economic geography and clusters, an analytical framework and a conclusion. This structure progressively narrows the research down from broader theoretical perspectives to the specific substantive concerns addressed in the thesis.

The first part of the chapter examines the literature on industrial clusters, including the definitions of clusters and cluster study theories. Cluster research has predominantly focused on the agglomeration effects brought about by clusters, such as knowledge spillovers and competitive advantages (Porter, 1998a; Maskell and Malmberg, 1999). However, clusters are complex and dynamic systems that are not just a combination of economic forces but also possess diverse factors, including social and cultural elements (Martin and Sunley, 2011a). Clusters are products of the interplay between various agencies and are constantly evolving. However, existing research has paid relatively little attention to analysing the evolutionary processes of clusters from a dynamic perspective, such as how clusters emerge, decline and transform over time, as well as whether the agglomeration effects persist (Martin and Sunley, 1998).

The following section critically examines the theoretical frameworks used to study the evolution of industrial clusters and introduces the ways in which evolutionary economic geography (EEG) has reshaped the way clusters are investigated. Key concepts such as path dependence, lock-in and resilience are introduced. The life cycle theory, which metaphorically compares clusters to living organisms with evolutionary paths of birth, growth, maturity and eventual death, is also discussed (Van de Ven and Poole, 1995; Press, 2006; Menzel and Fornahl, 2010), although Martin and Sunley (2011a) argue that the reality of industrial clusters is far more complex. To consider the fluctuations in resource accumulation potential, internal connectivity and system resilience during cluster development, this chapter introduces the Cluster Adaptive Cycle Model, which explains the processes and mechanisms of cluster evolution. But applying this model alone is not enough, and it is crucial to recognise contextual factors and interactions between different agencies, institutions and power relations. This perspective acknowledges the intricate spatial interweaving of contextual relationships and clusters. This chapter provides a detailed discussion of the relationships between agencies, policies, related variety and cluster development and constructs an analytical framework for examining the causes of divergent cluster development pathways. These theories collectively offer significant insights for this thesis and lay the groundwork for the study.

2.1 Industrial Clusters

When discussing industrial clusters, notable examples such as Silicon Valley in California, Genome Valley in Hyderabad or the East London Tech City are frequently mentioned. The legendary status of Silicon Valley has attracted numerous scholars, and attempts have even been made to replicate the economic growth pattern facilitated by clustering (Vicente, 2018). Since the seventeenth and eighteenth centuries, researchers have noted a trend for industries to concentrate in specific locations, sparking strong interest in industrial localisation (Von Thünen, 1842). Marshall (1920) proposed the classic theory of industrial agglomeration to explain the phenomenon and underlying mechanisms of related firms within the same industry tending to concentrate in specific geographical locations. These agglomeration forces primarily stem from various externalities that create interdependencies in firms' locational choices and ultimately lead to the spatial concentration of innovative activities.

Porter's (1990) *'The Competitive Advantage Of Nations'* is considered foundational in the study of clusters. Porter popularised clusters by conceptualising them as an analytical tool and advocating for their use as a crucial policy instrument (Asheim, Cooke and Martin, 2006). As a policy advisor and proponent of cluster theory, Porter has helped nations, regions and cities worldwide to identify clusters (Waits, 2000). Numerous organisations, including governments, policymakers and institutions, are now actively engaged in promoting and developing clusters (Doeringer and Terkla, 1996; Moyoyama, 2008).

Clusters have garnered significant global attention, becoming a focal point of academic inquiry (Martin and Sunley, 2003), and their study has evolved from a mix of disciplines including economics, industrial economics, urban planning, economic geography and strategic management. Consequently, the literature on clusters is extensive and diverse, offering a 'multi-perspective approach' to understanding spatial economic phenomena (Benneworth and Henry, 2004). This chapter begins by exploring the definition of clusters and follows this with an analysis and clarification of cluster theory before concluding by establishing the theoretical perspective adopted in this study.

2.1.1 What is an Industrial Cluster?

With the development of economic globalisation, the significance of geographical location has been questioned. However, scholars argue that regional rather than national economies are the focal points for global trade and wealth creation (Krugman, 1997; Porter, 1998b; Scott, 1998). Economic globalisation has led to increased specialisation at regional and local levels, fostering greater regional economic uniqueness (Asheim, Cooke and Martin, 2006). As transportation costs decrease and trade barriers are lowered, businesses are able to form clusters with similar enterprises, benefiting from local external economies of scale. Meanwhile, knowledge spillovers and competition stimulate local endogenous innovation and production growth. The concept of clusters has gained widespread acclaim due to its extensive application, particularly after Porter (1990) summarised and promoted it. Many governments have adopted clustering as a key policy tool to improve local and national competitiveness. However, despite its attractiveness, the concept also poses numerous challenges, and enthusiasm for the concept often leads academics to overlook fundamental conceptual, theoretical and empirical issues (Held, 1996; Rosenfeld, 1997; Steiner, 1998). Government agencies often employ overly broad general classifications, such as innovative or electronic information industries, but clusters are complex and can include different sectors. Scholars and researchers tend to rely too much on statistical and econometric analyses, such as agglomeration, transaction, NAICS or SCI codes, which are widely used classifications, so it is therefore essential to clarify exactly what clusters entail.

The origin of the cluster concept can be traced back to Alfred Marshall's analysis of economic exchanges under partial equilibrium. Marshall conducted a descriptive analysis of a specific form of organisational production activity that he termed 'industrial districts' (Sunley, 1992; Vicente, 2018). This concept first appeared in Marshall's *The Pure Theory of Domestic Values* (1879). Subsequently, in *Principles of Economics* (1890, p.348), Marshall discussed 'the concentration of specialised industries in particular localities' and explained this phenomenon through a 'triad of external economic factors.' The concepts of industrial agglomeration (Storper, 1989), innovation environments (Camagni, 1995), and technological agglomeration (Scott, 1990) are based on Marshall's ideas. These concepts were further developed by Italian researchers in the 1970s, coinciding with the beginning of a wave of research on the determinants of the post-Fordist economic production system in industrialised economies. This research defined industrial districts as regional realities in which workers and groups of companies in the same industry formed large-scale agglomerations within specific areas (Beccatini, 1979).

Dei Ottati (1994) developed this definition further by defining the production system of industrial distracts as:

> *'A concentration, in a specific area, of a large number of firms, each of which carries out a specialised activity that may regard either the realisation of a certain phase in*

> *the production process of the typical industry of the district [...] The division of labour within the industrial district is both vertical and horizontal (P.464).'*

Porter regarded industrial clusters as a group of industries connected vertically through relationships between buyers and suppliers or horizontally through relationships between customers, technology and channels. Subsequently, he incorporated industrial clusters into the scope of competitive strategy research and explicitly proposed the concept of industrial clusters. Porter (1998b)stated that:

> *'A cluster is a form of network that occurs within a geographic location, in which the proximity of firms and institutions ensures certain forms of commonality and increases the frequency and impact of interactions (p. 226).'*

In 2000, he included governments and other relevant institutions within the scope of geographic agglomerations (Porter, 2000b;a). Building upon Porter's cluster definition, Feser (1998) emphasised the competitive nature of institutions, arguing that 'economic clusters are not only related and supportive industries and institutions but also competitive institutions that enhance their competitiveness through relationships (p. 26).' Pyke (1998) defined industrial clusters as gatherings of interrelated enterprises in the process of reproduction, usually within an industry and rooted in local communities. Unlike Porter, he explicitly emphasised rootedness based on connectivity.

Martin and Sunley (2003) argued that there was some confusion in the definition of clusters, proposing that the concept should not be limited to predetermined geographical scales or patterns. Just as Porter (1998a) suggested, clusters 'vary in size, breadth, and state of development (p.204).' For instance, some clusters are predominantly composed of small and medium-sized enterprises, while others comprise small and large enterprises. There are natural clusters (bottom-up) and planned clusters (top-down). There are horizontal, vertical and lateral clusters; clusters centred around universities and clusters without university connections; traditional and high-tech industry clusters; clusters based on value chains, industry-specific knowledge, technology and skills; and various other classifications of clusters such as merging, mature and declining clusters.

Despite the existence of many definitions and classifications of clusters and a range of cluster typology models, it is still possible to identify three common characteristics of clusters. The first of these is a critical mass of co-located specialised industries; the second is a degree of local interaction, and the third is knowledge exchange through face-to-face interaction between businesses. As recently recognised in neo-Italian and evolutionary economic research, clusters are dynamic and constantly evolving rather than static (Uyarra and Ramlogan, 2012; Payne, 2022). Considering these features, this study follows Porters' (1998a) cluster theory and defines a cluster as a dynamic concentration of related, supportive and even competitive industries and institutions in a specific region.

2.1.2 Cluster Study Theories

This section begins with a systematic literature review of industrial cluster theory across various disciplines and schools of thought, including Marshall's and Porter's cluster research. Building on this foundation, the research focuses on the theoretical contributions and empirical studies of industrial clusters within economic geography. Economic geography offers a distinctive theoretical perspective on industrial clusters, conceptualising them as 'knowledge communities'. This theoretical framework transcends the traditional cluster definition that emphasises geographical proximity, instead highlighting the dynamic processes of knowledge creation, dissemination and application within clusters. Based on this approach, the study will specifically examine the mechanisms of tacit knowledge flow and sharing within clusters.

Marshall (1919) used the term 'industrial district' to describe the geographical concentration of specialised industries and explained that the development of industrial districts resulted from positive externalities arising from the concentration and interconnectedness of companies and industries. These externalities include inherited skills, the growth of affiliated firms, the use of highly specialised equipment, the formation of local labour markets for specialised workers, the 'industrial atmosphere' and leadership and the introduction of innovation (Marshall, 1920). Without these conditions, a collective industrial atmosphere would not emerge. To truly benefit from this industrial atmosphere, geographical proximity should promote a specific organisational structure based on various forms of cooperation and competition among local participants (Vicente, 2018).

For Marshall, the industrial district represented the logical outcome of economic evolution, with economic development achieved through the invention of more functional specialisation (differentiation) and their closer connection (integration) (Sunley, 1992; Martin, 2006). Industrial districts are regarded as an organisational model of economies of scale within large integrated enterprises (Marshall, 1920). When small companies within an industrial region specialise in specific stages of the production process and establish exchange relationships in the final integration stage, the economies of scale at the regional level surpass the economic benefits achieved internally by large individual companies through the division of labour. Marshall (1919) described these exchange relationships as 'related actions' that complement the traditional competitive relationships between companies operating in the same stage of the production process within a region. Within such industrial organisations, companies can specialise in technologies that are specific to their production stages while ensuring a degree of stability in the local market, allowing companies to compete within the region (Ravix, 2014). Marshall (1919) saw industrial districts as an efficient form of production ecosystem. As the entire production process is distributed among several interdependent companies, it generates greater productive, propagative and ideational dynamics within the region compared to a large bureaucratic organisation, and these dynamics lie at the core of economic development and innovation (Vicente, 2018).

Marshall's research findings are notably linked with the Italian industrial economics school (Asheim, Cooke and Martin, 2006). Researchers, through case studies of several micro-regions in Italy (Bagnasco, 1977; Becattini, 1987), supplemented Marshall's theories with a sociological dimension (Baccatini, 1990), emphasising that industrial districts are also socio-economic entities. Krugman (1992) later pointed out that firms have the ability to demonstrate economies of scale, primarily reflected in the continuous increase of scale returns and network effects (Arthur, 1994a). The new trade theory explains the issues of economies of scale and first-mover advantages. Economies of scale refer to lowering unit production costs through large-scale production, meaning that fixed costs are more effectively distributed (Krugman, 1991). Based on new trade theory and the concept of increasing returns, researchers then made advances in the realm of incomplete competition, nonlinear and multiple equilibrium models, developing highly formalised models of localised industrial specialisation to explain the relationship between declining transportation costs, increasing returns and the agglomeration of economic activities (Fujita, Krugman and Venables, 2001; Thisse, 2002; Baldwin et al., 2011). However, this model has been criticised as it does not consider non-transactional interdependencies that may affect the industrial organisation, such as social institutions (Martin and Sunley, 1996; Martin, 1999).

Porter's concept of 'neo-Marshallian' clusters emerged a century later (Martin and Sunley, 2003) when Porter integrated Marshall's ideas into business studies, linking microeconomic theories of competition with the role of localisation in creating competitive advantage. Porter (1990) developed a model that explained how localisation affects competition through four interrelated factors, which he represented graphically in the form of a diamond, including firm strategy, structure and rivalry, factor input (supply) conditions, demand conditions and related and supporting industries. Porter delineated a complex local environment that enabled him to identify numerous controlling factors in cluster development policies. Porter's diamond theory has also been widely applied in policy formulation (Martin and Sunley, 2003; Asheim, Cooke and Martin, 2006).

However, Porter's theory faced criticism. Firstly, his definition of clusters lacks precision, particularly in terms of geographical boundaries and industry, leading to significant confusion. His definition of clusters is not standardised (Martin and Sunley, 2003; Swann, 2006), and people may interchangeably use clusters, cities and regions (Baptista and Swann, 1998; May, Mason and Pinch, 2001). Notably, in Porter's (1998a) empirical studies, various scales ranging from cities and metropolitan areas to states are often used interchangeably, resulting in significant geographical ambiguity and substantial confusion at the level of policy formulation. Secondly, Porter's identification of clusters at the industrial level is ambiguous. Martin and Sunley (2003) criticised his rules for distinguishing clusters as highly arbitrary and impressionistic. Thirdly, Porter's view that clusters depend on competition and competitive advantage is one-sided, as some clusters are driven by science and innovation (Cooke, 2004). Finally, Porter's theoretical framework pays insufficient attention to the social dimensions of cluster formation and evolution, which limits a more comprehensive understanding of their dynamic mechanisms (Martin and Sunley, 2003).

Economic geographers see industrial clusters as 'knowledge communities' (Loasby, 1999), and this perspective emphasises the crucial role of local knowledge and 'collective learning' in the formation and development of clusters (Hassink, 1997; Maskell, 2017). The argument is that in the context of a globalised economy, the key to regional competitiveness lies in the capacity for localised knowledge creation. In this process, individuals and firms engage in collective learning by acquiring new technologies, establishing trust relationships and sharing and exchanging knowledge (Cohen and Fields, 1999). The geographical concentration of specialised and complementary firms increases opportunities for formal and informal (or tacit) knowledge exchange, which facilitates connections between local firms and external knowledge, accelerates the diffusion of new ideas within the locality and maintains and strengthens the uniqueness of various forms of knowledge (Marshall, 1890). However, the geographical scope of knowledge spillovers is limited, primarily because knowledge, particularly tacit knowledge, has strong regional characteristics. The dissemination of tacit knowledge relies mainly on face-to-face interactions and frequent communications, which decay with distance. Accessing external knowledge requires proximity to the sources and the holders of that knowledge. Audretsch and Feldman (1996b) pointed out that the cost of knowledge transfer increases with spatial distance. Leamer and Storper (2017) also argued that in the emerging information economy, the importance of tacit knowledge is continuously growing and strengthening the spatial agglomeration of economic activities and local specialisation trends.

Despite providing new perspectives for understanding industrial clusters, local knowledge on cluster theory faces many criticisms and challenges. Firstly, knowledge takes diverse forms, including formal and informal, codified and tacit types (Amin and Cohendet, 1999; Breschi and Lissoni, 2001; Breschi and Malerba, 2001). Simply associating specific forms of knowledge with particular socio-economic clusters tends to oversimplify the complex relationship between knowledge and clusters (Martin and Sunley, 2003). Secondly, while many theories emphasise the importance of localised tacit knowledge, there is still a lack of any clear definition and explanation of its specific content and how it serves as a source of competitive advantage (Martin and Sunley, 2003). This theoretical ambiguity limits our in-depth understanding of cluster dynamic mechanisms. Furthermore, some scholars criticise cluster theories for abstracting clusters from the broader economic landscape, neglecting the interaction between clusters and their external environment (Breschi and Malerba, 2001). Consequently, there is a need for a theoretical framework that can situate cluster development within the broader context of the evolution of industrial and innovation dynamics.

Economists such as Schumpeter (2013) introduced concepts such as ‘creative destruction’ to explore the role of innovation in transforming economic structures. Nelson (1985) and Witt (2016) subsequently developed a series of evolutionary economic models, extending this line of thought. However, the complexity of economic evolutionary processes and their close connection with territorial and local factors make it difficult to fully grasp their essence purely through economic analysis. Against this backdrop, the rise of EEG provided a new theoretical framework for integrating economic and spatial dimensions. Compared to traditional economics, geography can employ qualitative research methods to delve into factors such as social, cultural, network, and institutional aspects involved in evolutionary paths that are difficult to quantify. This methodological advantage enables EEG to more comprehensively capture the complexity of industrial cluster evolution. The following sections will provide a detailed introduction to this theoretical approach.

2.1.3 Summary: Industrial Cluster Theory

Industrial clusters have long been an important area of research, and in recent years, scholars have conducted in-depth studies on industrial clusters from diverse theoretical perspectives. These investigations have resulted in the development of a series of related yet distinctive theories, primarily encompassing new industrial districts, industrial clusters and regional innovation systems. The evolution of industrial cluster theory can be traced back to Marshall’s (1890) studies on the economic effects of industrial agglomeration, in which he posited that industrial agglomeration could lead to significant cost savings. Subsequently, Porter (1998a) introduced Marshall’s ideas into business research to further expand the concept and application of industrial clusters. Economic geographers tend to emphasise the role of industrial clusters as knowledge communities, highlighting the mechanisms of sharing tacit knowledge within clusters, considering it one of the key processes in cluster formation and development. However, despite the abundance of literature on industrial clusters, the concept remains somewhat ambiguous. Many important questions remain inadequately addressed, such as how do clusters emerge, form and grow? What are the core mechanisms driving cluster development? Do industrial clusters have life cycles, and if so, what are their characteristics and influencing factors? Can industrial clusters have negative effects, and if so, what are they, and how can they be mitigated or prevented?

Research on industrial clusters in China is less developed. Although research is growing (Kang and Ramirez, 2007; Fleisher et al., 2010; Huang et al., 2011; Barbieri, Di Tommaso and Bonnini, 2012), it is still inadequate. Theoretically, existing studies have not explicitly verified or developed theories on industrial clusters and have not theoretically elaborated on the impact of new phenomena such as marketisation, globalisation and urbanisation on the geographical concentration of industries in China. There is also a lack of research on less developed areas and at the level of enterprises, and the key question of whether various industrial concentration or agglomeration theories originating from developed market economies can explain China's industrial geographical concentrations remains unanswered. As Menzel and Fornahl (2010) assert, cluster formation is a historical process that can only be understood when it is seen in dynamic terms over time. To address these questions and the gaps in the research, relevant theories of EEG are introduced into the cluster study, which allows us to understand and clarify the evolutionary laws of clusters and their dynamic mechanisms.

2.2 Evolutionary Economic Geography and Clusters

Evolutionary Economic Geography (EEG) primarily focuses on how new economic development paths unfold over time and space and can be used to address the historical evolution of regional economic activities and reveal the mechanisms behind the spatial distribution of economic activities (Frenken and Boschma, 2007). The theoretical foundation of EEG involves the integration of generalised Darwinism, complexity theory and path dependency theory (Witt, 2003). The theoretical construction of this approach is mainly reflected under three headings. Firstly, generalised Darwinism provides EEG with a fundamental analytical framework, emphasising evolutionary mechanisms such as variation, selection and retention within economic systems. Secondly, based on Schumpeter's innovation theory, path dependency and complexity theory, EEG adheres to the 'historical importance' principle. This perspective stresses the irreversibility of time and the heterogeneity of space, offering a new lens for analysing the spatial distribution and changes in economic activities (Potts, 2007). Thirdly, the introduction of path dependency theory further enriches the analytical tools of EEG, as it underscores the significant role of historical contingencies and self-reinforcing dynamics in determining economic outcomes (David, 1985; Arthur, 1994b). Path dependency theory helps explain why certain regions can form sustained economic advantages while others fall into lock-in.

Following the global financial crisis 2007, EEG research underwent a significant paradigm shift (Bello, 2008; Bristow and Healy, 2020). Academics, policymakers and practitioners began to focus increasingly on the concept of economic resilience, particularly in the context of heightened economic uncertainty caused by recent geopolitical tensions, trade conflicts, climate change, the emergence of disruptive technologies and the COVID-19 pandemic (Gong et al., 2022). Although regional development demonstrates strong path-dependent characteristics, the process of historical evolution does not follow a simple linear pattern. In a dynamically changing macroeconomic environment, the concept of overemphasising historical research has been questioned, and the research focus of EEG has, therefore, shifted from the traditional perspective based on local industrial (spatial) evolution to exploring how regions cope with sudden events and future uncertainties through adaptive mechanisms. Evolutionary economic geographers have begun to employ concepts such as 'regional resilience' (Mensch, 1979; Schumpeter, 2013), 'recovery' and 'adjustment and adaptation' (Arrow, 1962; Howells, 2002) to delve more deeply into how local industrial clusters respond to sudden changes in the macro- or institutional environment, as well as examining their repair and adjustment mechanisms. These concepts are elaborated upon in the following sections.

2.2.1 Path Dependence

Over the past few years, 'path dependence' and 'lock-in' have emerged as crucial concepts in EEG (Martin and Sunley, 2006). Some evolutionary economists have even elevated these concepts to the status of 'first principles' in evolutionary economics (Hall, 1994). Walker (2000) argues that one of the most exciting ideas in contemporary economic geography is that past choices – such as technology, patents or labour skills – significantly influence later decisions regarding methods and designs. Scott (2006) further emphasises that any understanding of economic landscapes must be framed through a dynamic of cumulative causation, arguing that the ontological significance of regional growth and development is deeply rooted in path-dependent economic evolution and recursive interaction.

Path dependence theory transcends traditional equilibrium concepts, emphasising the significance of history and asserting that economic development cannot escape historical influences (Setterfield, 1997) and that, in essence, the outcomes of processes or systems are products of historical evolution (Martin and Sunley, 2006). This concept is frequently associated with technological lock-in (David, 1985), dynamic increasing returns (Arthur, 1988;1994a) and institutional hysteresis (North, 1990). David's (1985) research on path dependence emphasises its three main characteristics: Firstly, small-scale, historical contingencies can have long-term impacts on the developmental trajectories of technologies, organisations and systems. Secondly, early decisions resonate throughout historical processes, noting that these decisions are not necessarily the most rational or optimal. Consequently, technologies, organisations, and systems may become ‘locked-in’ to suboptimal forms or trajectories. Thirdly, technological ‘lock-in,’ emphases technical interrelatedness, economies of scale and the quasi-irreversibility of investments.

Certainly, path dependence does not simply equate to historical determinism or ‘past dependence’ (Håkansson and Lundgren, 1997). Instead, it emphasises a probabilistic and contingent process. Archer (1996) suggests that current developmental trajectories are gradually shaped through the interplay between existing innovations and historical inheritance. Pre-existing socio-economic structures and the cumulative effects of past actions collectively form the contextual background for current activities. The outcomes of this process, in turn, become the foundational conditions for the next round of activities (Martin and Sunley, 2006).

Building upon previous research, researchers proposed a fundamental model of path dependence, splitting path development into three stages (Martin and Sunley, 2006). In the pre-formation phase, new technologies and products are at an exploratory stage, which is considered directionless and characterised by random decisions. However, scholars have critiqued this, arguing that the emergence of new technologies and products results from purposeful behaviours and decisions by economic agents (Sydow, Schreyögg and Koch, 2005; Martin and Sunley, 2006). The second stage commences at a critical juncture, typically a historical contingency or a random event that leads to the adoption of a particular choice or opportunity. This choice then begins to attract other participants, generating agglomeration effects. Once the critical threshold is reached, the path becomes ‘locked-in.’ The third stage is characterised by accumulation and self-reinforcement processes. Sydow, Schreyögg and Koch (2005) emphasise that the dissolution of technological, industrial or institutional trajectories is often precipitated by external shocks, which disrupt system stability and create opportunities for new paths to emerge. Based on this analysis, developmental trajectory can be further divided into four stages: pre-formation, path creation, path lock-in and path dissolution (Figure 2.1).

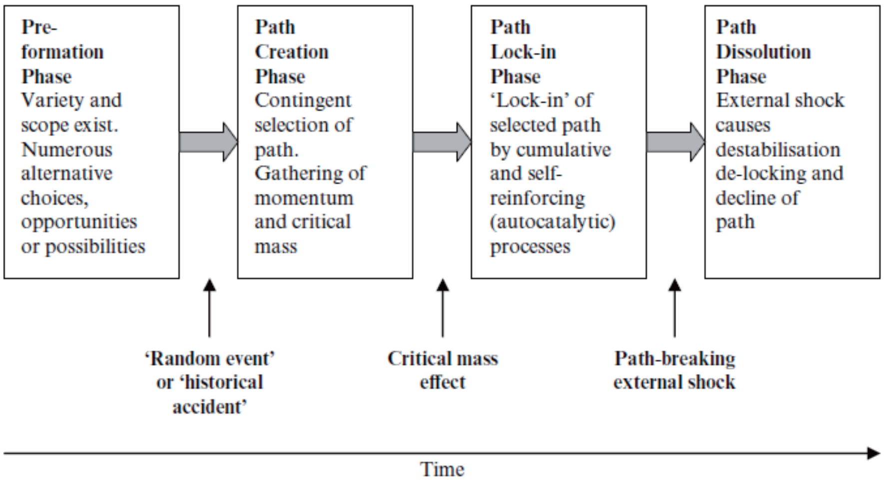

Figure 2.1 Phases of the economic evolution of an industry or technology implied by basic David-Arthur-type path dependence models (Martin and Sunley, 2010)

This path-dependence model has been widely adopted by economic geographers to explain the evolutionary processes of specific industries, technologies or institutions within particular geographic locations or across multiple regions (Martin and Sunley, 2010). The research primarily focuses on the mechanisms of local 'network externalities' and 'increasing returns.' When these two mechanisms effectively stimulate innovation and competition, they can generate positive lock-in effects, typically observed in high-tech agglomeration areas such as Silicon Valley, Munich, or Cambridge. Conversely, when a region becomes overly dependent on a specific industrial technological path, as seen in some traditional industrial areas, it may lead to the formation of a gradual rigidity in the regional economic structure, resulting in negative lock-in. In such circumstances, the regional economy exhibits lower adaptability and resilience, and such regions may experience industrial decline or overall economic regression when faced with external shocks.

2.2.2 Lock-in

As mentioned above, 'lock-in' is a core notion that helps to explain path dependence and historical embeddedness in regional economic development. David (1985) and Arthur (1989) initially proposed the phenomenon of 'lock-in' in their studies on technological evolution. David (1985), through the case study of the QWERTY keyboard, explained how technological choices can be influenced by historical contingencies, eventually leading to technological lock-in. Arthur (1989) developed this idea further, emphasising the role of increasing returns in technological lock-in. Grabher (1993) then introduced this concept into economic geography, significantly expanding its application. In economic geography, 'lock-in' describes a state in which a region or industry finds it difficult to adapt to changes in the external environment or shift towards new development directions due to specific structures, institutions or technological paths that were formed during long-term development (Martin, 2010). This concept is crucial in explaining why certain regions can maintain long-term economic advantages while others fall into developmental stagnation.

Grabher (1993) refined the typology of lock-in further, categorising it into functional, cognitive and political lock-ins. These types of lock-in often interact, forming a self-reinforcing system. Grabher's research revealed a paradoxical phenomenon: the factors that once drove the development of industrial districts – such as a strong industrial atmosphere, highly specialised infrastructure, close inter-firm connections and robust regional political support – may later evolve into stubborn barriers to innovation. This phenomenon shows that regional development can be constrained by socio-economic conditions that were shaped by its early success, falling into the so-called 'rigid specialisation' trap. Functional lock-in refers to the limits of innovation and transformation capabilities due to specific technological or industrial structures. Through an empirical study of the coal industry in the Ruhr region of Germany, Grabher (1993) pointed out that while the stability and mutual adaptability of relationships within industrial clusters are conducive to reducing transaction costs, long-term and close intra-regional relationships may lead to severe cross-border functional deficits. This will cause firms to fall into a dependent supplier situation, ultimately resulting in companies being locked into specific transaction relationships and finding it difficult to adapt to changes in the external environment.

Cognitive lock-in refers to the phenomenon by which inherent thought patterns hinder the acceptance of new ideas and the generation of innovation. Grabher (1993) pointed out that long-term personal relationships result in the formation of a standard language system among interacting subjects in terms of technology, rules and knowledge cognition. While this unique mode of communication can improve communication efficiency, it may also result in cognitive closure. Specifically, industrial clusters tend to form a distinctive worldview that determines which phenomena are perceived and which are ignored. This selective perception may lead to sluggish or inadequate responses from cluster members to changes in the external environment. Elster (1979) elaborated further on this phenomenon, arguing that group thinking promotes 'parametric rationality' rather than 'strategic rationality', which may result in an 'over compensatory response' where the group is more inclined to increase investment in existing technological paths rather than attempt innovations or new development directions. This cognitive lock-in limits the possibilities for innovation and may also cause clusters to react slowly or inappropriately when facing changes in the external environment.

Political lock-in demonstrates the obstructive effect of existing interest structures on the implementation of change. Grabher (1993) pointed out that the phenomenon of venality ('Filz') may also exist between industrial and political management systems, leading to the formation of powerful interest alliances between enterprises and governments, thereby hindering the entry and development of new industries. Specifically, dominant industrialists may collude with the government to maintain monopolistic positions. Kunzmann (1986) also claimed that the symbiotic relationship between the political-administrative system and traditional industries hinders the timely restructuring of industrial clusters while paralysing political innovation.

The impact of lock-in phenomena on regional economic development has a dual nature. In stable economic environments, lock-in can bring positive effects, such as the industrial agglomeration effects described by Marshall (1890), promoting the formation of economies of scale and advantages of specialisation. However, lock-in may cause regions or industries to lose competitiveness in rapidly changing environments, forming what Hassink (2010) termed 'declining regions.' Given the potential negative impacts of lock-in, breaking the lock-in dilemma has become a crucial objective in regional policy-making. Tödtling and Trippl (2005) proposed several potentially effective unlocking mechanisms, including external shocks, policy interventions and diversification strategies. Among these, cultivating new industrial or technological paths and improving system diversity and adaptability are key strategies to avoid negative lock-in. In recent years, with the dramatic changes in the global economic environment, the 'lock-in' concept has played an important role in understanding and building regional economic resilience. Simmie and Martin (2010) pointed out that avoiding negative lock-in and maintaining adaptability are core factors in building regional economic resilience, and this requires local policymakers to cultivate new development paths while maintaining existing advantages in order to address increasing uncertainty and external shocks.

2.2.3 Resilience

The term 'resilience' originates from the Latin root 'resilire,' referring to the capacity of an entity or system to recover its original form and position after experiencing disturbance or shocks (Martin, 2012). This concept has been widely applied in fields such as engineering, ecology and disaster science. However, it is only recently that economic geographers have begun to introduce the concept of resilience to examine how regional economic systems respond to shocks and disturbances and explain why different systems exhibit varying degrees of adaptability when faced with such shocks (Hassink, 2010; Martin, 2012).

In most applications, resilience is defined as the ability of a system to return to its pre-shock state after experiencing a disturbance, specifically reverting from a pre-shock equilibrium to a stable state or path, a process that is known as 'engineering resilience' (Holling, 1973). This concept is similar to the theory of self-restoring equilibrium dynamics in mainstream economics. According to this theory, economic systems are viewed as self-balancing; when they deviate from equilibrium, the free operation of market forces is expected to restore them to a new state of equilibrium. However, regional economies are in reality in a state of constant dynamic change rather than a state of equilibrium. In other words, the resilience of a region is itself constantly evolving (Simmie and Martin, 2010). This dynamic change may in turn influence the region's capacity to respond to future shocks.

The second definition of resilience is ecological resilience, which refers to a system's capacity to absorb shocks without altering its fundamental structure and functions (Walker et al., 2006). This concept assumes that economic systems possess multiple domains of stability and that when a system experiences a shock that exceeds its absorptive capacity, it transitions to another equilibrium state or path. This notion is often associated with hysteresis, suggesting that shocks can permanently affect economic systems either positively or negatively (Setterfield, 2010). However, some economists argue that the economy is a historical and contingent process, and multiple equilibria can only be observed retrospectively as an empirical phenomenon rather than as predetermined states (Metcalfe, Foster and Ramlogan, 2006).

Adaptive resilience is the third interpretation of resilience. This perspective originates from complex adaptive systems theory, which posits that the constituent elements of economic systems are able to co-evolve. These elements can spontaneously reorganise and adjust, particularly in response to external shocks (Martin and Sunley, 2007). Adaptive resilience sees resilience as a dynamic process that aligns with the ideas of evolutionary economics. This approach emphasises the self-adaptability of economic systems when confronted with changes and shocks and the interactions and co-evolution of various components (Martin, 2012).

Martin (2012) categorises regional resilience into four dimensions: resistance, recovery, reorientation and renewal, and suggests that regional resilience is a dynamic process (Figure 2.2). Before the shock, the region's previous growth trajectory and factors such as its economic structure, institutions, policies and resources collectively determine the region's sensitivity and capacity to respond to shocks. However, as shocks emerge, the regional economic structure changes, adapts and adjusts. Positive restructuring and recovery enable the region to rebuild its core functions and withstand external and internal shocks, thereby demonstrating the economy's adaptive robustness (Martin and Sunley, 2015a).

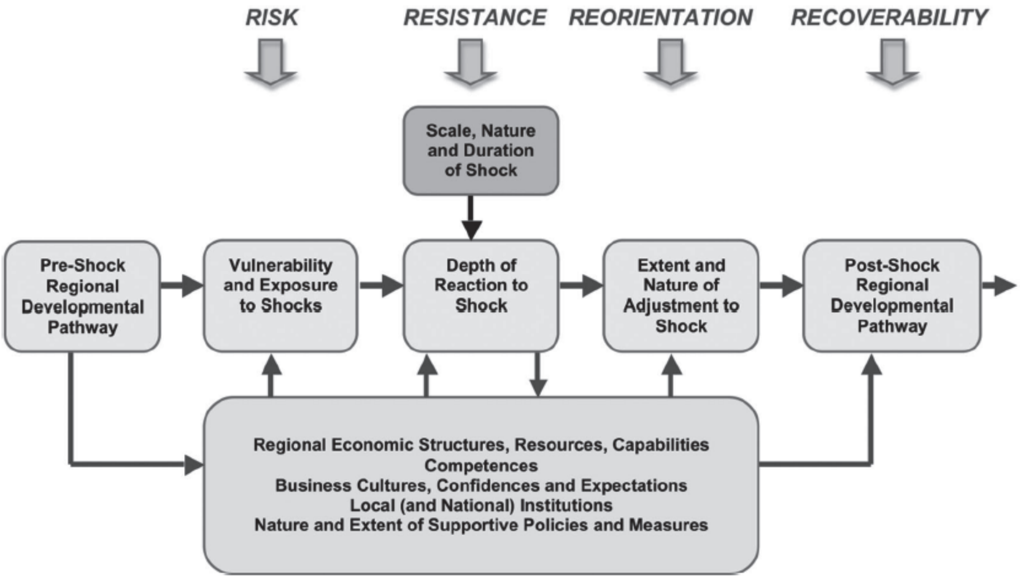

Figure 2.2 Regional resilience to recessions (Martin et al., 2016)

Regional resilience depends on various factors, including industrial and business structures, labour market conditions, agency and decision-making and financial and governance arrangements (Martin et al., 2016). Martin et al. (2016) categorise formal and informal labour markets, financial systems and governance as institutional factors, claiming that these elements have more enduring effects and that industrial structure determines a region's capacity to respond to external shocks. Relevant discussions primarily focus on specialisation, diversity (Farhauer and Kro¨ll, 2012) and related variety (Boschma and Frenken, 2006). Storper et al. (2015) argue that specialisation is the primary driver of regional economic growth, but Davies and Tonts (2010) offer a contrasting perspective, suggesting that greater economic diversification improves regional resilience, as diversified economic structures help to spread risks. Meanwhile, inherent and inherited structural factors – such as the entrepreneurial environment, entrepreneurial spirit and labour force skills – also significantly impact regional resilience (Martin et al., 2016).

2.2.4 Cluster Evolution Model

The uneven regional development pattern shows continuity and change, with widening disparities posing significant societal challenges (Iammarino, Rodríguez-Pose and Storper, 2017). In terms of how clusters emerge and evolve and why certain regions and clusters demonstrate greater resilience than others (Simmie and Martin, 2010; Boschma, 2015), two approaches, Cluster Life Cycle and Regional Path Dependence, offer compelling explanations (Rodríguez-Rodríguez and Morrison, 2016). These approaches provide in-depth insights into the aforementioned issues by explaining the interplay between the internal and external factors and mechanisms that underlie cluster development trajectories.

2.2.4.1 Life Cycle Model

Clusters, like living organisms, undergo processes of emergence, growth, transformation and potential decline or disappearance, and this reflects the overall evolutionary nature of clusters (Martin and Sunley, 2011a). Evolutionary economic geographers have adopted the 'life cycle' concept to study how clusters evolve over time. As early as the early 1950s, the 'life cycle' concept focused on the development of individual organisms, suggesting that external events, internal logic, rules or processes would influence the final production of products, with each stage of development seen as a necessary precursor to subsequent ones (Van de Ven and Poole, 1995). Scholars have also applied this concept to explain products' pre-sale and sales performance over time. Later, the 'life cycle' concept was used more widely to describe the development of industries, technologies, clusters and even entire economies (Storper, 1985; Audretsch and Feldman, 1996a; Klepper, 1997). Generally, the life cycle of clusters is described in terms of five main stages: embryonic, growth, mature, decline, and sometimes death. These stages are typically defined using indicators such as the number of companies, innovation capability and market share (Press, 2006).

In the literature on cluster research, cluster development is typically seen as synchronous with the stages of technological and industry life cycles (Swann, 1998). This perspective suggests that as the industry cycle matures, cluster advantages gradually transform into disadvantages, and as technological innovation develops, industries tend to disperse spatially (Dalum, Ch and Villumsen, 2002; Maggioni, 2004). An alternative interpretation of cluster life cycles suggests that cluster evolution is primarily determined by the inherent strengths and weaknesses of each cluster (Maskell and Malmberg, 2007). Iammarino and McCann (2006) propose that clusters evolve through transitions between different types of organisational structures, including pure agglomerations, industrial complexes and new and old social networks. They emphasise that these transitions are not just determined by industry type, technological, or knowledge characteristics. The main cause of cluster decline is attributed to technological lock-in (Pouder and St. John, 1996). Meanwhile, if a cluster grows too large, it may incur agglomeration costs, potentially leading to a decline during any stage of its development (Martin and Sunley, 2011a).

The concept of life cycles carries distinct biological connotations (Martin and Sunley, 2011a). Although external events may influence the evolutionary process of clusters, these processes are primarily controlled by the internal logic and conditions of the cluster, and internal forces are the true drivers of cluster evolution (Van de Ven and Poole, 1995). As such, clusters appear to follow a programmed and specific evolutionary sequence. However, cluster systems are in reality extremely complex. As Marshall (1890) pointed out: 'Every place has its own events [...]

Even in the same place and the same industry, two men who are aiming at the same end will not necessarily take the same course (p.355).'

If we accept this understanding, the life cycle model needs to be re-examined, and the developmental trajectory of clusters should not be viewed as a simple, predetermined process but should consider each cluster's unique environment, internal dynamics and external influencing factors. This more complex and dynamic perspective may be more conducive to understanding the true evolutionary paths of clusters.

2.2.4.2 Adaptive Cycle Model

Clusters make up complex adaptive systems that are influenced by connectivity, capital and resilience, making simplistic lifecycle analytical frameworks insufficient to capture this complexity (Martin and Sunley, 2011a). Firstly, clusters comprise multiple interconnected actors, including firms, suppliers, service providers and related institutions (Porter and Porter, 1998). Secondly, clusters are not closed systems with clear boundaries. The macrostructure and developmental dynamics of clusters result from the micro-level behaviours of firms and the interactions between various agents who are capable of adapting to changes in the external environment (Martin and Sunley, 2011a). In the real world, clusters' internal structures and environments are diverse and complex, and their evolutionary processes are characterised by non-uniform paths that follow a pattern of multi-path dependence (Martin and Sunley, 2003;2007; Belussi and Sedita, 2009). Clusters also exhibit emergent and self-organising characteristics that endow complex systems with the potential to adapt their structure and dynamics, irrespective of external shocks or internal functional and structural constraints (Belussi and Sedita, 2009; Martin and Sunley, 2011b). Consequently, complex systems can generate multiple potential evolutionary trajectories and unpredictable change processes (Folke, 2006).

Cumming and Collier (2005) identified different 'meta-models' of change or evolution in complex systems (Life Cycle, Random Walk, Replacement, Limitation, Succession, Adaptive Cycle and Evolutionary), which are distinguished by whether the research object maintains continuity over time, whether another stable state is possible in the same physical location and the strength of exogenous forces and processes. Martin and Sunley (2011a) argue that the adaptive cycle model is one of the clearer and better-supported explanations for the dynamics of complex systems. This conceptual framework focuses particularly on the concept of systems' resilience to external changes and shocks and how resilience itself changes as the system evolves. The adaptive cycle model explains the process and mechanisms of cluster evolution, including the phases of exploitation, conservation, release and reorganisation (Gunderson and Holling, 2002; Cumming and Collier, 2005).

2.2.4.3 The Modified Adaptive Cycle Model

However, the adaptive cycle model does not apply to all types of ecosystems (Cumming and Collier, 2005). The evolutionary dynamics of complex systems, including clusters, are also shaped by the interaction of ‘bottom-up’ and ‘top-down’ causal relationships (de Haan, 2006). As a result of this bidirectional interaction, the evolutionary paths that systems adopt can undergo frequent shocks and redirections, thus demonstrating unpredictability. Martin and Sunley (2011a) proposed an improved model of cluster evolution, the adaptive cycle model, which allows for a broader range of stochastic agents and key responses to shocks.

This model encompasses six potential evolutionary pathways (Figure 2.3). The first of these is the full Cluster adaptive cycle (α-r-k-Ω), in which clusters undergo various stages of emergence, growth, maturation, decline and reorganisation. As clusters progress through the stages of the cycle, resilience initially increases but subsequently decreases. Reasons for cluster contraction may include internal rigidity, the exhaustion of increasing returns or the inability to withstand significant external competitive pressures. However, sufficient resources, inherited capabilities and competencies are retained, providing a foundation for the emergence of new clusters based on related or analogous specialities. The second pathway is constant cluster mutation (α-r-r’ -r”…), where after the emergence and growth phases, clusters continuously adapt and evolve through structural and technological changes. Enterprises within the cluster are able to sustain innovation to varying degrees, while the cluster itself undergoes continuous variation or expansion in industrial specialisation and technological regimes. The rate of fragmentation of existing companies and local research institutions or universities is high, indicating a high degree of resilience within the clusters. The third pathway is cluster stabilisation (α-r-k-k’ -k”…), where clusters mature and enter a relatively stable stage. Although clusters may undergo phases of scale decline, remaining companies survive by upgrading products and focusing on niche or prestige markets. The cluster maintains a certain degree of resilience, but it may still be susceptible to decline. The fourth pathway is cluster reorientation (α-r-k-α), where new clusters emerge by redirecting to new industries or technological fields as the cluster approaches maturity or decline. In fact, clusters may branch into new forms without experiencing a prolonged decline. Leading companies with more significant innovation potential can play a vital role in this process, such as reacting effectively to market saturation, the growth of major competitors or technological breakthroughs that may trigger repositioning. The fifth pathway leads to cluster failure (α-r-k-Ω-d), where clusters fail to develop beyond a specific scale during the generation phase, and remaining enterprises do not constitute a normally functioning cluster. The cluster fails to reach a sufficient critical mass, or achieve externalities or a market share, and this also affects innovation. Factors such as a low rate of new business formation and a high rate of business failure will hinder new entrants. The sixth pathway results in cluster disappearance (α-f), a process whereby clusters decline and eventually perish because they cannot restructure and renew themselves effectively. Ultimately, clusters undergo the same contraction and decline as in the full adaptation cycle pattern when the inherited resources and capabilities are insufficient or unsuitable to form the basis for the formation of new clusters (Martin and Sunley, 2011a).

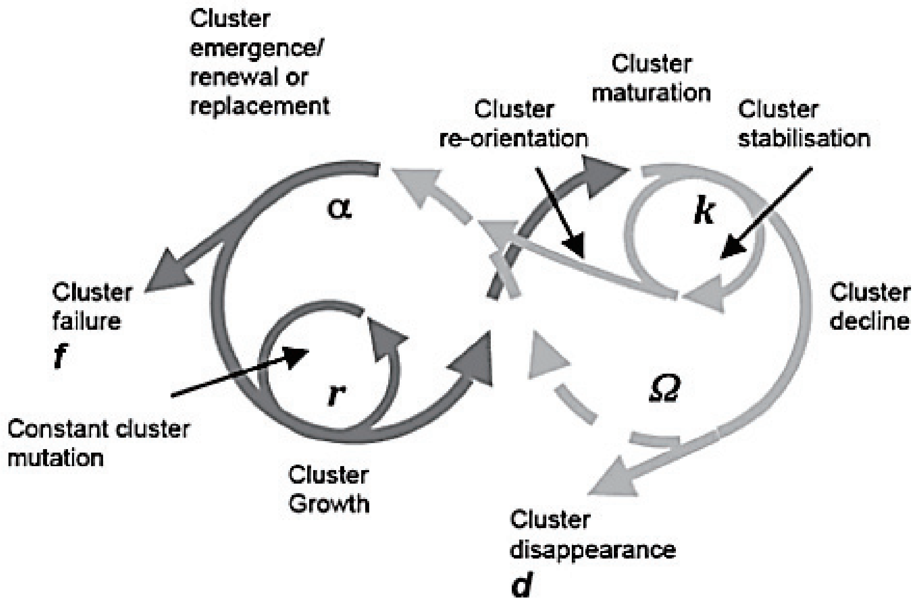

Figure 2.3 The modified cluster adaptive cycle model (Martin and Sunley, 2011a)

To summarise, the adaptive model emphasises the importance of capital, connectivity and resilience. However, these concepts primarily focus on path dependence and lock-in phenomena, which offer a relatively simplistic perspective. In studying the evolution of e-waste industrial clusters, I found that existing research frameworks are insufficient to fully capture their complexity. To gain a deeper understanding of the evolutionary processes of e-waste industrial clusters and to address related research questions, it is necessary to integrate multiple theoretical perspectives. These theories include but are not limited to agency theory, focusing particularly on aspects of institutions, policies and entrepreneurship, and related variety theory. In the following sections, I will provide a detailed introduction to these concepts.

2.2.5 Agency and Cluster Evolution

Cluster life cycle theories have introduced a dynamic perspective into cluster development research by acknowledging the importance of historical factors (Martin and Sunley, 2011a). These theories claim that structural factors such as the heterogeneity of firm capabilities, localised learning processes and the openness and rigidity of enterprise networks are crucial in explaining transitions between different developmental stages of clusters (Trippl et al., 2015).

However, these theories pay little attention to the role of actors and institutional factors in the evolutionary process, specifically those individuals who create economic value within firms and clusters (Asheim and Coenen, 2006; Uyarra et al., 2017). This limitation makes it difficult for these theories to explain why clusters with similar structural preconditions may exhibit different developmental paths and forms.

Martin and Sunley (2006) proposed integrating human agency into path dependence theory, arguing that certain aspects of path dependence are intentionally chosen and created by the actors involved. They suggested that the choices and actions of agents can significantly influence cluster resilience and developmental trajectories across different geographical regions (Webber, Healy and Bristow, 2018). Henn and Laureys (2010) analysed the evolutionary path of the Antwerp diamond district after World War II, and found that key figures such as diamond merchants, representatives of diamond mining companies and politicians played crucial roles in its re-emergence, confirming the significant impact of the actions of key agents on cluster evolutionary paths. Meanwhile, Feldman, Francis and Bercovitz (2005) introduced entrepreneurship into cluster evolution research, arguing that entrepreneurs 'spark cluster formation and regional competitive advantage (p.130).'

Although agency plays a crucial role in the creation, recreation and transformation of paths (Grillitsch and Sotarauta, 2020), the focus of discussion so far has primarily been on the types of agency involved (Bækkelund, 2021). According to existing research, agency can be categorised into three types: change agency, reproductive agency (Bækkelund, 2021), and maintenance agency (Baumgartinger-Seiringer, 2022). Change agency refers to the ability of actors to initiate and drive significant changes. Garud and Karnøe (2001) emphasised that change agency is essential for breaking path dependence and creating new development trajectories. In the context of industrial cluster research, Simmie (2012) highlighted the crucial role of innovative entrepreneurs in driving cluster transformation. Grillitsch and Sotarauta (2020) developed the concept of change agency further by proposing the 'trinity of change agency' model, which comprises three core elements: Schumpeterian innovative entrepreneurship, institutional entrepreneurship and place-based leadership. This model highlights the interplay of change agency at individual, collective and systemic levels in the development of regional industrial paths to provide a more detailed theoretical framework for understanding regional economic transformation.

Reproductive agency involves behaviours that reinforce existing structures and practices, which are often understood as sources of lock-in or barriers to innovation (Bækkelund, 2021). Giddens (1984) first introduced the concept of reproductive agency in his structuration theory, emphasising how actors continuously reproduce and strengthen social structures through their daily practices. In industrial cluster research, Østergaard and Park (2015) explored how reproductive agency can lead to path dependence in clusters, sometimes even preventing necessary change. However, Martin and Sunley (2006) pointed out that reproductive agency is not always negative and that in some cases it can help clusters to consolidate advantages and improve efficiency, thus playing a positive role during specific stages of development. Bækkelund (2021) further noted that reproductive agency is multifaceted and should not be simply regarded as an obstacle or equated with inaction. Isaksen et al. (2019) noted that while reproductive agency may resist new activities, it also involves actions that exist in their own right (rather than merely opposing something), which suggests that reproductive agency can lead to a certain degree of change, albeit a smaller potential for change when compared to change agency (Kurikka and Grillitsch, 2021).

Maintenance agency refers to activities that are focused on actively mitigating or suppressing change to maintain the stability of existing systems (Jolly, Grillitsch and Hansen, 2020). This concept was first introduced by Lawrence and Suddaby (2006) as part of their institutional work theory, emphasising the importance of maintenance behaviours in organisational fields. In industrial cluster research, Kilduff and Tsai (2003) explored the ways in which social networks use maintenance agency to preserve cluster cohesion and stability. Tödtling and Trippl (2013) also highlighted the role of maintenance agency in ensuring the long-term survival of clusters and their capacity to respond to external shocks. They argued that moderate maintenance behaviours can help clusters maintain stability when facing uncertainty and external pressures, thereby improving cluster resilience. However, they also cautioned that excessive maintenance agency might lead to cluster rigidity and a decline in innovation capacity. Maintenance agency is seen as being associated with the inherent inertia of incumbents, who typically benefit from the status quo, tend to protect their strong vested interests and are therefore less likely to promote reforms or support radical innovations (Heyen, Hermwille and Wehnert, 2017; Patala et al., 2019).

In recent years, increasing academic attention has been paid to the interactions between different types of agency and their impact on the evolution of industrial clusters. Grillitsch, Asheim and Trippl (2018) introduced the concept of ‘regional agency mix,’ emphasising that the balance of different types of agency is crucial for the sustainable development of clusters. Isaksen et al. (2019), through an empirical study of Norway’s maritime industry cluster, showed how change agency interacted with reproductive and maintenance agency to jointly promote the gradual innovation and adaptive evolution of the cluster. Turnheim and Sovacool (2020) also identified a flexible conversion relationship between different types of agency, suggesting that at different stages of regional industrial change, and that the same actor may simultaneously play the role of maintenance and change agency. Research by Kumaraswamy, Garud and Ansari

(2018) and Patala *et al.* (2019) supported this view, claiming that some actors can simultaneously be resistors to change and promoters of embracing disruptive innovation. Bækkelund's (2021) research expanded on this by exploring the transition processes between different forms of agency and arguing that the dominant type of agency can shift at different stages of cluster development. For example, the reproductive agency that dominates during the path formation stage may transition to a change agency mode during the path creation stage.

Despite significant progress in research on different types of agency, gaps still remain. The primary research gap lies in the lack of empirical studies, particularly regarding the specific manifestations and impacts of different types of agency within particular industrial clusters. There is also a lack of dynamic studies on how types of agency change over time. Specifically, the forms and relative importance of agency may vary significantly across different stages of the lifecycle of an industrial cluster. Meanwhile, further investigation is needed into how institutional and socio-cultural environments shape and influence different types of agency.

2.2.6 Related Variety and Cluster Evolution

Cluster diversification has become a focal point for both academics and policymakers (Boschma, 2017). EEG suggests that the cluster development process may follow two distinct paths: one that gradually evolves from existing economic activities or knowledge and another that breaks away from these paths to enter entirely new developmental states (Bathelt and Glückler, 2000; Martin and Sunley, 2006). Further research (Neffke, Henning and Boschma, 2011; Rigby, 2015) indicates that clusters typically achieve diversification and break out of lock-in by developing new activities that are related to existing ones, combining these new activities with local capabilities and using existing to realise path transformation or upgrading. Related variety has been a significant area of study in EEG, and this concept suggests that when a cluster's product or technological diversification is closely related to existing activities, it can promote the development of the cluster's economy (Bathelt and Storper, 2023).

The concept of related variety was initially proposed by Frenken, Van Oort and Verburg (2007) to address the academic debate on whether clusters benefit more from specialisation or diversification. They categorised agglomeration economies into four types: internal increasing returns to scale, localisation economies, urbanisation economies and Jacobs externalities, and suggested that all these types may originate from spillover effects. They also emphasised that significant innovations often stem from the recombination of knowledge from different industries. Geographical concentration facilitates this recombination of knowledge, especially when firms operate under similar conditions. This concept further explains that knowledge spillovers primarily occur between related sectors, and a higher degree of diversity implies greater potential for inter-industry knowledge spillovers. Clusters with related variety exhibit higher Jacobs externalities than sectors with unrelated variety.

Related variety is a specific form of internal diversified specialisation or related diversification (Frenken, Van Oort and Verburg, 2007), which suggests that closely related economic activities can yield significant benefits through marginal knowledge spillovers and technological innovation (Bathelt and Storper, 2023). Simultaneously, as these activities cover multiple economic sectors, they possess the potential to hedge against risks associated with economic downturns. Within this theoretical framework, geographical and technological proximity typically exhibit interconnected characteristics. This interconnection is primarily shown by the tendency for related activities to occur in the same geographical location, thus facilitating the generation of knowledge spillover effects and fostering a process of co-evolutionary learning.

Numerous scholars, including Frenken, Van Oort and Verburg (2007) and Boschma and Iammarino (2009), have used quantitative methods to investigate the relationship between regional development and related variety. These studies generally show a positive correlation between regional performance variables and related variety, hypothesising that knowledge spillovers and economic synergies drive this relationship. However, these studies do not provide direct empirical results or causal identification in terms of the specific mechanisms that drive successful or unsuccessful regions. The causal relationship of related variety remains inadequately understood, and the systematic exploration of control variables is insufficient (Bathelt and Storper, 2023). It is, therefore, challenging to determine whether related variety directly leads to innovation or employment growth.

Meanwhile, the measurement of technological relatedness typically relies on industrial classification systems (such as SIC or NAICS) (Reardon and Firebaugh, 2002). However, these industrial classifications are output-based and do not adequately consider sub-sectoral interrelations and technological spillovers (Bathelt and Storper, 2023). Industrial classification systems also exhibit significant lag, making timely and accurate analysis difficult. Moreover, different classification codes (such as two-digit and three-digit NAICS codes) yield dramatically different results, while the fundamental nature of related variety as a static concept has also been questioned by evolutionary geographers (Juhász, Broekel and Boschma, 2021; Kuusk and Martynovich, 2021).

The concept of related variety focuses on the entire regional industrial structure rather than a single sector or cluster. It posits that the dynamics within one cluster may be influenced by its relationships with other industries and clusters, highlighting the interconnectedness of various regional economic pathways. Any analysis should, therefore, consider the specific context of a given area and the actual conditions of various industries in the contemporary economy (Bathelt and Storper, 2023). Different backgrounds, cultures, policies and industrial structures can influence cluster development trajectories in various ways, potentially leading to diverse causal relationships resulting in growth, stagnation or decline (Glückler and Bathelt, 2017; Gong and Hassink, 2020). Given this complexity, studies of the relationship between related variety and cluster development should adopt a broader socio-economic development perspective. This would involve considering the regional conditions of clusters while also focusing on the role of agency actors, policies and relationships between paths and industries, thus examining the relationship from multiple perspectives.

2.2.7 Political Economy and Cluster Evolution

Since its inception, EEG has primarily focused on how interactions between economic agents shape regional economic landscapes. However, traditional EEG research has paid relatively insufficient attention to political factors and the role of the state. In recent years, an increasing number of scholars have begun to recognise the importance of incorporating political economy perspectives into the EEG research framework (Hassink, Klaerding and Marques, 2014). This trend reflects the deepening recognition within academia of the significance of political dimensions in economic evolutionary processes. MacKinnon *et al.* (2009) point out that neglecting political economy perspectives prevents EEG research from adequately explaining the diversity and complexity of regional development, with notable deficiencies, particularly in explaining how institutional environments influence the behaviour of economic agents.

In terms of theoretical integration, Martin and Sunley (2015b) propose that EEG needs to better incorporate core concepts from political economy to explain both the drivers and barriers of regional economic change. They emphasise that power relations and institutional structures are key factors in shaping the choice space of economic actors. Similarly, Gertler (2010) argues that there exists a complex relationship of mutual influence between institutions and economic evolution and that this relationship needs to be understood through a political economy perspective. Pike *et al.* (2016) further develop this line of thinking by introducing the concept of 'local political economy', emphasising the need to focus on how local political actors influence economic path development through institutional arrangements.

The role of the state in regional economic development has received widespread attention. Dawley *et al.* (2015), through their study of the development of the offshore wind energy industry in northeastern England, reveal how national policies promote path creation for emerging industries by creating 'protected spaces'. Schmidt (2016) comparatively examines industrial policies in Germany, France, and Italy, highlighting how differences in government intervention across national models influence regional economic diversification pathways. In Nordic countries, Isaksen and Jakobsen (2018) analyse Norway's regional innovation policies, emphasising the state's positive role in promoting regional innovation system construction, particularly in terms of institutional support for responding to external shocks. Morgan (2017) proposes the concept of the ‘transformative state’, arguing that the state is not merely a corrector of market failures but a key actor actively shaping the direction of innovation. Rodríguez - Pose and Wilkie (2019), through global comparative research, reveal the close relationship between state capacity and the effectiveness of regional economic policies, emphasising the decisive impact of institutional quality on policy implementation outcomes.

In research on emerging economies, such as China, political factors and the role of the state demonstrate particularly prominent influence. Yeung (2016) introduces the concept of ‘strategic coupling’, emphasising the strategic role of East Asian developmental states in facilitating the integration of local enterprises with global production networks. Wei (2015) examines China's regional industrial evolution, pointing out how the distinctive nature of central-local relations has shaped China's unique pathway of regional economic development. Hu and Hassink (2017) provide an in-depth analysis of how the interaction between central and local governments within China's political system influences the formulation and implementation of regional development policies, highlighting the profound impact of political networks on economic activities in the context of China's transition. Wang (2018) through a study of the Pearl River Delta region, reveals how local governments function as entrepreneurial actors to promote regional industrial upgrading. Research by Zhu, He and Zhou (2017) demonstrates that Chinese local governments actively shape regional industrial paths through tools such as land policies and tax incentives, with these policy practices being deeply influenced by local political ecologies.

In the Chinese context, local governments play a distinctive role in regional economic evolution. Zhou (2008) analyse how local governments facilitate the formation and upgrading of industrial clusters through industrial policies and resource allocation, emphasising the significance of local governments as quasi-market actors. Yang (2014) examines how political promotion mechanisms influence local officials' choices of industrial policies, thereby shaping regional development paths. Wu (2016) using Chinese urbanisation as an example, analyses how the interaction between national strategies and local policies shapes regional spatial development patterns. Li and Jonas (2019) study industrial transformation in the Yangtze River Delta region, revealing the complex interactive relationships among central policies, local political competition, and corporate strategies. Zhang and Peck (2016) from a comparative political economy perspective, analyse the differences in state intervention models between China and Western developed countries, pointing out that Chinese government intervention features stronger development orientation and direct intervention characteristics. Liu and Dunford

(2016) investigate how national geopolitical strategies shape spaces of regional economic cooperation in the context of the ‘Belt and Road Initiative’.

A deeper exploration of theoretical integration between political economy and EEG is required. MacKinnon *et al.* (2009) advocate for the development of ‘Evolutionary Political Economic Geography’, combining power analysis from political economy with the micro-behavioral foundations of EEG. Bathelt and Glückler (2014) emphasise the need for a better understanding of the co-evolutionary relationship between institutional change and economic change. Methodologically, Pike *et al.* (2016) recommend adopting more mixed research methods, integrating quantitative analysis with qualitative case studies to more comprehensively understand the mechanisms through which political factors influence economic evolution. Additionally, Zukauskaite, Trippl and Plechero (2017) highlight the importance of longitudinal historical research for better grasping how political-economic factors shape regional long-term development trajectories.

2.2.8 Summary: Evolutionary Economic Geography Theory

Evolutionary economic geography explores the unfolding of new path development over time and space, emphasising resilience and industries’ responses to shocks. However, critiques suggest that the framework proposed by EEG is too narrow (Hassink, Isaksen and Trippl, 2019). Firstly, while EEG has inspired conceptual and empirical research on the development of new regional industrial paths in economic geography, it often overlooks institutions, policies and social relationships. Firms and institutions, as well as social relationships, interact significantly across various scales and are influenced by local externalities, national or international regulations and global markets in their cooperation or location decisions (Hassink, Isaksen and Trippl, 2019). Secondly, there is a tendency to emphasise local sources, processes and impacts in the development of new regional industrial paths at the expense of non-local factors. Thirdly, there is a disproportionate focus on explaining how the past has shaped new path development, with insufficient attention given to the potential impact of the future. Fourthly, the conceptualisation of relationships between pathways is narrow, primarily highlighting the positive impacts associated with technology and skills while neglecting other critical links that may influence their development (Hassink, Isaksen and Trippl, 2019).

However, no detailed theoretical framework exists that integrates all these factors. In light of that, this study reviews key theories in EEG, including path dependence and life cycle theory, while also exploring the relationship between agency and cluster development as well as the connection between related variety and cluster evolution. These theories provide new perspectives for explaining the evolutionary trajectories of industrial clusters and why different clusters may exhibit divergent evolutionary paths.

EEG, which originated in Europe, predominantly relies on European and American cases, with the notable oversight of transition countries with mixed market economies, such as China. This gap persists despite China's varying technological innovation capabilities, which range from high-end innovative industry clusters to labour-intensive assembly clusters based on low costs. Since the reform and opening up of China (gaige kaifang) in 1978, the spatial expansion of industries in metropolitan areas and the speed of internal restructuring have been unparalleled, resulting in a distinct spatial pattern compared to Europe, the US and post-socialist countries. Government-created parks have emerged as significant drivers of China's spatial expansion, highlighting the influence of China's political and economic system, the interplay between endogenous and exogenous forces and the land system. There is therefore a pressing need to focus on cases from China to bridge this gap in EEG research.

2.3 Analytical Framework

Following a comprehensive review of cluster research and relevant theoretical literature in EEG, this study constructs an integrated analytical framework aimed at investigating the differentiated developmental trajectories of clusters—specifically examining why certain clusters become locked-in and ultimately disappear, while others successfully achieve upgrading or transformation. From an EEG perspective, cluster development is conceptualised as a complex dynamic process, influenced by multiple factors that evolve over time (Martin and Sunley, 2011a). The co-evolutionary relationships among these factors generate unpredictable impacts on cluster development trajectories and life cycles, potentially resulting in lock-in situations or other outcomes (Gong and Hassink, 2019).

The analytical framework of this study is inspired by Grabher's (1993) theory of three types of lock-in (functional lock-in, cognitive lock-in, and political lock-in). Grabher's research revealed how industrial clusters can fall into development difficulties due to over-specialisation, while also recognising that lock-in represents only a single pathway in cluster evolution. As Martin (2010) pointed out, cluster evolution may lead to diversified outcomes such as adaptation, transformation, or resilience, rather than being limited to the negative outcome of lock-in. Therefore, this research focuses on exploring how three sets of processes interact over time, leading to different evolutionary trajectories, in order to construct a comprehensive process framework capable of explaining both change and lock-in. This analytical framework adopts a multidimensional perspective, examining the combinations of processes that produce diverse outcomes, covering dimensions such as functional and structural assets and relationships, agency and cognition, and political and institutional contexts. This perspective aligns with the ideas of EEG proposed by Boschma and Frenken (2006), emphasising the dialectical relationship between path dependence and path creation. Meanwhile, the framework also draws on Bathelt and Glückler (2017) relational economic geography, emphasising the social embeddedness of economic behaviour and its impact on spatial development.

Functional and Structural Assets and Relationships

This dimension focuses on the economic structure and network characteristics within clusters, forming the foundation for understanding cluster adaptability. First, industrial structure and related variety have significant impacts on cluster evolution. Frenken, Van Oort and Verburg (2007) point out that related variety can promote knowledge spillovers between different but cognitively proximate industries, enhancing regional innovation capacity. This framework particularly focuses on the characteristics of industry combinations within clusters, analysing how related variety influences clusters' ability to respond to external shocks and their potential development paths.

Second, inter-firm relationship networks constitute the basic infrastructure for cluster operation. Giuliani's (2007) research reveals that the structural characteristics of knowledge networks within clusters have a decisive influence on innovation diffusion. This framework analyses cooperation and competition relationships between firms, knowledge exchange channels, and supply chain structures, exploring how these network characteristics affect collective learning and adaptation processes within clusters. Specifically, network density, centrality distribution, and degree of openness are viewed as key factors influencing cluster responsiveness.

Third, connections between clusters and the external world are equally crucial. The concept of 'local buzz and global pipelines' proposed by Bathelt, Malmberg and Maskell (2004) emphasises that successful clusters need to achieve a balance between internal interactions and external connections. This framework examines the strength and diversity of connections between clusters and external markets, knowledge sources, and institutional environments, analysing how these connections provide renewal momentum for clusters and prevent excessive lock-in.

Agency and Cognition

The second dimension focuses on the agency of key actors within clusters and their cognitive frameworks, emphasising the role of human factors in cluster evolution. First, entrepreneurial agency plays a crucial role in shaping cluster development paths. Research by Feldman, Francis and Bercovitz (2005) demonstrates that entrepreneurs not only passively adapt to their environment but also actively participate in creating and changing it. This framework explores how core firms and individual entrepreneurs influence the direction of cluster evolution through strategic choices, innovation activities, and organisational change, with particular attention to their strategic responses and resource allocation capabilities when facing external shocks.

Second, collective cognitive frameworks have profound effects on how clusters respond to change. Hassink (2010) points out that dominant thinking patterns formed within a region may either promote innovation or lead to cognitive lock-in. This framework analyses shared values, risk perceptions, and innovation culture within clusters, examining how these collective cognitions influence clusters' identification of new opportunities and breakthrough from traditional paths. Cognitive diversity and openness are viewed as important factors in enhancing cluster resilience.

Third, learning capacity determines a cluster's effectiveness in absorbing new knowledge and adapting to changes. Asheim and Coenen (2005) emphasise the influence of different types of knowledge bases on regional innovation patterns. This framework focuses on learning patterns of firms and institutions within clusters, knowledge integration capabilities, and institutionalised learning mechanisms, analysing how clusters achieve self-renewal and path creation through effective learning.

Political and Institutional Context

The third dimension examines the broader political-economic environment and institutional frameworks, which constitute the external conditions for cluster evolution. First, policy interventions play an important role in guiding cluster development. Research by Uyarra and Ramlogan (2016) shows that different types of policy instruments have varying effects on cluster innovation and adaptive capacity. This framework analyses the selection of policy tools by governments at various levels, their implementation paths, and their mechanisms of influence on cluster evolution, with particular attention to how policies affect adaptive transformation of clusters.

Second, the local institutional environment provides basic rules for cluster activities. Rodríguez-Pose (2013) emphasises the importance of local institutional quality for regional development. This framework explores how formal institutions (laws and regulations, property rights protection, etc.) and informal institutions (conventions, trust mechanisms, etc.) shape cluster behavioural norms and interaction patterns, thereby influencing their ability to adapt to external changes. Institutional inclusiveness and adaptability are viewed as key characteristics supporting cluster innovation.

Third, multi-scalar governance structures reflect the influence of power relationships at different levels on cluster development. Pike, Rodríguez-Pose and Tomaney (2007) point out that governance interactions across different spatial scales affect regional development trajectories. We focus on how governance structures at local and national levels interact to jointly influence clusters' resource acquisition, innovation support, and development direction, with particular attention to the coordination capacity of this multi-level governance when clusters face transformation pressures.

Dynamic Processes and Interactive Mechanisms

This framework not only focuses on individual elements but emphasises how three sets of processes interact over time to form dynamic evolutionary patterns. First, the co-evolutionary perspective proposed by Martin and Sunley (2006) informs us that elements within regional economic systems exhibit interdependence and mutual influence. This framework examines how functional structures, cognitive frameworks, and institutional environments mutually shape each other, collectively driving clusters along specific development paths or facilitating path transitions at critical moments.

Second, the framework pays particular attention to the role of critical turning points in cluster evolution. Simmie and Martin (2010) emphasise that external shocks may trigger adaptive changes in clusters. This framework identifies key historical nodes and analyses how interactions among different elements at these moments lead to path continuation or creation, thereby revealing the non-linear characteristics of cluster evolution.

Third, feedback loop mechanisms have continuous influence on cluster evolutionary direction. This framework explores how positive feedback mechanisms (such as successful experiences reinforcing existing paths) and negative feedback mechanisms (such as crises triggering path adjustments) alternately function in cluster development, leading to path dependence or innovative breakthroughs. This perspective helps understand the alternating phenomena of stable periods and transformative periods in cluster evolution.

Based on the interactions of the three sets of processes described above, clusters may exhibit different evolutionary outcomes. First, path continuation is characterised by clusters maintaining existing development paths, implementing incremental improvements while keeping basic structures and directions stable. Second, path renewal refers to clusters introducing new elements based on existing paths, achieving partial updates and functional upgrades. Third, path creation embodies clusters developing entirely new development paths, realising fundamental transformation and strategic repositioning. Fourth, path lock-in is manifested as clusters becoming trapped in rigid structures, unable to effectively respond to external changes, leading to declining competitiveness. Finally, path dissolution refers to clusters being unable to maintain competitiveness, ultimately moving toward decline and disintegration (Martin and Sunley, 2011a).

These diverse evolutionary outcomes reflect different capabilities and strategies of clusters in responding to changes and also embody the complexity of interactions among the three dimensions: functional structure, agency cognition, and political-institutional context. By analysing the combinations of processes that lead to different outcomes, I can develop a more comprehensive understanding of the evolutionary dynamics and mechanisms of industrial clusters. This analytical framework, by integrating multidisciplinary perspectives, provides a systematic tool for understanding the diversified evolutionary pathways of industrial clusters. It transcends the traditional lock-in perspective, emphasising that cluster evolution is a dynamic process of multidimensional factors interacting with each other, potentially leading to multiple possible outcomes. This framework helps explain why similar external shocks produce different impacts across different clusters, and why different clusters within the same region may exhibit differentiated development trajectories.

2.4 Conclusion

This chapter conducted a critical analysis of the literature to explore the evolutionary perspective as a theoretical framework for cluster study. I have systematically examined the complex relationships between path dependence, life cycles, agency and related variety in cluster evolution. The innovative aspect of this study lies in its attempt to integrate a series of theories, constructing a multi-dimensional theoretical perspective to address the following core questions: Why do different clusters exhibit divergent evolutionary paths? What factors endow certain clusters with higher resilience and adaptability, enabling them to successfully transform or upgrade? And what causes some clusters to become locked-in, ultimately leading to decline or disappearance?

Although current EEG theories touch upon these issues, they have yet to construct an in-depth framework of cluster evolution, and related empirical research remains insufficient. Research and practice on the evolution of e-waste industry clusters are especially difficult to fully incorporate into existing research frameworks. Given these limitations, this study combines a series of theories to answer the above research questions.

Industrial clusters have long been a core research topic in economic geography, and many scholars from various theoretical backgrounds have proposed distinctive analytical frameworks to enrich the theoretical system of industrial cluster research. The origins of industrial cluster theory can be traced back to Marshall’s (1890) research on the economic effects of industrial agglomeration. Marshall pointed out that industrial agglomeration could bring significant cost-saving effects, and his view was later introduced into the field of business research by Porter (1998a), further expanding the conceptual connotations and application scope of industrial clusters. However, economic geographers tend to understand industrial clusters more in terms of their role as knowledge communities (Vicente, 2018). This perspective emphasises the sharing mechanism of tacit knowledge within clusters, seeing it as one of the key driving forces for cluster formation and development. EEG, on the other hand, examines the dynamic evolutionary paths of clusters from the dual perspectives of time and space. This theoretical framework highlights the importance of history in cluster development, emphasising the irreversibility of the development process and spatial heterogeneity. Path dependence and lock-in have become two core research themes within this framework. As global crises and shocks have become more frequent, the focus of EEG has shifted, and it has moved from the traditional perspective of local industrial (spatial) evolution to exploring the adaptive mechanisms by which regions respond to sudden events and future uncertainties. Against this backdrop, economic resilience has emerged as a prominent research topic.

Although EEG has significantly improved our understanding of industrial clusters by introducing concepts such as path dependence and lock-in, these perspectives often focus on the macro level, failing to fully capture the micro-dynamics of cluster evolution. To grasp the development process of clusters, we need to shift our research perspective downwards to explore the roles of relationships, agency and various institutions in cluster evolution. The behaviour and decisions of individuals who create economic value within enterprises and clusters significantly impact the development trajectory of clusters, and we must also consider external factors such as industrial chains, national or international regulations and market environments that influence cluster evolution.

However, the academic community currently lacks a theoretical framework that can integrate these complex factors. In light of this, my study builds upon path dependence and cluster life cycle theories to further explore the impact of agency and related variety on cluster evolution. Notably, this study draws upon evolutionary economics theories and extends Grabher's (1993) three-fold typology of lock-in to develop a comprehensive process framework for analysing the mechanisms of change or lock-in that underlie divergent cluster development pathways. This framework systematically integrates multiple theoretical perspectives that explain the differentiated evolution of clusters and validates these theoretical propositions through rigorous empirical research. This analytical framework not only addresses gaps in existing literature regarding explanations of cluster evolutionary dynamic mechanisms but also provides theoretical guidance and analytical tools for understanding the diversity of regional industrial cluster development trajectories. This approach reflects a recognition of the complexity of industrial cluster evolution while providing diverse theoretical perspectives for future research. Through this multi-dimensional theoretical integration, I aim to reveal the complex dynamic mechanisms that govern the evolutionary process of industrial clusters, identify key factors that influence cluster resilience and adaptability, explore potential causes of cluster lock-in and decline and provide a theoretical foundation for research on emerging and complex industrial clusters, such as the e-waste industry. Furthermore, through this research approach, I hope to bridge the gap between macro and micro perspectives to offer a more holistic and in-depth analytical framework for industrial cluster evolution. This will help the academic community to better understand the intrinsic mechanisms of cluster development and provide policymakers with more precise and effective intervention strategies to promote sustainable regional economic development.

Chapter 3 Methodology

Drawing on the existing literature, this chapter outlines the research design and methodology employed in the study to address the research questions. This approach aligns with the perspective of Coffey and Atkinson (1996), who emphasise that 'research questions, research design, data collection methods and analytic approaches should all be part of an overall methodological approach and should imply one another (p.11)'. This chapter outlines the research design, including the research questions, field sites, and pilot study used in the study. To ensure the feasibility of the selected methods, a one-month pilot study was conducted in one field site. This pilot study helped refine the research questions and procedures.

This chapter provides a detailed account of the data collection process, including information on the final sample collected, as well as the methods and techniques employed for data analysis, which involved various methods such as archival and documentary examination, participant observation, and interviews. This research focuses on Guiyu and Huaqiangbei as case studies, conducting eight months of fieldwork across two sites. A total of 85 interviews were completed, involving local workers and government officials at both local and higher levels, ensuring comprehensive and representative data collection.

By outlining the research methods and procedures in this chapter, the chapter also includes a section that reflects on my positionality and reflexivity as a researcher, as well as ethical dilemmas since these have become essential factors and affected the way in which the overall research progressed. In the final section, I detail the method used to analyse the data collected in this research. This study lays a groundwork for the subsequent analysis and findings while ensuring transparency and rigour in the research process.

3.1 Research Design

3.1.1 Research Questions

Based on the aforementioned empirical and theoretical discussions, in line with the research objectives, this study proposes four research questions regarding the evolution of the e-waste industry clusters in China.

Research Question 1:

How did the e-waste industrial clusters emerge, grow, mature, decline, and eventually cease to exist in different regions of China under various regulatory frameworks?

Research Question 2:

Why do these two e-waste clusters present different developing paths, one lock-in and one upgrading? What are the policy lessons for the development and transition of e-waste industrial clusters?

Research Question 3:

What are the policy lessons for the development and transition of e-waste industrial clusters?

3.1.2 Field Sites

This research chose two major e-waste clusters as field sites to gather data and build a comparative case-study analysis. The comparative case study is a method of analysing phenomena that is widely used in social science, including sociology, education, geography and political science (Barringer and Greening, 1998; Esser and Vliegenthart, 2017). This method involves selecting two or more cases, using a variety of data collection methods, like in-depth interviews, documentary analysis, observation and data collection to collect and analyse data from each case, gaining an in-depth understanding of their unique characteristics, behaviours, and decisions, identifying similarities and differences in their attitudes, or outcomes, and attempting to explain the reasons for these differences and commonalities by building theoretical explanations (Holt and Turner, 1970; Goodrick, 2014; Mokhtarianpour, 2016). The use of comparative methodology facilitates the dynamic interplay between theory development and testing (Shahrokh and Miri, 2019). By adopting a comparative perspective, researchers can identify weaknesses in research design, gain insight into the essential features of a phenomenon and validate or revise existing theories to provide new ideas for subsequent research (Goodrick, 2014).

The selection of cases for comparative analysis is crucial in the research process. Careful consideration is needed at this stage, as the decisions made can significantly impact how causality is addressed in the subsequent data analysis and synthesis (Goodrick, 2014). Cases can be selected randomly and purposefully. Random selection can mitigate selection bias and enhance representativeness, but it cannot guarantee the relevance of cases to research questions and objectives. However, selecting cases that align with research questions and objectives is crucial to ensure the validity of the study (Taherdoost, 2016). A random sampling of cases is unnecessary in this study as it does not aim to test the theory of industrial cluster evolution. The research focus lies in examining the diverse responses of various clusters to external shocks, with the ultimate goal of identifying factors that influence e-waste industrial cluster reorganisation. Therefore, the selection of cases in this paper is based on a purposive sampling of the research questions and objectives (Goetz and LeCompte, 1984; Patton, 2014). Guiyu and Huaqiangbei, Shenzhen in Guangdong Province were selected.

China is one of the world's largest producers and recipients of e-waste, hosting several prominent e-waste clusters. Among them, Guiyu and Huaqiangbei stand out as two significant clusters. Guiyu, once regarded as the largest e-waste cluster globally (Glenday, 2013), focused on e-waste disassembly and processed an estimated 150–300 million tons of e-waste annually (Lora-Wainwright, 2015). Huaqiangbei, on the other hand, is known for leveraging technology in e-waste reassembly and is renowned for hosting China's largest second-hand mobile phone resale market (Xu, 2023). These clusters are particularly suited to address the research questions and objectives of this study. Given the time constraints, limited accessibility due to COVID-19 and the sensitivity of the e-waste industry, as well as the complexity of the research, only these two clusters were selected as case studies.

For a comparative study, these two cases, located within the same province and approximately 300 kilometres apart, initially share similar geographical, cultural, and social contexts. Both clusters originated in impoverished towns and faced comparable policy shocks during their development as e-waste industrial clusters. However, they diverged significantly in their development trajectories, making them ideal for comparative analysis. This research investigates the reasons behind their divergent paths, examines the origins of these differences, and explores their long-term consequences. By comparing these two cases, the study not only sheds light on the varying developmental paths of industrial clusters in China but also highlights the differing responses to external shocks. The comparative framework allows for a comprehensive analysis of the underlying logic driving industrial cluster development in China. Incorporating both individual case analyses and cross-case comparisons, this research strengthens its findings through triangulation, enhancing its overall robustness (Baxter, 2010; Bryman, 2016). Moreover, the selection of these cases is practical and justified, as Guangdong Province, one of China's most significant economic zones, offers an appropriate context for constructing a sample that aligns with the specific research profile (Barringer and Greening, 1998). Its convenient location further supports its selection.

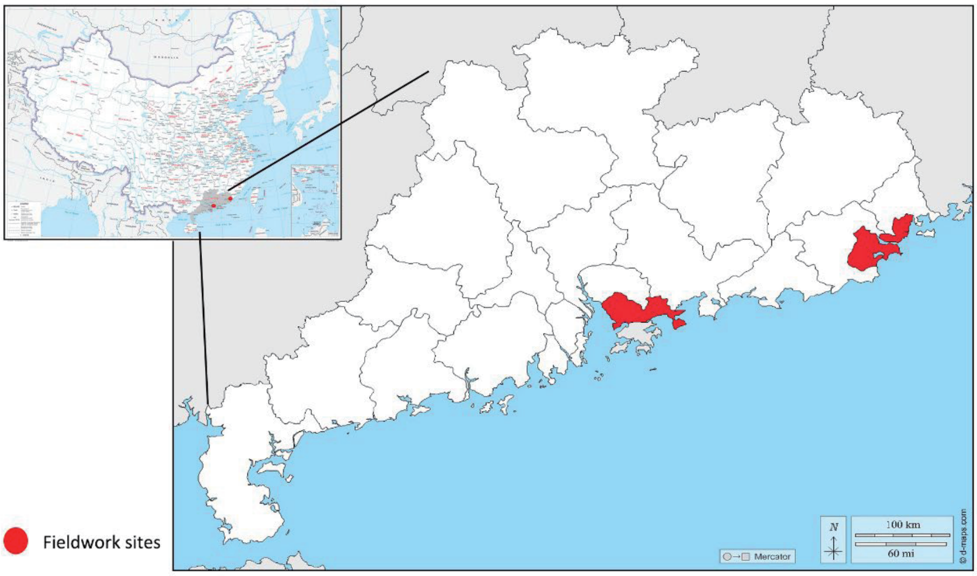

Figure 3.1 Fieldwork locations (Author)

3.1.2.1 Guiyu

Guiyu is a small town comprising 28 villages and communities, with an administrative area of 52.13 square kilometres and a population of 162649 in 2020, located in Chaoyang District, Shantou City, Guangdong Province (Shantou City Chaoyang District Statistics Bureau, 2021). Shantou is an old trading port and remains the only major port in eastern Guangdong. Guiyu was originally a small town that made its living growing rice but was essentially insecure in agriculture due to its low-lying terrain and frequent flooding (Greenpeace, 2003). It began receiving e-waste around 1995, becoming an informal centre for e-waste recycling and developing into a significant hub for the global e-waste trade (Wong et al., 2007; Wang, Qian and He, 2022). In its heyday, Guiyu was once regarded as one of the largest e-waste hubs in the world, with more than 100,000 people and 80 per cent of local families involved, and processes 150-300 million tons of e-waste annually, mostly from developed countries (Jensen et al., 2007; Lora-Wainwright, 2015). In there, people abandoned their farmland, with large amounts of e-waste piled up everywhere around the town, some on the farmland and some on the roads. The young children ran around and played with the waste while the youth used primitive and simple sorting, dismantling, baking, or acid-washing techniques to extract valuable materials and metals like gold from e-waste. Since most of Guiyu's e-waste industry was made up of family workshops, they did not have the technology or capital to reduce pollution. All of the work was mainly done without any protective methods. Toxic smoke and wastewater were eliminated and covered the whole city directly (Mujezinovic, 2020).

Recycling activities grew steadily throughout the 1990s in Guiyu but were struck at the start of the new millennium. Initially, this unjustified way of exporting e-waste from developed to developing countries attracted the attention of Greenpeace, who became concerned about what has happened in these e-waste hubs. Through field visits and research, the documentary Exporting Harm first exposed the situation of Guiyu to Westerners, and in 2008, CBS's 60 Minutes episode, the Wasteland, widely spread. They portrayed Guiyu as a vast, dirty, smelly, e-waste city (Puckett et al., 2002). Meanwhile, several international environmental organisations targeted environmental pollution and precarious working conditions and produced reports on the Guiyu industry (Brigden, 2005). These reports have prompted the Chinese government to take more proactive environmental measures. Many central and local policies have been implemented to regulate environmental pollution resulting from uncontrolled recycling activities, with an initial focus on e-waste imports and environmental pollution control (Tong et al., 2015). The international exposure has accelerated the reform process. Since the early 2000s, the central government has been urging the local government in Guiyu to regulate the e-waste dismantling industry. In 2003, the Guiyu government proposed the establishment of a National Circular Economy Pilot Industry Park, but it was not until 2013 that comprehensive construction began. The local government faces a significant challenge in balancing the demands of the local economy with the central government's environmental protection mandates.

This study raises several critical questions regarding the evolution and resilience of the Guiyu e-waste industrial cluster: What was the evolutionary trajectory of the Guiyu e-waste industrial cluster, and how did it respond to shocks? How did various stakeholders and agents interact within the cluster ecosystem? What factors contributed to the lock-in, and what potential strategies could address this issue? What transferable lessons can be derived from the management of the Guiyu e-waste cluster for application in other contexts? These questions require further in-depth analysis and discussion.

3.1.2.2 Huaqiangbei, Shenzhen

Shenzhen, a city located on the east coast of the Pearl River Estuary along the central coast of Guangdong Province, is adjacent to Hong Kong, with a total area of 1997.47 square kilometres and nine districts under its jurisdiction (Shenzhen Municipal Bureau of Statistics, 2021). As one of the experimental zones of China's reform and opening-up policy, Shenzhen has been exploring new economic, social and political systems and, therefore, has many 'first try' privileges, including tax incentives, free exchange of foreign currency, and land use rights. From a small fishing village with an area of 2.9 square kilometres (Statistics Bureau, 1970) and a permanent population of 310,000 in 1970 to an electronic technology hub of 17.68 million people in 2022 and achieving an annual average GDP growth rate of 21% since 1979, reaching 3.24 trillion yuan (Shenzhen Municipal Bureau of Statistics, 2022), Shenzhen's rapid industrial transformation provides an exceptional Chinese case study for industrial cluster economy research.

During Shenzhen's development process, the e-waste industry has always been ignored due to Shenzhen's complex industrial structure and the prominence of other industries. The recycling and reuse of e-waste in Shenzhen are primarily concentrated in the Huaqiangbei area. Located in the eastern part of Futian District, Huaqiangbei enjoys a prime geographic position—bordered by the Shenzhen Municipal Committee of the Chinese People's Political Consultative Conference to the east and Shenzhen Central Park to the west. It is one of the most iconic electronic commercial clusters in Guangdong Province and is widely recognised as 'China's First Street of Electronics', which was initially established to sell electronic components and second-hand electronic products due to the scarcity of electronic products in China and its proximity to Hong Kong (HQBMuseum, 2020). During the early days, obsolete electronic products from developed countries were auctioned by Hong Kong companies. Afterwards, Shenzhen merchants went to Hong Kong to buy them and then shipped them to mainland China. After the process of sorting, dismantling, refurbishing, and reassembling, they were sold to other dealers and consumers in other areas of China.

During China's reform and opening-up period, Huaqiangbei became a symbol of grassroots entrepreneurship, often described through the popular narrative of 'billionaires born from a one-meter stall'. However, the area has also gained notoriety for the widespread sale of counterfeit, knock-off, and second-hand electronic products. The total area of Huaqiangbei spans approximately 1.45 square kilometres, with a north-south length of around 930 meters and an east-west width of about 1,560 meters. Administratively, the area falls under the jurisdiction of Futian District. Huaqiangbei has been described as China's largest second-hand electronics market (Xu, 2023). Its commercial landscape is highly diversified, with a dynamic industrial ecosystem that supports a dense network of electronic product distribution, second-hand refurbishment, and component processing.

During its development, Huaqiangbei is notorious for its 'copycat' and smuggled products. In an attempt to change this situation, the government began to regulate the industry. Enterprises and factories with low-end technology and prone to pollution were forced to close down or move to other places, which caused a period of confusion in Huaqiangbei. However, with government policies and funding support, Huaqiangbei has successfully completed its industrial upgrading and transfer and developed multiple evolution paths.

Despite the proliferation of second-hand electronics recycling markets in various locations, Huaqiangbei has maintained its position as the largest distribution centre for second-hand electronic products. This dominance can be attributed to the historical accumulation of expertise and infrastructure within its electronic industrial cluster. According to the China Second-hand Goods Association (2022), Shenzhen's transaction volume in the first quarter of 2022 ranks first nationally. Concurrent with its leadership in the second-hand electronics market, Shenzhen has experienced significant technological advancement and economic growth. The city has achieved global recognition as an Alpha (global first-tier) city, as classified by the Globalisation and World Cities Research Network (GaWc, 2020). Furthermore, its nominal GDP has surpassed neighbouring metropolises such as Guangzhou and Hong Kong, positioning it as one of the world's top ten largest economic cities. Shenzhen, this rapidly developing metropolis, has conferred significant locational advantages and positive externalities upon Huaqiangbei. Major urban centers do not merely function as incubators for industrial clusters; they also facilitate cluster adaptation and resilience during periods of external shock. As such, Huaqiangbei serves as a critical empirical site for studying industrial clusters and the emerging waste economy in the context of urban China.

3.1.3 Pilot Study

I completed my pilot study in Guiyu in March and April 2021 to check whether I could access the field site, get the materials I wanted through the interview questions, and determine whether the research method and research questions were feasible. Due to various factors, including the lack of direct flights between China and the UK, the meltdown policy on flights, high airfare costs caused by the COVID-19 pandemic, and China's stringent policy on the COVID-19 epidemic, after completing the pilot study, I did not return to the UK to analyse the collected material. Instead, I promptly conducted an online meeting in China with my supervisors to discuss the issues encountered during the fieldwork and determine the necessary revisions. This approach allowed for timely feedback and enabled me to promptly address shortcomings in the data collection process while continuing the formal fieldwork quickly.

I chose to conduct the pilot study in Guiyu because my prior research on the 'copycat' (shanzhai) mobile phone was in Shenzhen, which provided me with a certain understanding of the local situation and facilitated the identification of interviewees in this field site. The primary purpose of the pilot study was to assess the feasibility of conducting fieldwork in Guiyu. Upon arriving in Guiyu, I began searching for gatekeepers and utilised snowball sampling methods to conduct semi-structured interviews. Finally, I interviewed eight people, including two government officials and six workers. I found that through these approaches, I could access the field, find people to participate in the interview and yield the materials that I needed to address the research questions if I continued.

However, as an outsider and a researcher from a university in a foreign country, I found that it was not easy to establish trust with the local people. Therefore, during the fieldwork, I planned to spend considerable time engaging in participant observation and gaining a deeper understanding of their lives instead of simply critiquing and criticising their lifestyles as an outsider or a researcher. Furthermore, in light of the potential challenges regarding the validity of interviews with workers with low levels of education and questions that involved historical memory, starting with specific questions was not always effective in establishing a relaxed and trusting atmosphere for the interviewees nor producing enough materials from these interview questions. Building trust is a critical issue in this fieldwork. Without trust between the interviewer and interviewees, their answers may be superficial, and it may be challenging to obtain their honest thoughts, especially some critical attitudes or opposite behaviours. Interviewees may feel pressured, and some may even answer questions inaccurately because they want to move on to the next question and quickly end the interview in this hurried and formal setting. Their answers are, therefore, sometimes very simple, vague and even hostile, with little valid information.

During the pilot study, I found that participants could express their opinions well through regular communication. The use of narrative interviews proved to be pragmatic in eliciting information about their occupational experiences, attitudes and industrial history. It shapes a neutral setting where the interviewer and interviewees are in an equal relationship and are able to obtain information from the interviewees with less bias (Bowling, 2002). Therefore, after discussing with my supervisors and considering and adjusting the fieldwork, I changed the way of interviewing and the order of the interview questions, deciding to use semi-structured interviews with narratives at the start and then move to specific questions. Additionally, I abandoned the idea of conducting online interviews with some difficult-to-schedule interviewees, like government officials, as they were highly resistant to this format.

In terms of the sample, I initially planned to classify workers into managers and staff and interview them with separate questions. However, during the pilot study, I found that the e-waste industry in Guiyu is comprised chiefly of family workshops, making it difficult to differentiate between managers and staff. Additionally, due to the predominantly male nature of this industry, where men work outside and socialise while women take care of the household, it was challenging to achieve gender balance among the interviewees. Nevertheless, the unbalanced gender composition reflected the actual gender composition of the e-waste industry. All these problems were adjusted for subsequent fieldwork.

At the same time, I tried to collect statistical data to support the research, including the collection of Annual Government Reports, Socio-economic Statistics, Annual Financial

Accounts and Budget Reports of Guiyu and Shenzhen, usable data, like economic, industrial output, population, and enterprise data. However, data on the e-waste industry is minimal. The lack of a universal definition of e-waste is the primary reason. Secondly, exporting e-waste to developing countries is illegal under the Basel Convention, resulting in many countries providing false data on e-waste. Accurate reporting might lead to charges of illicit trade. In accordance with the Basel Convention, the export of e-waste to developing countries must be preceded by the consent of the recipient nation. The failure to obtain such an agreement constitutes a violation of the convention. Official e-waste statistics are only available for 41 countries, with most missing export data. The lack of accurate data on the e-waste industry is a worldwide challenge.

In China, there is a significant lack of data on the e-waste industry due to the late establishment of its statistical system. The country's attention to e-waste came relatively late, and it has not yet formed a specialised statistical department to make statistics. Moreover, since most e-waste companies are small family workshops, they have not registered with the government's industrial and commercial departments or paid taxes, making it difficult to obtain specific figures. E-waste falls in a grey area often associated with illegal activities and crime, resulting in a lack of official statistical data on import and export figures, processing quantity, and industrial scale. Most available data can only be obtained through news reports and interviews, resulting in relatively ambiguous statistics.

Not only that, in Guiyu, the local government had limited economic and industrial data available before 2010, particularly concerning the e-waste industry, including production value and enterprise numbers. Consequently, the pre-2010 data was incorporated following a thorough review of textual materials gathered during previous searches, excluding clearly erroneous information. This process was used to ensure the accuracy and reliability of the data. For these reasons, it is challenging to conduct quantitative research on the e-waste industry. Therefore, this study focused on archival and documentary research to extract statistics from news articles and official publications, in addition to using interviews and participant observation to collect empirical data.

After consulting with my supervisor online and taking a brief rest, I commenced my formal fieldwork immediately. I revisited Guiyu in both May and June to continue the fieldwork. However, I had to return home to prepare for the university's second-year confirmation review in June and July. Following the review, I spent four months conducting further fieldwork in Shenzhen, from August to November. Overall, I completed eight months of extensive fieldwork in Guiyu and Shenzhen.

3.2 Data Collection

This research employs various methods of data collection, including archival and documentary examination, participant observation, and interviews. The archival and documentary materials serve as sources of background information. However, despite a few before-and-after comparisons of e-waste regulation published by the government, there is a lack of studies and reports on the transformation of the e-waste industry and different agents' reactions. Notably, there is little information on the industrial transformation process, the challenges encountered during the process, the negotiations and attitudes among different agents, and the subsequent developments. Therefore, this study conducted participant observations as the basis for understanding the current state of development in Guiyu and Shenzhen, as well as the actual living, working status and attitudes of various groups. Drawing on these secondary data and observations, this research developed semi-structured interview questions and conducted interviews.

3.2.1 Archival and Documentary Examination

Since this study plans to adopt the qualitative method to study the evolution path of industrial clusters, there may be some information deviation in obtaining retrospective information only from interviews, while archival and documentary materials could compensate for these weaknesses. That is because, firstly, the industrial evolution path spans an extensive period of time, and it is not easy to find many interviewees who have experienced and know the whole process. Furthermore, there may be loss or fragmentation of memory. Each person may have different recollections differently depending on their own experiences. It is tough to cover all the retrospective information. Therefore, prior to the interviews, this study analysed the historical materials of the industry in Guiyu and Shenzhen, including the government policy, news reports, and documentaries, and recorded the milestones and changes of the industry so as to have a superficial image of the evolution of the industrial clusters in these two places.

To begin this process, a systematic and chronological approach was taken to collect relevant newspaper articles and documentaries on the e-waste industry in Guiyu and Shenzhen through keyword searching. Since Guiyu is relatively backward and the local government does not pay much attention to information collection, the materials are somewhat lacking. Furthermore, as many newspapers and data have been virtually synchronised, the internet network has become a vital accumulation place of information, so I searched the internet directly using 'Guiyu' as a keyword on Baidu (the most used Chinese search engine) and Google respectively. The word that was most related to Guiyu was e-waste. In this process, I controlled the time frame of the search and found that the earliest article on Guiyu e-waste on Google appeared in February

2002, and the report on Baidu was first published in 2004. Searches were then conducted at five-year intervals. I scanned the titles and the contents of the texts in order to make sure whether they were related to the topic of the e-waste industry in Guiyu. Once relevant, samples were extracted and, after removing duplicates, were saved in chronological order to a laptop for further coding and analysis, including text, video, and images.

The approach to gathering materials and information in Shenzhen differed from the methods employed in Guiyu. Shenzhen has emerged as China's leading city and a hub of rapid development, making it a central focus of Chinese propaganda efforts. As a result, there is a wealth of comprehensive and abundant information available on the city. There is a significant challenge in searching the city with keywords such as ' Shenzhen e-waste' or 'Shenzhen electronic industry' since the prevalence of irrelevant information arises from a search. Besides, very few people have paid attention to the e-waste industry in Shenzhen. This yields a vast number of web pages, including the websites of e-waste, which may not be relevant to the research being conducted. So, the information collection on Shenzhen's e-waste industry is mainly focused on the government website. Through the search in Shenzhen Statistic Bureau, Shenzhen Historical Records Websites, Guangdong database, Shenzhen news, and other official authoritative websites collected comprehensive information such as 'Shenzhen Oral history 1980-1992', 'Shenzhen Oral history 1992-2002', 'Shenzhen Oral history 2002-2012', and 'Shenzhen Special Economic Zone 30 years.' Simultaneously, in order to obtain more comprehensive official data, I visited the Shenzhen Reform and Opening-up Museum, Shenzhen City Planning Museum, Shenzhen Folk Culture Museum, Huaqiangbei Museum and other government exhibition halls, collecting the pictures and videos on display and saving them in the computer. While understanding the background to the development of Shenzhen's e-waste and electronic industry in terms of history and policy, official attitudinal texts are coded for subsequent analysis. After that, a further search was conducted based on significant policies, milestones, time slots, and regions in the above materials, copying and saving them into another database for textual analysis.

3.2.2 Participant Observation

Participant observation is a commonly used data collection method in disciplines such as sociology, human geography, anthropology and others, particularly for qualitative research and ethnography (Jackson, 1983; Anderson, 2005; Pink, 2006; McMorran, 2012). The aim of this method is to gain new insights by enabling the researchers' extended personal involvement in the social life of the people being studied and to provide a first-hand account of their experiences (Musante and DeWalt, 2010; Emerson, Fretz and Shaw, 2011). This method helps researchers to identify and explore cultural norms, behaviours, attitudes, and values that are difficult to observe through other research methods (Atkinson, 2007; Hammersley, 2018). Thus, it facilitates obtaining detailed and accurate information about individuals, communities, and other research groups against over-reliance on respondents' self-reports to identify social phenomena, particularly discovering discrepancies between what participants say should happen as well as what they do (or do not do), and the actual conflicts between conscious representations and actual behaviour, which may be hidden by research methods such as interviews (Silverman and Marvasti, 2008).

In the field research, I conducted participant observation mainly through the gatekeepers, which included the people engaged in the industry, government officials, and a dual identity person who once worked in the e-waste industry and is now a government official. These three types of people helped me to get a multi-faceted and multi-perspective view of the actual situation of Guiyu and Huaqiangbei. During the research, I obtained permission from multiple individuals involved in the local industry to work with them and have a participant observation. Due to the COVID-19 pandemic, visiting factories in Shenzhen was not feasible, but instead, I participated in the collection and delivery of products, as well as the negotiation of collaborations with upstream and downstream companies. Furthermore, the preparation for the 20th National Congress prevented me from finding government officials in Shenzhen who could accompany me during participant observation. However, in Guiyu, I was able to visit enterprises in the current National Circular Economy Pilot Industry Park, including the TCL Deqing Environmental Development Co., Ltd, the largest and most profitable e-waste recycling company in Guiyu. Government officials took me on a site visit where enterprise staff showed me every dismantling line. In cases where lines were not operational at the time, they were played back through monitoring. Furthermore, every working procedure was thoroughly explained to me. Another interviewee with a dual identity (e-waste worker and government official) in Guiyu took me to participate in the activities and parties organised by his friends and family after his government work. He also took me on a tour of the entire Guiyu region, pointing out the clear rivers, clean fields, and parks, which had previously suffered from severe pollution. During the observation, I maintained communication with him, particularly when I made new discoveries or uncovered new information. This allowed me to gather more information and deepen my understanding of the e-waste industry in Guiyu. At the end of each day, I made detailed field notes to keep track of what I observed. Field notes can help me to understand and review the scene as it happened and enable me to quickly access the memory of the time in the subsequent analysis.

3.2.3 Interviews

While participant observation provides a more comprehensive understanding of a research case, it can also be difficult for researchers to accurately capture or misinterpret the meaning of the participants' words during the data collection. Thus, it can be difficult to provide a complete and accurate description of a group of people or events (Peshkin, 1993; Aktinson and Hammersley, 1998). Therefore, in addition to observation and data collection, this research combined secondary data analysis and interviews. This triangulation method allows for the cross-checking of data from multiple sources, reducing the researchers' personal preferences and increasing the credibility and validity of the findings (O'donoghue and Punch, 2003; Denzin, 2017).

This research employed the interview as the primary research method to examine the evolution path of the industry, the impact of distinct factors on different developmental phases of industrial clusters, particularly social networks and policies, and their response to the shocks in the context of the 'disruptive process' of economic and compulsory government control. Based on the pilot study, this research utilised semi-structured interviews with individuals. The interview approach employed a narrative method initially, transitioning to a more specific question thereafter. A total of 85 interviews were completed, involving local workers and government officials at both local and higher levels. Each interview lasted at least an hour.

Based on the experiences in the pilot study and the comparison of different interview methods, this research chooses the semi-structured interview with narratives to do the research. The semi-structured interview is a qualitative research method that combines elements of both structured and unstructured interviews, which involves a flexible and structured way of conducting interviews (Fylan, 2005). In the semi-structured interview, the interviewer has a range of open-ended questions and topics that maintain clarity of the research questions and research objectives while at the same time creating a relatively relaxed and conversational environment for the interviewees to fully express and share their thoughts and experiences in a more open and honest manner, such as their attitudes on sensitive issues, due to the looser structure of these questions (Magaldi and Berler, 2020; Knott et al., 2022). In such a friendly atmosphere, it is easier for the interviewer to establish a personal connection with the interviewees and thus convene follow-up interviewees (Brinkmann, 2014).

During the interview, the narrative method was first used to ask participants to describe their occupational development in a relaxed and casual way, which helped them relax and, at the same time, obtain plenty of historical information about the development of the local industry in chronological order. It is because the changes in one's career development are often related to local policies, the economy, industrial development, and, in some cases, even similar to the evolutionary path of the local industry. Significant transitions and changes that emerged in the interviewees' descriptions were questioned and recorded. Further questions were asked if the respondents mentioned the changes in policies, government management, or stories about their interactions with the government or other organisations. The author would ask questions or stimulate the memory of the participants in combination with the previously collected information and their descriptions. In order to get a more detailed insight into their attitudes and opinions, interviewees were encouraged to describe things in the form of examples, which facilitated the author's understanding of the whole event and also helped some less educated and poor expressions to summarise their thoughts better in a more appropriate language.

Afterwards, the author conducted semi-structured interviews with specific questions with respondents from a larger context on the theme of local industry development. The interview outline would be adjusted differently according to different types of people. For interviewees with long working experience (see Appendix C), the questions focused on the historical development process of the industry, local conditions and context, the policies, and power relations. The interview questions posed to respondents who had only recently joined the industry primarily focused on their reasons for choosing this particular field, what made the region attractive to them, and their experience with government management (see Appendix D). For government officials, the questions concentrated on the tensions between central and local governance. They included how much power local governments have, how they enforce the regulations promulgated by the central government, how they balance the different demands and attitudes between different stakeholders, such as the central government, local industrial entrepreneurs, and local community, and specific problems they encountered in the process of enforcement (See Appendix B). All questions, especially the academic words, were replaced with language that the interviewees could understand, and the words were phrased as neutrally as possible to avoid influencing interviewees' emotions and judgments. To ensure the reliability of the data, each interview was recorded with permission. After each interview, I created detailed field notes by collating the memos. The samples and memos were stored on password-set computers and transcribed into text files for further analysis.

3.2.3.1 Access

For this research, accessing the 'field' posed a threefold challenge. Firstly, there was difficulty obtaining permission from government officials to conduct interviews. Secondly, the ongoing COVID-19 pandemic has made it challenging to contact people and arrange suitable times and locations for interviews. Finally, the preference among Chinese people for in-person interviews over online ones has made it difficult to gain a sufficient number of valid interviews.

Obtaining consent to interview government officials proved difficult due to the sensitive nature of their work and their rigorous professional standards. Many officials were hesitant to participate in interviews, fearing that they represented the government and may be held accountable for their statements. Therefore, it is essential to find key references in the research. Amidst the COVID-19 pandemic in 2022, while I was doing my fieldwork, the Chinese central government exercised strict control measures to contain the spread of COVID-19. As a result, many officials were occupied in COVID-19 containment efforts, and the government departments were unwilling to receive visits from outsiders (author) for fear of the virus transmission. Additionally, during the same period, I encountered difficulty conducting personal interviews with local officials in Shenzhen due to the impending 20th National Congress, resulting in the lack of samples of government officials from this city. Therefore, in order to address this and provide a more comprehensive understanding of the topic, official museums in Shenzhen, such as the Huaqiangbei Museum, were visited. These museums offer detailed information on the history of the development of Shenzhen's electronic industry and, to some extent, can reflect official attitudes and opinions.

Meanwhile, in China, people prefer face-to-face communication. They consider it polite and respectful to communicate by looking into each other's eyes. Moreover, coupled with being afraid of information leakage on the internet, many people, especially older ones, are reluctant to accept online interviews. Some participants said online interviews are like exams, with one question after another, which made them uncomfortable and nervous. It has been proven in the pilot study that the quality of face-to-face interviews was much higher than that of online interviews. Additionally, it was not easy to let people generate interest in my research through just one or two hours of online interviews, resulting in limited success in establishing good relationships with these 'strangers' so that they could act as informants and recommend other interviewees to me. The effectiveness of text-based interviews via email or other social media has been shown to be the most limited. To address this issue, this study opted to employ face-to-face interviews as the primary means of data collection.

3.2.3.2 Recruitment

Two techniques were employed to recruit the interviewees in this research. Firstly, I used the gatekeeper approach to contact the participants. Recruiting participants through gatekeepers is a commonly employed approach in qualitative research since it allows for the facilitation of communication between the researcher and informants by someone who is familiar with the latter, thus streamlining the research process (Tarrant, 2014). This approach underscores the significance of intermediaries in connecting the researcher and the researched (Campbell et al., 2006). In this research, gatekeepers played an integral role in facilitating interviewee recruitment. I first contacted acquaintances or authorities who were familiar with the potential participants and selected some of them as gatekeepers. However, it is worth noting that these gatekeepers may have many sources of informants but may not be participants themselves. The recruitment of informants through gatekeepers may be limited to my personal networks and pose difficulties sustaining the process. Therefore, I adopted snowball sampling as an alternative method of recruitment. Most of the informants were recruited through this method. Snowball sampling relies on and takes part in the dynamics of social networks and helps researchers find 'hidden' informants (Noy, 2008). In this research process, informants referred the researcher to additional informants, who were subsequently contacted by the researcher and directed to further informants, creating a repetitive cycle.

The gatekeeper and snowball sampling began with the pilot work. In the pilot and formal fieldwork, I selected one person engaged in the e-waste industry in Guiyu and one inHuaqiangbei as the informant. At the beginning of the fieldwork, I asked them to introduce my research and me to their acquaintances who were engaged in the industry or government officials. Once the new informants agreed to participate in my research, I began the second round of snowball sampling. However, not everyone they recommended, especially government officials, accepted an invitation to become involved in the study. They often refused to be interviewed with the reasons that they were busy and did not have time. Several workers also declined to participate in interviews, citing concerns that their comments might result in negative consequences, although they were uncertain about the specifics. Moreover, they feared that any statements made by the author could lead to difficulties for both themselves and the locality. Numerous respondents reported that several foreign journalists and scholars had previously conducted research here, but their biased comments had significantly impacted the region and led to the collapse of the e-waste industry. They were apprehensive about repeating this experience.

Government officials

Government officials were selected and approached through snowball sampling and gatekeeping, which were dynamic and repetitive recruiting processes. The gatekeeper method in Guiyu started with the pilot study. At an informal social gathering, I made contact with a businessman from Guiyu who had a personal connection to a previous Party Secretary of Guiyu Town[1]. Through his relationship, I contacted some town officials, National Circular Economy Pilot Industry Park managers, and village officials. As a result, I expeditiously gained introductions to government officials at various levels. While some declined to participate in the

[1] Note: The Party Secretary is the highest-ranking leader in Guiyu Town.

interview, I request each to recommend potential informants. Following their recommendations, I initiated a second round of introductions and invitations to participate in the study.

In Huaqiangbei, the snowball sampling began with an entrepreneur I interviewed in 2017 about the Shanzhai (copycat) mobile phone industry. Now, he has a more successful business and a closer relationship with some government officials. Through his relationship networks, I contacted several government officials in Shenzhen and invited them to take the interview. But most of them rejected it for the reason I mentioned above. Therefore, their samples were small, and the quality of the interviews was not very good.

People engaged in the industry

To recruit individuals involved in the local industry, this research also employed a hybrid approach that combined gatekeeper and snowball sampling methods. In Guiyu, a government official introduced me to a gatekeeper who subsequently assisted with introductions to individuals who had previously or were currently engaged in the industry. Meanwhile, he also invited me to a gathering with friends and introduced me, enabling us to exchange contact information for future communication. Utilising the snowball sampling approach, I recruited additional participants through the gatekeeper's network. At the end of each interview, I requested participants to recommend my research to their friends and acquaintances. Similarly, I employed these recruitment methods in Shenzhen, but the process was smoother due to my prior experience in the area. I ceased sampling as I reached descriptive saturation, meaning I could not obtain more novel information from the interviews (Hennink, Kaiser and Marconi, 2017).

3.2.3.3 Sample

This research conducted 85 interviews, 45 in Guiyu and 40 in Shenzhen. Each interview lasted at least an hour. In order to obtain more integrated information, some interviewees were invited to conduct two or three supplementary interviews. Interviewees could be divided into government officials and people engaged in the industry. 23 government officials took part in the interview, 8 in Shenzhen and 16 in Guiyu, and the occupation levels could be categorised as village, town, municipal, and provincial. 69 industry workers were interviewed, including Shenzhen, 32 and Guiyu, 37. Some interviewees have mixed identities as both government officials and workers, leading to an overlap in the count of interviewed government officials and workers, with an overall count exceeding the total number of individual interviewees.

Except for the interviewees of the two large enterprises currently located in the National Circular Economy Pilot Industry Park, the remaining interviewees were from family workshops and small companies. It is worth noting that these two companies are the only two largest listed companies in Guiyu. Since this study wanted to explore the history of the industry, such as retrospective information, the employees were categorised into three types. Questions and interview methods were different according to different types of interviewees. The classification was based on whether they had encountered the transition of government regulations in the e-waste industry, specifically transitioning from a lenient period to a more stringent regulatory phase. Participants were categorised into those who had experienced the regulatory transition but were no longer involved in the e-waste industry, those who had experienced the transition and had remained actively engaged in the field, and a category for individuals who recently entered the industry, lacking direct experience but possessing knowledge regarding its current status and operational practices. In total, 35 individuals interviewed had experienced the transition, and of these, 11 continue to work in e-waste-related jobs. Two interviewees had less than three years of experience in the industry and were recruited by T recycling company from outside Guiyu. Given the decline of the e-waste industry in Guiyu and the exodus of many individuals, the proportion of people who had previously worked in the industry and individuals from workshops was relatively more prominent.

The situation in Shenzhen is much more complex because the e-waste industry is only a part of its overall industrial development process. To investigate the historical context and the interconnections between industries, I divided them into those who have experience working in the e-waste industry and had commenced their work in Shenzhen before the year 2017 and those who have experience working in the e-waste industry but arrived in Shenzhen after 2017, with 25 and 5 interviewees, respectively. In Shenzhen, most of the e-waste industry was settled in Huangqiangbei. During the period from 2013 to 2017, Huanqiangbei in Shenzhen was closed for transformation under the leadership of the local government, which sealed the main road of Huanqiangbei for metro construction and commercial and industry transformation and upgrading (HQBMuseum, 2020). Therefore, the year 2017 was chosen as the time period. Among the interviewed workers, only five of them still related to e-waste, fixing and selling second-hand mobile phones. The rest of them all transferred to other industries or upgraded.

In addition to gathering basic information about government officials and workers involved in the e-waste industry, this research also conducted interviews with two individuals from prominent companies that do not operate within the e-waste industry. These interviewees were affiliated with China's leading electronic technology companies, possessing higher education and strong skill sets. Their insights can partially shed light on the factors that attract highly educated young individuals to Shenzhen, including government policies and the prospects of industrial development. Moreover, their perspectives contribute to a more in-depth understanding of the potential for a successful transformation withinHuaqiangbei's e-waste industry and provide a perspective from the high-electronic technology industry.

The gender imbalance of the interviewees at the two field sites was apparent, with more men than females, 34 males, 2 females, and a couple in Guiyu and 26 males and 4 females in Shenzhen, which somehow reflected the gender structure of labour within the e-waste industry. In Guiyu, the e-waste industry is primarily composed of family workshops. Women's participation in the industry was limited to performing dismantling work in their spare time after fulfilling their familial responsibilities, resulting in a lack of knowledge regarding the e-waste industry. Moreover, the traditional culture in Guangdong Province dictates that men take the lead in external affairs while women manage the household. Consequently, men were typically more socially active and vocal. Whenever a family workshop was visited, the male member was the representative for the interview. The women often shrugged off their involvement and stated that they were merely providing simple assistance and did not have significant knowledge of the industry. During the interviews, they typically observed the conversation with their husband or engaged in other activities. In Shenzhen, the Opening-up Policy prompted men to leave their hometowns in pursuit of employment opportunities. While some women were involved, they were typically not in leadership positions, limiting the information they could obtain. Consequently, the majority of interviewees in this study were male, and the female participants interviewed were primarily engaged in critical roles and possessed a good understanding of the e-waste industry.

3.3 Positionality and Reflexivity

Fieldwork is a fundamental process wherein researchers engage in direct observation and interaction with a research subject or phenomenon in a non-laboratory setting (Massey, 2003; Whatmore, 2003). Positionality recognises that individuals' identities and experiences are not neutral and that their understanding of the world is influenced by power dynamics, privileges, and forms of oppression (Holmes, 2020). By critically examining one's positionality, individuals can become more aware of their own biases and privileges and also develop an appreciation for the diverse experiences and perspectives of others (Madge, 1993). This self-reflection fosters a deeper understanding of social issues and facilitates the cultivation of empathy and inclusiveness in interpersonal interactions and decision-making processes (Rose, 1997). These factors ultimately shape the collected data and the outcomes of the analysis (Mullings, 1999), which is also widely organised by geographers (Chattopadhyay, 2013). This section explains how the research addresses the position of identity and the relationships with the participants during fieldwork conducted in the e-waste industry in China.

As a Chinese researcher studying within a Western academic context, I am confronted with the question of representing and addressing whom. Firstly, compared to Western scholars, I have a distinct advantage in accessing the sensitive e-waste industry in China. This advantage enables me to acquire more comprehensive and detailed information, thereby presenting the Western academic community with an authentic depiction of the Chinese e-waste industry they have not seen. Additionally, as a scholar educated in the Western context, I can merge theoretical knowledge with practical experiences, offering fresh insights and recommendations for advancing the Chinese e-waste industry.

During my fieldwork, I employed a combination of qualitative research methods to gain insights into the working experiences of individuals in the e-waste industry. It is widely acknowledged that highly educated researchers often possess advantages in terms of material resources, educational background, and professional networks, granting them access to power dynamics inherent in producing knowledge about others (Russell, 1995). This material inequality could separate me from the interviewer as an outsider. McLafferty (1995) argues that researchers have a privileged position in terms of the questions they ask, the way they take the interview, the materials they choose, and the form they present. Staeheli and Lawson (1995) further suggest that, especially in research on Third World countries, when the researchers enter a developing context, they inevitably become associated with questions of authority, communication and representation, and the positions that arise from these issues are inherently political in nature (Radcliffe, 1994). In my fieldwork, interviewees were initially resistant to the interviews, stating that in the past, the researcher had always taken a high position of power to criticise their way of life and work. These reports have caused great disasters for local people and industry. As the one with power, the researcher speaks on behalf of those who do not have power. These statements were perceived by locals as a distortion of their views with a hidden agenda (Rabe, 2003). Therefore, in this research, I tried to maintain equal communication with interviewees and a neutral attitude with less emotional inclination during the fieldwork. The questions were mainly open-ended, with a minimum of directional questions. Interviewees were encouraged to express their views narratively, using stories or descriptions. Meanwhile, the translation is also deeply influenced by power relations (Madge, 1993). It was not possible to translate ultimately between two languages, so direct word-by-word translations were used to minimise the introduction of personal feelings and biases of the author (Smith, 1996).

Identity is also complex, variable and fluid when it comes to different research objects (Rabe, 2003). When doing research with workers, I was, on the one hand, an external researcher (from a foreign university), so interviewees were initially suspicious. On the other hand, workers anticipate that the researcher can voice opinions on their behalf, articulating viewpoints that may be constrained by cultural norms and taboos within their own community provide them with a platform to express their grievances and work towards rectifying their current unfavourable circumstances (Spiegel and Mehlwana, 1997). When interviewing government officials, they were, on the one hand, cautious because their words represented the government, and every statement made to an outsider (the author) may be perceived as an official opinion and attitude and be disseminated. On the other hand, they are anxious to obtain the researcher's help in propaganda, and they are more inclined to show all the good aspects without mentioning other aspects, such as the conflict between the government and workers. When conducting interviews, multiple identities sometimes embarrassed both the participants and the researcher. In order to obtain more detailed data, I conducted many observations and interviews with workers at the early stage to get more materials. Based on these resources, I discussed specific cases as an entry to interview government officials.

3.4 Ethical Considerations

Ethical considerations are essential in social science (Silverman and Marvasti, 2008). They are the principles and guidelines that researchers should follow in fieldwork to ensure the ethical treatment of participants and the integrity of the research process for the complete protection of the health and safety of researchers and participants (Morrow, 2008). Before the commencement of field research, ethical reviews are usually required in geography research (Phillips and Johns, 2012). Ethics is also a compulsory course for PhD students at the University of Southampton. After conducting the online learning and application, this study was approved by the University of Southampton Ethics application on 1 December 2022 (See Appendix E).

The first ethical consideration in this study is the acquisition of secondary materials. The main concern here is the legal compliance of the acquired materials. All the secondary materials utilised in this research were sourced from publicly available and published materials. The second ethics of this study is the interview. In this process, all interviewees participated voluntarily and were fully informed. A total of 85 interviews were conducted in this research, and each interview was participated in based on the interviewees' complete understanding of the research content and interview outline. Meanwhile, to protect the participants' safety, all interviews were conducted on a one-to-one basis.

Before the interview, all participants were provided with a copy of the induction of this research, Participant Information Sheet, and Participant Consent Form. These documents enabled them to know the research project's objectives, approaches, and aspects. The participants could decide whether they wanted to participate. Once they had accepted the interview, I informed the interviewees by phone, SMS, or WeChat[2] of the research topic, the general questions involved, the process of the interview, and the approximate time that would be taken for the interview. The interviewees usually set the time and place at their convenience. I confirmed the time and place with the participants one or two days before the interview to ensure they could participate. According to COVID-19, all interviews were held in an open space or at a social distance.

Before the interview, I asked them whether I could record our conversation, and then we started. They were invited to ask any questions about the research project at any point. After each interview, the final notes, photos, and transcripts were handed over to the participants to check their authenticity and appropriateness to ensure that the researcher could use these materials to structure the thesis. All questions asked and information collected would not be personally aggressive and would keep their personal information confidential. If the participant felt uncomfortable and had any complaints, they could stop or quit at any time. If so, all of their data would be destroyed immediately and never used. If participants change their minds, they could withdraw until the interview has been transcribed, which would be one month later. Moreover, to safeguard the personal information of the interviewees, all names and identities shown in this study were pseudonyms, which were based on the field site, the order they interviewed and the first letter of their surname. For example, G stands for Guiyu and S for Shenzhen. G1Z means the first interviewee Z in Guiyu, and S2Z represent the second interviewee Z in Shenzhen.

3.5 Data analysis

To synthesise and interpret the comprehensive data collected during fieldwork—encompassing interview transcripts, observational notes, and supplementary documents—a systematic qualitative analysis was conducted using NVIVO 14. This analytical approach facilitated the transformation of raw qualitative data into a cohesive and comprehensive analysis of e-waste industrial clusters. The study employed thematic analysis, a methodological approach particularly well-suited for managing large datasets and identifying patterns relevant to specific research questions (Nowell et al., 2017). This method enables researchers to distil complex, multi-faceted qualitative data into coherent themes and concepts, thereby illuminating the intricate dynamics of e-waste industrial clusters.

[2] A social networking app widely used in China.

Prior to initiating the analytical process, all recordings and notes were transcribed. This process served as a crucial step in data familiarisation, recalling the researcher's recollection of the fieldwork experience (Hennink, Hutter and Bailey, 2020). To capture subtle nuances that might overlooked in purely verbal accounts, non-verbal cues such as body language and facial expressions were systematically incorporated into the corresponding transcripts.

In the analysis of visual materials, including photographs and videos collected during fieldwork and from museum visits, I made detailed notes. Each image was described with details regarding when, who, how, and why they were taken. All this information was subsequently added to NVIVO 14 for further analysis. It allowed for the triangulation of data sources, enhancing the validity and depth of the research findings.

The data analysis process commenced with initial coding. This phase involved reading the data repeatedly to identify interesting phenomena, attitudes, and actions of various agents, which were subsequently labelled with codes. These codes were a combination of descriptive and analytical labels linked to themes that corresponded with the research questions and theories. The 'Nodes' tab in NVIVO 14 was utilised to create and insert codes, facilitating subsequent analysis.

Following this, I initiated focus coding to develop the initial codes into subthemes and detailed concepts (Emerson, Fretz and Shaw, 2011). This process employed both deductive and inductive approaches. For instance, I applied key concepts from cluster theories, such as agents, knowledge spillover, and the entrepreneurial ecosystem, to link the data to existing research and theories. Subthemes included entities like government, research institutions, and workers under the agents category and loose and tight networks under the entrepreneurial ecosystem. This stage involved aggregating relevant initial codes in NVIVO 14.

Subsequently, an iterative 'flip-flop' process of recoding and decoding was undertaken to refine and enhance the precision of the coding system. This process involved critically evaluating the empirical support for each code and assessing the specificity and breadth of themes to ensure they adequately captured the complexity of the data. The extracts of each theme were verified to ensure they were both specific enough to be meaningful and broad enough to be theoretically relevant (Nowell et al., 2017).

The emergent themes and concepts derived from the coding process formed the structural framework for the thesis. Given that all interviews were conducted in Chinese, and the majority of documents and field notes were also in Chinese, all codes and memos were written in Chinese to the original meaning conveyed by the informants and to mitigate the potential loss of semantic richness through premature translation (Van Nes et al., 2010). Only the quotes selected for inclusion in the final thesis were translated from Chinese to English. This translation process involved careful consideration of linguistic and cultural equivalence to ensure that the translation accurately represented the original meanings conveyed by the informants.

3.6 Conclusion

This chapter illustrates the research method and process employed to collect first-hand and secondary data within the e-waste industry in Huaqiangbei and Guiyu. Working with 85 individuals, including people engaged in the e-waste industry and government officials, the working experiences of workers within the e-waste industry, as well as the process of regulation of the industry, are captured through a combination of interviews and participant observations. Then, these data were coded and analysed with NVIVO 14 based on the grounded theory.

The e-waste industry is sensitive in China, and it is challenging for researchers, especially those from Western countries, to access this community and obtain comprehensive resources (Mujezinovic, 2020). As a Chinese researcher, I encountered relatively less rejection compared to foreign researchers, and interviewees were more accessible and willing to trust and communicate with me. I employed gatekeeper and snowball sampling methods, which proved instrumental in gaining an adequate number of interviewees and facilitating abundant data collection. Additionally, I immersed myself in these two field sites for eight months, allowing me to establish a rapport with the local community and allowing me numerous opportunities to observe the unfolding events on the ground directly. This first-hand experience encompassed various aspects, including changes in people's daily and working lives, attitudes to the government, conflicts between their living conditions and the environment, and the evolution of the e-waste industry. The adoption of multiple research methods in this research, such as archival and documentary examination, participant observation and interviews, not only facilitated the acquisition of rich and diverse materials but also enabled triangulation analysis.

However, there are certain limitations when doing the fieldwork. Firstly, the lack of comprehensive statistical data restricts my ability to present an entirely objective view of the evolution of the e-waste industry in terms of quantitative data. Consequently, investigating the e-waste industry's evolutionary trajectory on a national or global scale becomes challenging. Due to time constraints and limited access to field sites, I selected only two locations for the case study. Furthermore, inviting government officials for interviews proved challenging during the fieldwork, resulting in fewer interviews with this group. These can be further researched. Despite these limitations, I am confident that the data I have collected based on the research method I introduced above is sufficient to address the research questions and fulfil the research objectives. The subsequent chapters present detailed analyses based on the available data.

Chapter 4 Global E-waste and E-waste in China

> *'Such flows constitute global phenomena because consumption and production systems increasingly move resources, energy, pollution, and health effects around the world. Computers are designed in the US, Europe, and Japan, manufactured in countries like Taiwan and Singapore, produced with materials extracted from Africa and Australia, used almost everywhere in the world, and sent for recycling and disposal, often in China, India, and Pakistan* (Iles, 2004a, p.76).*'*

E-waste is the central focus of this research, and this chapter is divided into two main sections: the global e-waste system and e-waste in China. Before beginning my case study of two Chinese regions, it is essential to fully understand the context of the subject. Given that e-waste is a global issue, e-waste is not confined to local levels but follows a global trend (Iles, 2004a). Due to the high processing costs and environmental pollution associated with e-waste, the practice of transporting e-waste to less developed countries for processing became prevalent from the late 1970s onwards (Clapp, 1994b). The global flow of e-waste has led to the emergence of specific regions as e-waste processing hubs in countries of the Global South, such as Guiyu in China and New Delhi in India. Policy adjustments or industrial transformations in e-waste recycling in a particular region can profoundly impact the global e-waste industry landscape and the development of local clusters. China, formerly the world's largest importer of e-waste, serves as a prime example of this. Research by Gregson and Crang (2019) on China's e-waste recycling policies shows that the country's ban on e-waste imports triggered a crisis in the global flow of e-waste. It is, therefore, imperative to understand the global e-waste developmental trends and their contextual factors at global, national and local scales.

Placing the two case studies in the broader context of e-waste development helps to make sense of the uneven distribution of the global e-waste industry at a larger scale as well as the emergence of the industrial e-waste clusters in the two case locations of this study, Guiyu and Huaqiangbei. The ability to situate the e-waste industry within the context of China also helps to explain specific aspects of China's industrial development and offer essential contextual knowledge and background for subsequent studies.

The first section begins with an explanation of the nature of e-waste, including its composition and the reasons that have contributed to its significance as a subject of academic research. It also explores the distinct features of the e-waste industry, including the global dynamics of e-waste movement, methods of disposal and management and their associated environmental implications. This comprehensive understanding serves as the research backdrop, facilitating subsequent empirical analyses of the case studies.

The second section offers an overview of the e-waste industry in China, including the inflow of e-waste (particularly illicit shipments), the e-waste value chain, the problems stemming from e-waste proliferation, and China's regulations. This section mainly explains the distinctive nature and relevance of researching e-waste in China. China stands as one of the world's largest e-waste producers and was historically the main recipient of global e-waste (Zhou and Xu, 2012; Zhao and Bai, 2021). While the e-waste industry has contributed to economic prosperity, it has also caused significant health and environmental problems. The Chinese government responded in 2021 with stringent regulations that banned all e-waste imports while initiating comprehensive management of the industry (The State Council The People's Republic of China, 2020).

A significant conflict emerged as a result between environmental concerns and economic interests. Donald and Gray (2019) identified a 'double crisis' based on the coexistence of economic and environmental problems coupled with a disregard for social and environmental factors during economic development and advocated for new regional models that linked economic and environmental issues to reduce inequality and waste. In 2012, the Chinese government brought in rigorous regulations to control the country's e-waste clusters, leading some regions to impose near-total industry shutdowns in the pursuit of environmental improvement.

E-waste industrial clusters in developing countries emerged as a consequence of underlying global economic inequalities. It has become incumbent upon developed countries not to criticise the pollution of the e-waste industry in less developed countries, instead recognising it as the result of inequality and social and environmental injustice based on the uneven development. It is also pivotal to acknowledge that e-waste is a systemic, rather than an individual problem. By adopting this approach, this study aims to bridge the gap between the previous authoritative viewpoints on the e-waste industry and grassroots perspectives. The research will contribute to discourses on environmental and social justice by shedding new light on these important issues and providing a comprehensive background for further research.

4.1 E-waste: A Global Problem

Waste Electrical and Electronic Equipment (WEEE), also known as e-waste, is an established and growing global waste stream which is closely tied to the increasing consumption of electronic products (Mihai et al., 2019). Global digitalisation and electronic transformation has resulted in significant changes to people's lifestyles, learning patterns and working methodologies. The growth and diversity of consumer demands have resulted in a rapid increase in the production and consumption of electrical and electronic equipment worldwide

(Gu et al., 2016). According to ITU (2022), there are 108 mobile phones for every 100 individuals globally, while the Global E-waste Monitor (2024) revealed that high-income countries possess an average of 109 electronic devices per capita, excluding lamps (Baldé et al., 2024b). Meanwhile, advances and innovation within the electronics industry have accelerated the obsolescence of electronic products, leading to a continuous rise in the volume of e-waste (Tong and Wang, 2004). Many electronic devices are discarded after only 2 to 3 years of use, and e-waste is regarded as one of the world's fastest-growing waste streams (Zeng et al., 2013; Umair, Björklund and Petersen, 2015). In 2022, the global generation of e-waste reached 620 billion kilograms, equivalent to 7.8 kilograms per capita annually. This was made up of 310 billion kilograms of metals, 170 billion kilograms of plastics, and 140 billion kilograms of other materials (including minerals, glass and composite materials) (Baldé et al., 2024b). The estimated economic value of these metals amounted to $910 billion, including approximately $190 billion worth of copper, $150 billion of gold and $10 billion of iron. However, only 22.3% of all e-waste is formally collected and recycled (Baldé et al., 2024b). The Global E-waste Monitor (2024) indicates that since 2010, the growth rate of e-waste has been five times higher than that of formal recycling. Most e-waste undergoes informal management methods such as manual dismantling, incineration or landfills. Due to non-compliant management practices, approximately 58,000 kilograms of mercury and 45 million kilograms of plastics containing brominated flame retardants are released into the environment annually (Baldé et al., 2024b). This has significantly affected the environment and human health; for instance, Guiyu in China has been referred to as the world's most toxic place because of the severity of pollution caused by e-waste dismantling. Meanwhile, the low recycling rate of e-waste contributes to a wider waste of non-renewable resources such as rare earth minerals. Currently, systematic recycling only accounts for approximately 1% of the demand for rare earth element recovery (Baldé et al., 2024b). The production and recycling of e-waste poses a global problem.

4.1.1 Transboundary E-waste Flows

In studies of e-waste trade networks, the phenomenon of developed countries dumping their e-waste in developing nations is a common occurrence (Iles, 2004a; Lepawsky and Mather, 2011), and it is estimated that 50% to 80% of e-waste from developed countries is exported overseas for recycling each year (Puckett et al., 2002). This e-waste is either disposed of into general waste streams or illegally exported to rudimentary e-waste recycling centres in Asian countries such as China, India and Pakistan and African countries like Ghana and Nigeria before the Chinese government banned e-waste import (Lundgren, 2012). However, specific information regarding the exact amount of e-waste generated, its sources, and destinations is currently lacking (Baldé et al., 2024b). A significant portion of the e-waste industry operates in 'grey areas' associated with informality and criminality, compounded by the inability of national information collection systems related to production, sales and trade to account for second-hand, used and discarded products (Management, 2009). Moreover, different countries have different monitoring standards, making it difficult to quantify waste flows and estimate the transboundary transfer of e-waste.

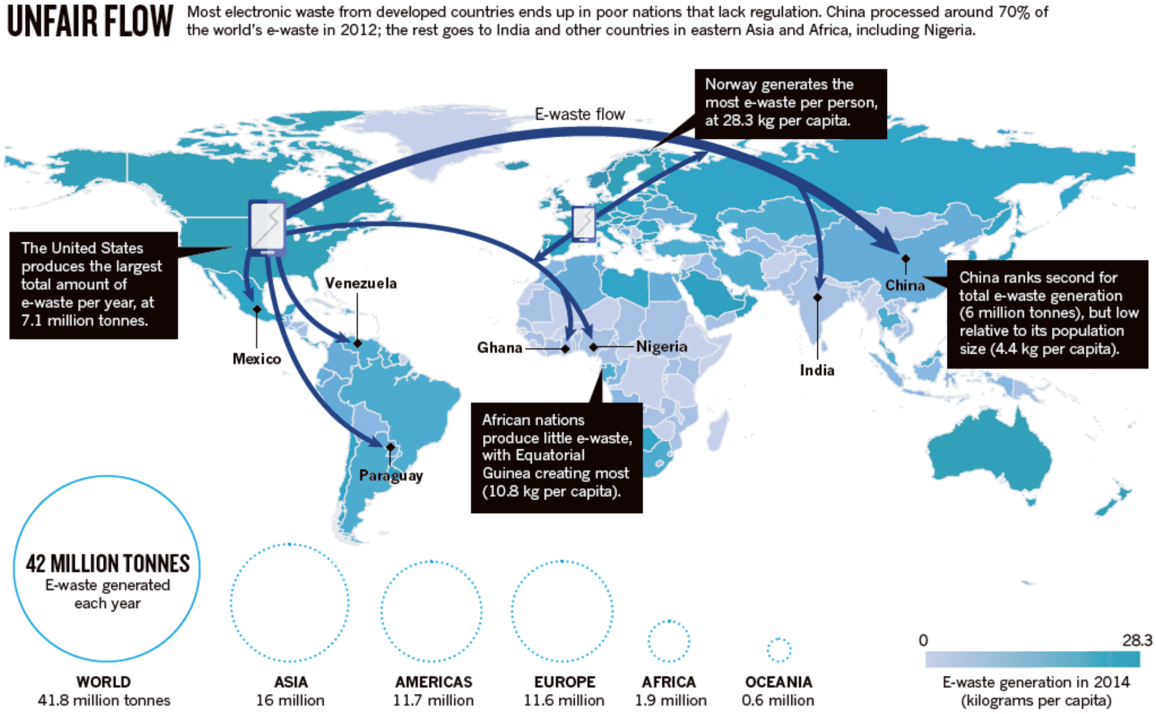

Figure 4.1 The global flow of e-waste (Wang, Zhang and Guan, 2016)

However, monitoring the movement of e-waste is vital for countries to better control the transboundary transfer of hazardous waste and to advance its scientific treatment and management. Many scholars and research institutions have explored this issue. According to Clapp (1994b), the export of toxic waste to countries with lower levels of industrialisation began in the late 1970s, continued to grow throughout the 1980s and persists to this day. According to Puckett *et al.* (2002), 50% to 80% of e-waste generated annually in the United States was exported overseas. Journalists and the Basel Action Network (BAN) placed GPS trackers in discarded equipment in the European Union and the United States to trace the movement paths of e-waste, concluding that of 205 trackers, 34% of devices went offshore, with almost all ending up in developing countries, 93% of which went to developing Asian countries (Hopson and Puckett, 2018). Another way of measuring the import volume of used electronic appliances and e-waste is to put a researcher at the receiving port as part of the 'port personnel'. This was done in Nigeria, where roughly 71,000 tonnes of WEEE were imported into Nigeria annually through two main ports in Lagos in 2015 and 2016. Of this, 77% came from EU member states (Baldé et al., 2017). Lepawsky and McNabb (2010) used data from the United Nations

Commodity Trade Statistics Database (UN COMTRADE) to illustrate the global trade in e-waste, pointing out that a significant amount of international trade now occurs internally between developing countries as well as between developing countries, rather than just between developed and developing countries. Meanwhile, some developing countries also export e-waste to developed countries. For example, most of Africa's e-waste trade is exported to South Korea and Spain, while the majority of the Caribbean's e-waste trade is exported to the United States.

Figure 4.2 Institutional labels from the United States found on computers in Guiyu, China © BAN (Puckett et al., 2002)

There are many reasons for exporting e-waste to developing countries (Davis, Akese and Garb, 2019). E-waste contains a significant amount of metal, and its disposal methods, such as incineration and landfilling, can result in significant environmental pollution. Many developed countries resist the unmonitored handling of e-waste, leading to the enactment of numerous waste disposal regulations that increase the cost of e-waste management (Andreatta and Favarin, 2020). For example, landfill fees in the United States increased from $15 per ton in 1980 to $250 per ton in 1988 (Strohm, 1993). The escalating costs of legal disposal in developed countries have prompted such countries to seek new markets in developing countries with weaker levels of social awareness and environmental regulation (Lambrechts and Hector, 2016; Anand, 2017), and waste-generating countries are becoming increasingly unwilling to handle toxic waste within their own borders. The composition of e-waste is extremely complex, and its recycling process is not automated, making it very complex, lengthy and harmful to workers' health.

Additionally, labour costs in developed countries are high, and local workers are reluctant to engage in such work (Tannock, 2015). In contrast, labour resources and low labour costs in developing countries are abundant, which attracts waste processors to these countries (Kellenberg, 2010; Efthymiou, Mavragani and Tsagarakis, 2016). For instance, in the 2000s, the average wage for e-waste dismantling in Guiyu was roughly US$2.7 a day, based on my interviews. According to the pollution haven hypothesis, as environmental regulations in developed countries become more stringent, disposal costs continue to rise, driving the recycling industry to move to developing countries with less stringent environmental regulations (Davis, Akese and Garb, 2019). Coupled with the decreasing costs of international transportation, industrialised countries rapidly became more inclined to export electronic waste to countries in the global south. From a global perspective, pollution is, therefore, being transferred from one place to another rather than being adequately dealt with in the regions where the polluting products are manufactured and used, and rural and peri-urban areas that lack pollution controls and are comparatively immune to prosecution by environmental protection agencies have become havens for waste (Ma and Ortolano, 2000), such as Guiyu Town (Lepawsky and McNabb, 2010).

These destinations for e-waste are typically found in relatively underdeveloped rural or urban areas of developing countries, where widespread unemployment, migration, poverty and lack of economic alternatives prevail, necessitating an urgent need for additional sources of income. Many workers, migrants and farmers find themselves left with no choice but to engage in the e-waste industry to sustain their livelihoods (Kellenberg, 2010). In Hebron, for instance, rising unemployment rates have driven people to seek alternative employment opportunities, such as e-waste processing (Davis, Akese and Garb, 2019). While waste management systems in developed countries rely heavily on capital-intensive technological solutions that require significant public expenditure, informal recycling sectors in developing countries offer a low-cost alternative for waste reduction in which scavengers manually extract recyclable and reusable materials from mixed waste. The waste management industry does, to some extent, address labour market issues by providing employment opportunities for unskilled labourers in rural areas (Lin, Yan and Davis, 2001) and contributes to strengthening the industrial infrastructure of developing countries (Iles, 2004a). Recycling entrepreneurs find it easier to access investment and technology, which can prove beneficial to developments. In some developing countries, advanced recycling facilities are emerging, such as HMR in the Philippines (Iles, 2004b). Importing e-waste also serves as a crucial means of alleviating debt burdens in underdeveloped regions. During the 1980s, as incomes declined and international debt soared, many less industrialised countries sought to increase their foreign exchange earnings by importing e-waste and engaging in unsustainable natural resource extraction

(Clapp, 1994b). Through waste recycling, the significant demand for raw materials in many industrialised countries is met (Iles, 2004a), which means that importing e-waste can generate more opportunities for profit, thus promoting economic prosperity.

However, underdeveloped regions generally suffer from a severe lack of equipment, funding, necessary technology, and the capacity for proper e-waste disposal. Instead, they resort to labour-intensive and hazardous methods such as open-air incineration, chemical leaching and dismantling to recover valuable metals, resulting in inefficiencies in resource utilisation and the contamination of land resources. In pursuit of economic development, local entrepreneurs often show little concern for labour, health issues or the environment, resulting in significant pollution and the exploitation of the local labour force, exacerbating the problem of uneven development (Parizeau, 2015).

4.1.2 Problems Caused by E-waste

Dumping or recycling e-waste in economically disadvantaged and poorly regulated countries may seem like an economically advantageous solution in the short term, but in the long run it undermines prospects for economic development. Although it provides funds for some countries in the short term, the cost of cleaning up hazardous waste dumping and unregulated recycling operations is prohibitively high for impoverished nations, which usually lack the capacity to adequately address these issues. As the e-waste industry expands, the detrimental effects of waste pollution are becoming increasingly apparent (Davis, Akese and Garb, 2019).

Most researchers consider the recycling of e-waste as an economically beneficial but environmentally harmful activity (Lin, Yan and Davis, 2001). E-waste contains over 1000 substances, many of which are directly toxic when released (Widmer et al., 2005; Chan et al., 2007; Wen et al., 2009), particularly heavy metals and organic compounds such as dioxins, furans and brominated flame retardants (Brigden, 2005; Li et al., 2006; Gullett et al., 2007; Wu et al., 2008). Most underdeveloped regions that handle e-waste lack proper pollution control equipment and technology, and extracting precious and non-ferrous metals from e-waste, such as circuit boards or plastic-coated cables, can lead to severe environmental and health problems. Residual heavy metals can contaminate soil and groundwater, while the incineration of plastics that contain brominated flame retardants emits toxic substances that significantly exacerbate air pollution (Sepúlveda et al., 2010; Chan and Wong, 2013; Wang and Xu, 2014).

Incineration also increases the mobility of heavy metals, especially lead (Gullett et al., 2007). In 2000, a study conducted by The Basel Action Network analysed water samples near Guiyu, finding lead levels that exceeded the World Health Organization’s drinking water standards by 2400 times (Puckett et al., 2002). Pollutants are also sometimes spread in the form of dust into the atmosphere, which people can ingest, inhale or absorb through the skin, posing severe health hazards (Mielke and Reagan, 1998). Notorious e-waste ‘recycling’ sites, such as Agbogbloshie in Ghana and Guiyu in China, serve as extreme examples of improper e-waste recycling, leading to severe air, water and soil pollution. Numerous studies have investigated the relationship between e-waste and health issues such as cancer, birth defects, neurological disorders and respiratory diseases (Xu et al., 2012; Vaccari et al., 2019; Zeng et al., 2020). Some scholars have found high concentrations of dioxins in the breast milk, placenta and hair of individuals living near e-waste processing clusters, indicating that human exposure to dioxins from air, water or food poses serious health risks (Chan et al., 2007).

The unequal power dynamics that allow developed countries to transfer e-waste to developing nations have prompted many scholars to discuss its moral implications in terms of environmental and social justice (Cutchin, 2002; Bauman, 2013). Due to the highly complex nature of the e-waste recycling process, increased concentrations of heavy metals in the air have been observed even in advanced facilities in developed countries, while underdeveloped regions lack the funds, technology and equipment for pollution-free processing. Meanwhile, in pursuit of profit and to maintain low operating costs, informal recycling chains have always been a significant component of the e-waste industry, presenting substantial challenges in terms of labour issues, particularly concerning women and child labour. Numerous studies and field investigations have found that a significant number of children are directly involved in working at e-waste sites or come into contact with e-waste while scavenging at refuse sites (Prakash et al., 2010), with most workers not covered by health insurance or unemployment and retirement plans.

An increasing body of literature in green criminology has also investigated the effects of toxic substance dumping and leakage, air pollution and freshwater contamination on vulnerable populations (Wonders and Danner, 2015; Heydon, 2020; Nurse, 2020). Most instances of waste dumping cause environmental harm, as they occur under suboptimal and uncontrolled conditions. Many such incidents masquerade as green recycling, whereby e-waste is collected from consumers and then exported to regions where environmental regulations are relatively lax, thereby deceiving consumers who dispose of their old electronic products in this way. Recyclers receive dual payments in the form of fees collected from consumers and payments to e-waste brokers in developing countries (Lepawsky, 2018). Bribing officials in non-OECD countries and regions such as Africa and Asia for illegal e-waste exports is a common practice, and local governments, driven by economic incentives, provide regulatory and oversight loopholes (Iles, 2004a). In some instances, customs officials release containers of e-waste for profit (Lundgren, 2012). Smith, Sonnenfeld and Pellow (2006) also reported that e-waste from India passes through customs without proper clearance certificates.

Another common practice is misreporting items during customs declaration, where e-waste is disguised as other goods. For example, one US company mixed 1000 tons of copper smelting furnace dust with high lead content with fertiliser (Clapp, 1994b). Some waste that is exported to non-OECD countries even carries labels marking it as aid and humanitarian assistance (Petrić, 2019). Waste export companies have devised other creative methods to conceal the hazardous waste they export, such as a US company that attempted to convince the government of the Marshall Islands that imported waste could be used to build land to mitigate sea-level rise caused by global warming (Clapp, 1994b). Mislabelled waste has become a severe issue for developing countries, as they often lack the necessary methods to identify the contents of each imported container. Hazardous waste exports are not only concealed by waste traders but also openly exported under the guise of 'further use'(Clapp, 1994a). By the early 1990s, approximately 90% of hazardous waste exported to less industrialised countries was touted as 'waste-to-energy' or 'recycling' operations (Clapp, 1994b). Green crime has therefore emerged as a significant concern in the e-waste industry.

4.1.3 Global E-waste Management

Recycling activities have long been tolerated and endorsed by authorities as a driver of local economic growth, allowing waste to be freely collected and transferred. Work began in recycling e-waste and transforming it into usable resources in the 1980s (Kirby and Lora‐Wainwright, 2015). However, in recent years, the scale of illegal transfer and improper handling of e-waste has had a more significant impact on public health and the environment (Lora-Wainwright, 2015; Schulz, 2015), and many countries and NGOs have now established regulations to prohibit waste import and recycling. The Basel Convention, adopted in 1989 and effective since 1992, is the first international treaty on the trans-border trade in e-waste. It is a multilateral environmental agreement aimed at guiding global governments to control the transboundary movement of hazardous waste (including e-waste). To date, 187 countries have signed the agreement. According to the Basel Convention, the movement of hazardous and non-hazardous waste must follow prior informed consent procedures, with the competent authorities of the exporting country required to notify the competent authorities of the importing country (and any transit countries) of the nature and contents of waste shipments (UNEP, 1989). However, country reports voluntarily submitted under the convention currently account for less than 50% of signatory countries, and there are administrative issues surrounding prior informed consent procedures (Baldé et al., 2024b). The EU and other developed countries have now enacted a series of laws prohibiting the export of e-waste to countries in the Global South, such as the Rotterdam Convention, the Stockholm Convention and the Montreal Convention, among others (Lundgren, 2012). Many countries and regions have also established bilateral, multilateral or regional agreements on the transboundary movement of hazardous waste, including the Bamako Convention, the Durban Declaration and the Libreville Declaration in Africa, the Aarhus Convention, the Waste Electrical and Electronic Equipment (WEEE) Directive, the Restriction of Hazardous Substances Directive in Europe and the Waigani Convention in the South Pacific (Lundgren, 2012).

As well as restricting the transfer of e-waste, many experts argue that the root of the problem should be addressed by underscoring the concept of Extended Producer Responsibility (EPR). EPR is a process that supports product design and production by considering and promoting the efficient utilisation of resources throughout the entire lifecycle, including repair, reuse, dismantling and recycling, while not impeding the free circulation of products in the domestic market (European Commission, 2008, p.6). Its idea is to encourage producers to take responsibility for their products beyond their effective lives by incentivising eco-design (Lifset, Atasu and Tojo, 2013), internalising waste management costs, improving resource efficiency (Massarutto, 2014) and integrating reverse logistics into the redesign of the value chain (Lindhqvist, 2000). EPR policy strategies first appeared in Sweden and Germany in the early 1990s (Lifset, Atasu and Tojo, 2013). The core principle of the approach is that the costs of waste recovery – as well as operational responsibilities in some cases – should be transferred to producers, who must be accountable for the material characteristics of their products (Lifset, Atasu and Tojo, 2013).

As of June 2023, only 81 countries worldwide (42% of the world's countries) had enacted policies, regulations or laws concerning e-waste. This figure fell short of the ITU's target of 50% by 2023, which would equate to 97 countries. Of these 81 countries (ITU, 2022), 67 had implemented legislation regarding EPR, 62 had enacted laws involving national or international environmental, health and safety standards, 46 had set national e-waste collection targets within their regulations, and 36 had established e-waste recycling goals at the national level (Baldé *et al.*, 2024b). However, these laws and conventions are not universally mandatory, and there are significant issues with data collection, including corruption and concealment, so they yield minimal benefits (Davis and Garb, 2015).

As one of the world's largest producers and recipients of e-waste, China has promulgated numerous laws and regulations to restrict the import and disposal of e-waste. Notably, in 2017, the Chinese government notified the WTO that by 2020, it would prohibit the importation of many types of waste, including plastics, scrap metals and e-waste, an action that led to chaos in global waste recycling (Gregson and Crang, 2019). Many countries' waste shipments had to be reassigned to export destinations or were left waiting at ports while new destination arrangements could be made. Subsequent sections will provide more detailed insights into the development of China's e-waste industry.

4.2 China: The Largest Producer and Recipient of E-waste

As one of the world's largest producers and consumers of electronic products, China finds itself facing an unprecedented wave of e-waste. According to Baldé *et al.* (2024a), China's electronic product output reached 12,066 kilotons in 2022, with an annual processing capacity of approximately 80 million units. At the same time, China was once one of the world's largest recipients of e-waste. In 2002 alone, the United States exported 10.2 million obsolete computers to Asia, with the majority ending up in China (Iles, 2004a). It is estimated that China illegally imports between 1.5 and 3.3 million tons of e-waste annually (Zhou and Xu, 2012), but due to inefficiencies in data collection, it is difficult to accurately determine the amount of e-waste the country actually imports. According to my interviewees, a significant portion of the e-waste processed in Guiyu before 2015 was imported, and the reassembly of electronic products in Huaqiangbei still mainly relies on imported e-waste. To address the issue of 'unequal ecological exchange', China has implemented numerous regulations to prohibit waste imports since 2013. This section provides a comprehensive overview of China's e-waste development from the perspective of import pathways and policy management.

4.2.1 E-waste Pathways to China

Despite the implementation of numerous prohibitions by the government, cross-border legal loopholes facilitate the illegal flow of e-waste, which continues to enter China through various channels. Some reports indicate that the issue of e-waste importation remains severe in regions such as Guangdong, Zhejiang and Shanghai (Wang et al., 2013). It has been reported that from 1994 to 2007, Chinese authorities intercepted at least 30 instances of illegal e-waste transportation, primarily concentrated in these provinces (Pacific, 2012). The pathways and methods frequently mentioned in literature and interviews regarding the entry of cross-border electronic waste into China are discussed below.

Directly shipping e-waste to Chinese ports and importing it through customs is the most formal route. However, with the government's comprehensive ban on e-waste imports and its increasingly stringent customs regulations, it is now rare for entire containers of e-waste to enter mainland China directly through ports unless different materials are mixed together. Some interviewees noted that individuals may import e-waste mixed with other scrap metals, as China permits the import of mixed scrap metal. However, due to the higher risk associated with e-waste, this route is generally not used.

Hong Kong is a common choice as an intermediary for the transfer of e-waste to mainland China. Hong Kong differs from the mainland in many aspects due to the implementation of its 'One country, Two systems' policy, whereby Mainland China's laws and regulations do not apply to Hong Kong. Under this policy, China, as a signatory to the Basel Convention, implements customs controls only on the mainland, while Hong Kong exercises independent control. This means that despite China's comprehensive ban on e-waste imports in 2000, import permits can still be obtained in Hong Kong, which allows the legal importation of second-hand electronic appliances and e-waste (Yoshida, 2005). As a free port and a central hub in the global e-waste trading network, once second-hand equipment is imported into Hong Kong, it can be legally re-exported to other countries and regions, including mainland China, for dismantling, refurbishment and recycling (Wong, 2018). Due to its proximity to Shenzhen, Hong Kong has historically served as a crucial entry point for e-waste into mainland China, and E-waste from Huaqiangbei and Guiyu is also mainly shipped through Hong Kong. Despite the fact that the Chinese Ministry of Environmental Protection and the Hong Kong Environmental Protection Department signed a cooperation agreement in November 2007 to combat illegal waste transfer between the mainland and the Hong Kong Special Administrative Region, this phenomenon persists. In 2010, the Hong Kong Environmental Protection Department seized 760 metric tons of electronic waste in 38 cases (45 containers), with 25 cases originating from the United States (HKEPD, 2010; Chan, 2011). In 2018, the Hong Kong Environmental Protection Department and Customs intercepted a container imported from the United States at the Kwai Chung Container Terminal that was declared to contain scrap metal. Upon inspection, the container was found to contain approximately 9 tons of hazardous e-waste batteries (China News, 2018). In 2019, the Hong Kong Environmental Protection Department also intercepted three cases of illegal imports of hazardous e-waste from the United States, South Korea and Bangladesh at the Kwai Chung Container Terminal (HKEPD, 2019).

Figure 4.3 China’s geographical relations with Vietnam and Hong Kong (Author)

With the tightening of import controls on e-waste in Hong Kong, Vietnam has emerged as another route by which e-waste enters China. Despite the Vietnamese government’s ban on importing e-waste, they allow the transfer of e-waste (import intended for export), thus creating a loophole for many imports (Wang et al., 2013). E-waste and used electronic appliances, such as discarded CRT televisions and household appliances exported from the United States and Japan, enter Vietnam through international ports in the north of the country. They are then transported to the border gate at Mong Cai, where they cross into Dongxing, China. Dongxing borders Vietnam, and there is frequent interaction between the residents of the two areas. Immigration inspections at Dongxing are convenient and fast, as is the phenomenon of ‘cross-border commuting’ (Chen and Wu, 2019). Smuggling e-waste between Dongxing and Mong Cai is convenient, requiring only a small boat to cross the river.

Despite China enacting numerous laws prohibiting the import of e-waste driven by financial incentives, traders continue to bring e-waste into the country through alternative unofficial channels. This generates considerable wealth but leads to serious environmental issues, exacerbating the ongoing conflict between local economic development pursuits and government environmental policy management.

4.2.2 E-waste Value Chain

The global flow pattern and regional distribution of e-waste exhibit distinct spatiotemporal evolutionary characteristics. In the initial phase, e-waste primarily originated from developed economies such as North America, Europe, and Japan, which contributed the vast majority of the global e-waste volume. However, with the global diffusion of information technology and the proliferation of electronic products in emerging markets, developing economies like China, India, and Latin America have increasingly become significant generators of e-waste (Lepawsky, 2015). Based on differences in technological approaches and value realisation methods for e-waste processing, this study proposes a binary classification framework, categorising e-waste treatment models into two basic types: disassembly and reassembly. These two models demonstrate significant differences in waste acquisition channels, processing techniques, value chain composition, and environmental impacts (Chi et al., 2011; Williams et al., 2013).

The disassembly-oriented processing model primarily focuses on extracting economically valuable materials from e-waste, including electronic components, gold, silver, and other rare metals. In the early developmental stage of this industry, China predominantly played the role of a passive receiver in the global e-waste flow network. E-waste from developed countries such as the United States entered the Chinese market through various informal channels, typically first being transported to Hong Kong or Taiwan as transit points, before subsequently entering mainland Chinese coastal cities such as Shenzhen, Nanhai, and Guangzhou (Tong & Wang, 2004). Upon arrival of e-waste at port cities like Shenzhen or Guangzhou, major purchasers from Guiyu (sometimes operating through agents or proxies as intermediaries) would travel to these cities, acquire goods through commercial negotiations, and transport them using container vehicles to local factories and workshops in Guiyu for subsequent processing (Tong et al., 2015). A notable characteristic of this disassembly model is the ‘wholesale acceptance’ of e-waste, with relatively little consideration given to specific product models, performance status, or usage duration. In the Guiyu region, e-waste processing has evolved into a complete industrial chain encompassing acquisition, classification, disassembly, and resource recovery. Through this series of processes, precious metals, non-ferrous metals, and other materials recovered from discarded electronic products are ultimately transported to places like Shenzhen for sale, entering the recycled resource market. In this process, Shenzhen merely serves as a simple e-waste transit point and sales location.

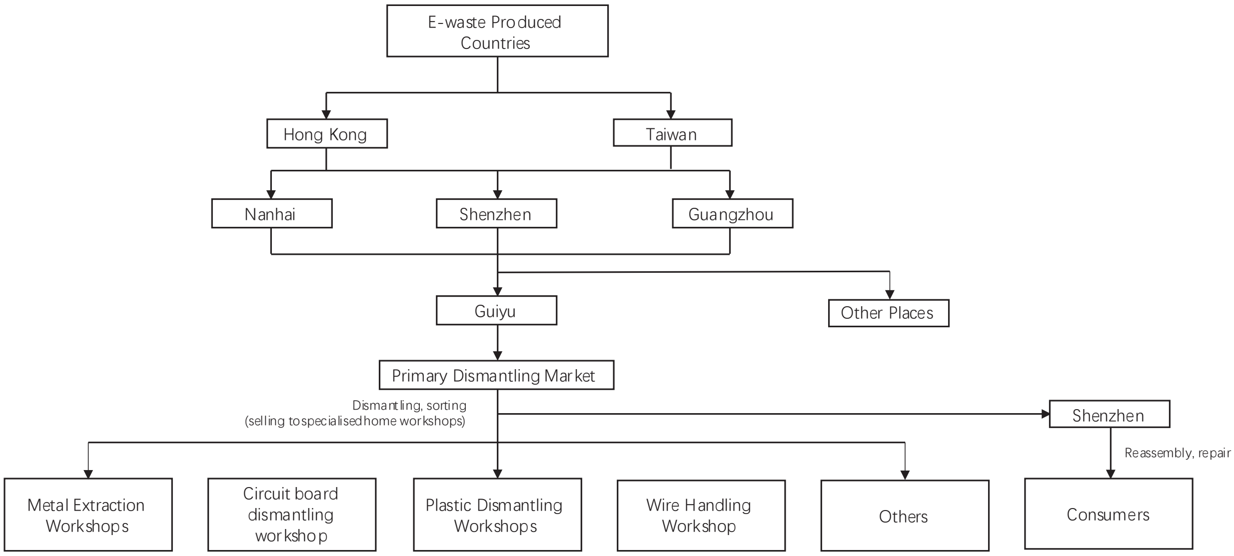

Figure 4.4 Guiyu e-waste dismantling logistics (Adapted from (Greenpeace, 2003)

In contrast to the disassembly model, the reassembly processing model centres on restoring functional value and extending the use of electronic products, primarily maximising the value of discarded electronic products through refurbishment and reuse. This model exhibits characteristics of proactivity and selectivity; given the evident time-sensitivity of technological updates and market demand for electronic products, reassembly processing must selectively choose newer, better-performing products for refurbishment and resale (Williams et al., 2013). The global flow path of reassembly-oriented e-waste typically begins with professional electronic recycling companies in developed countries such as the United States, which primarily recover high-end electronic products like iPhones. These recycling enterprises conduct preliminary functional assessments and classification of these devices, subsequently transferring devices with reuse value to traders primarily from Hong Kong through market mechanisms such as auctions (Lepawsky & Mather, 2011). After acquiring these goods, Hong Kong traders similarly distribute these obsoleted electronic devices to merchants in Shenzhen through auctions or bidding processes, forming a cross-border second-hand electronic product trading network. Upon flowing into Shenzhen, these electronic devices undergo a series of more refined processes including classification, technical testing, functional repair, and appearance refurbishment, ultimately re-entering the consumer market as ‘refurbished machines’ or ‘second-hand phones’. The Huaqiangbei district in Shenzhen has developed into a significant agglomeration area for this type of reassembly-oriented electronic waste processing, constructing a complete industrial chain including procurement, sorting, testing, repair, assembly, packaging, and sales, exhibiting distinct characteristics of specialised division of labour and clustering (Yang et al., 2008; Schulz, 2015).

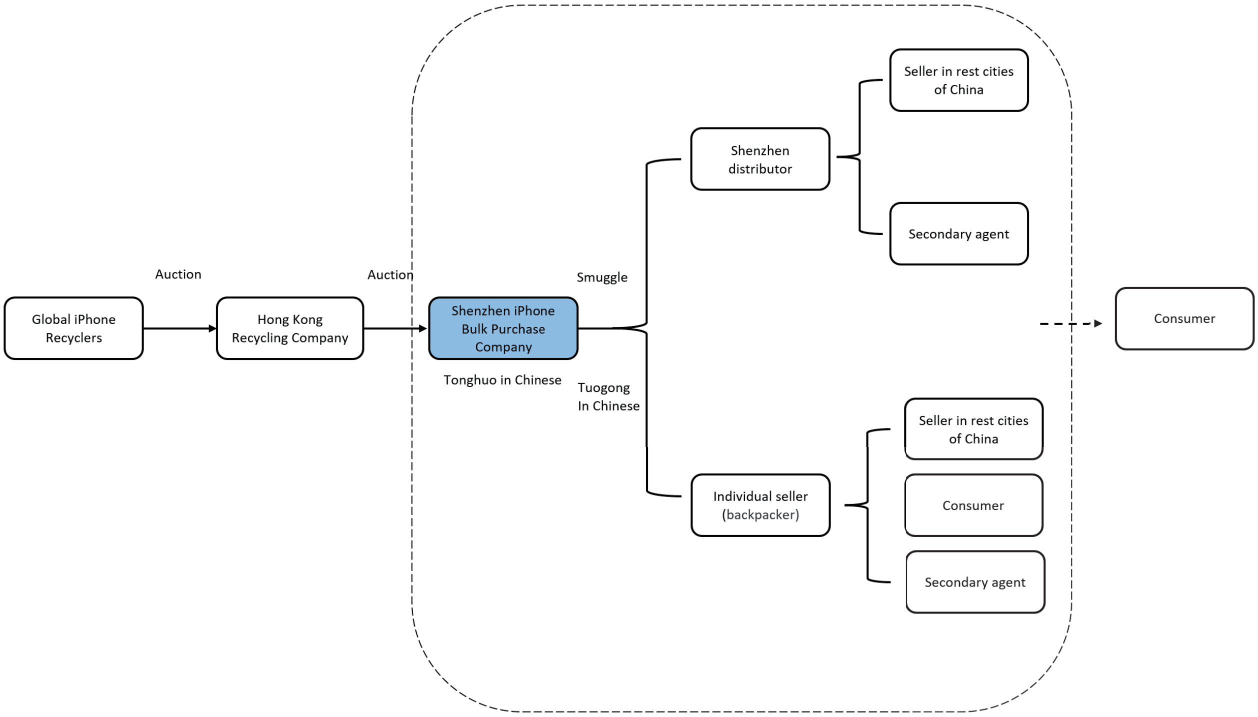

Figure 4.5 The iPhone's operation process in Huaqiangbei (Author)

Overall, the formation and development of the global e-waste industry chain constitutes a complex transnational network system, encompassing diverse stages including production, circulation, recycling, disassembly, and refurbishment. Within this global system, developed and developing countries exhibit distinct functional divisions of labour. Developed countries, facing strict environmental regulatory constraints and high processing cost pressures, export a portion of their e-waste through informal channels; meanwhile, developing countries, in the context of still-incomplete environmental regulatory systems, have become the primary recipients of this e-waste, and based on their respective technological capabilities and market demands, have formed two differentiated processing models: disassembly-oriented and reassembly-oriented.

4.2.3 Problems Caused by E-waste in China

The development of China's e-waste recycling system began in the early 1990s as the transnational phenomenon of developed countries exporting e-waste to developing countries grew (Tong and Wang, 2004). At that time, due to the relative scarcity of resources in China and the constraints of its planned economic system, many of the nation's resources were allocated to state-owned enterprises, making it difficult for emerging industries and private enterprises to obtain supplies through official channels (Tong and Wang, 2004). The import of e-waste, in part, met the resource demands of industrial development at that time (Tong et al., 2015), and with the increasing demand for industrial raw materials and functional components, an active informal recycling sector emerged. The e-waste industry also created a large number of employment opportunities and was seen by local governments as an important engine for economic growth (Lora-Wainwright, 2015).

However, the rapid development of the e-waste industry triggered a multitude of issues, the primary one being environmental pollution. The Guiyu region in China has been labelled as the most polluted place in the world because of pollution caused by the e-waste industry, and the barium content in the soil was at one point nearly 10 times higher than the environmental risk threshold set by the Environmental Protection Agency, while the tin content was 152 times higher than the EPA standard and the chromium content in one sample exceeded the EPA threshold by 1338 times. In another sample, the copper content (apparently from residues dumped during the recycling process and found on the riverbank) accounted for 13.6% of the soil (Puckett et al., 2002). As well as issues relating to environmental pollution, the lack of proper operational knowledge and training has resulted in many workers being injured during the process, especially in the acid-washing stage, in which the workers lack any protection or safeguards. Some interviewees showed scars from acid-washing processes that occurred many years ago.

Due to the particular characteristics of the e-waste industry, it is generally dominated by informal sectors (Li et al., 2013), characterised by small scales, low entry barriers, high labour intensity, lack of registration, taxation and social welfare benefits (Wilson, Velis and Cheeseman, 2006; Chi et al., 2011; Ezeah, Fazakerley and Roberts, 2013). Typically, labour-intensive and dangerous tools, methods and technologies are used for dismantling in backyards or small workshops, such as chemical leaching, disassembly and open-air incineration to recover valuable precious metals (He et al., 2006; Nnorom and Osibanjo, 2008). E-waste is usually disposed of in open dumpsites, landfills or water bodies (Ongondo, Williams and Cherrett, 2011; Oswald and Reller, 2011). This leads to ineffective resource development, waste and pollution, making it difficult for governments to manage the processes involved (Nnorom and Osibanjo, 2008). Although informal e-waste processing can offer a relatively good income, particularly for individuals without formal qualifications, the workplace lacks health and safety conditions, job stability, and social security benefits, and child labour is widespread (Prakash et al., 2010; Umair, Björklund and Petersen, 2015).

The e-waste industry in China is often perceived as being based on criminal and corrupt activities to ensure the supply, transportation and sale of materials and the continued operation of suspicious facilities (Davis and Garb, 2015). Tax evasion means that income does not flow into systems that are intended to provide broader infrastructure, services and investments. Meanwhile, informal recyclers are very flexible and can adapt quickly to newly implemented policies. For example, when the government required the closure of all informal dismantling workshops in Guiyu, they were quickly moved to hidden locations, such as riversides and forests, where they operated at night, making them harder to identify and shut down (Chi et al., 2011). However, this informality also makes it difficult for workshops to expand their scale and obtain capital for industrial upgrading and transformation, resulting in poor resilience.

The high level of pollution caused by China's e-waste industry initially drew the attention of foreign media, which extensively reported on and used shock tactics to describe Guiyu, condemning the government's inaction. This forced the government to take action to manage and forcibly shut down the local e-waste industry. Consequently, significant conflicts of interest emerged between policymakers, urban residents and e-waste workers in terms of waste recycling and reduction. Urban residents expected a convenient and affordable waste management system while adhering to the 'not in my backyard' principle, but they also required convenient and affordable e-waste recycling services. The government has tried to establish a modern and clean waste management system that does not rely on imported e-waste, but it is challenging to strike a balance between economic demands and the environment.

4.2.4 Regulations in China

Faced with the negative impacts of the e-waste industry and public pressure, the Chinese government initiated a series of interventions and management measures. China has been exploring sustainable development since the 1990s, and in 2012, the government proposed 'Building a Beautiful China' as a new strategic goal for an 'ecological civilisation'. In 2013, China implemented a 'Green Fence' to limit the import of global waste (Wang, Qian and Liu, 2020), and in 2016, China's Thirteenth Five-Year Plan (2016-2021) was considered its 'greenest' five-year plan ever. The central government pledged to build a 'Beautiful China', promote 'green development', and integrate 'green development into all aspects and processes of economic, political, cultural and social development' to achieve sustainable development (Gregson and Crang, 2019). Environmental protection was emphasised in all sectors, with the government not only focusing on polluted natural environments but also planning to transform China into a green economy. E-waste, from import to disposal, contains significant pollutants, posing threats to the environment and human health, and has become a key focus for regulation and monitoring efforts.

In 1990, China was one of the first countries to sign the Basel Convention, subsequently enacting a series of regulations regarding the import of e-waste. In 1996, China promulgated the 'Regulations on the Prevention and Control of Solid Waste Pollution in China' and jointly issued the 'Interim Regulations on the Environmental Protection Management of Waste Import'. The seventh waste category in these regulations includes 'electrical and electronic equipment', and only licenced importers with a national waste import approval certificate were allowed to import e-waste into China. In 2000, the China National Environmental Protection Agency issued a notice on 'Issues Related to the Import of the Seventh Category of Waste', formally prohibiting the import of most forms of e-waste. In 2013, China launched its first 'green fence' action to prevent the import of illegal waste, and in July 2017, the government notified the WTO of the prohibition of certain types of global waste imports (Gregson and Crang, 2019). In 2018, China expanded this ban to include most categories of second-hand goods and materials, and on 28 November 2020, the government announced a comprehensive ban on the import of solid waste by 2021. Over time, China's prohibition on the import of e-waste has therefore become increasingly stringent.

Since prohibiting the import of e-waste, the Chinese government has intensified its management of the e-waste industry. In 1996, the China National Environmental Protection Agency identified over 460 companies that were engaged in the import or disposal of waste. By 2002, this number had grown to 509. The following year, China's National Development and Reform Commission collaborated with four major electronics giants[3] to jointly control the market through legitimate e-waste processing companies. In 2007, the China State Environmental Protection Agency issued the 'Measures for the Prevention and Control of Electronic Waste Pollution', regulating the development of e-waste recycling enterprises, particularly informal ones. The Chinese government also levied charges on manufacturers to subsidise legitimate e-waste recycling. The 'Old-for-New Tax Rebate Program for Household Appliances' from 2009 to 2011 was a supportive law that helped stimulate the economy in response to the 2008 global financial crisis. Consumers selling old appliances to certified recycling companies received a 10% discount when purchasing new appliances, including televisions, air conditioners, refrigerators, washing machines and personal computers.

Meanwhile, the government stipulated that only those who held licenses issued by the state could legally operate in the destruction and disposal of e-waste. The State Council of China promulgated the 'Regulations on the Recycling and Disposal of Waste Electrical and Electronic Products' in 2011, establishing the Electronic Waste Disposal Fund to subsidise the collection and disposal of e-waste and requiring that e-waste was sent to government-authorised facilities for processing before reuse. Imported e-waste also had to comply with relevant regulations on pollution control information and provide details of any harmful or toxic content, and illegal activities were penalised. After a series of consultations with e-waste recycling companies and electronic and electrical product manufacturers and importers, the Chinese Ministry of

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[3] Da Di in Hangzhou, Hua Xing in Beijing, Haier in Qingdao and Da Tong in Tianjin.

Environmental Protection, the Ministry of Industry and Information Technology and many other ministries jointly formulated and published the ‘Measures for the Management of Funds for Recycling and Disposal of Waste Electrical and Electronic Products’. Since the implementation of this e-waste disposal fund plan, two batches of 64 e-waste recycling companies have been certified by the Ministry of Finance, the Ministry of Environmental Protection, the National Development and Reform Commission, and the Ministry of Industry and Information Technology. Among China’s 31 major cities, provinces and autonomous regions, 22 cities now have certified recycling companies. In recent years, the Chinese government has successively issued policy documents regarding the e-waste industry, including the ‘Action Plan for Promoting Green Consumption’ (2022), the ‘Notice on the Implementation of the Responsibility System for Achieving Recycling Targets by Household Appliance Manufacturers in 2022’ (2022) and the ‘Guidelines for the Renewal, Upgrade, and Recycling of Household Electrical Appliances’ (2023). These policies have improved the circulation and transaction management system of e-waste – particularly the standardisation of electronic product information erasure – and strengthened the environmental regulation of the e-waste industry.

China’s strategy for managing e-waste is still in accordance with the Basel Convention, not only prohibiting the import of e-waste but also attempting to establish a formal nationwide e-waste recycling system with the support of government funding, subject to strict environmental protection standards. However, despite the regulation at the national level, many prohibitions are little more than empty words (Gregson and Crang, 2019), and they face significant limitations in actual implementation. This mirrors the problems faced by many other countries in e-waste management. To achieve the goals of a green economy, China’s central government is increasingly committed to banning the import of e-waste and shutting down informal e-waste dismantling activities at local levels. However, local governments and businesses are reluctant to sacrifice their economic development, tax support and regional stability. This means that in the execution phase, local government agencies often lack sufficient resources to enforce national regulations, resulting in a significant gap between policy and implementation. At the same time, the implementation of waste management policies redefines who has the right to handle and recycle e-waste (Inverardi - Ferri, 2018). Although e-waste is a recognised market, only a limited number of companies are legally granted the right to handle such waste (Schlager and Ostrom, 1992; Lane, 2011). This pattern of ownership, its practices and the dynamics of deprivation are a result of economic and political strategies in which both the market and the state participate (Jessop, 2014). However, in reality, the e-waste industry is a much more diverse phenomenon, driven by market-based informal sectors in collection and processing that make it difficult for formal recycling enterprises to compete with informal ones. As well as a robust legal framework, factors such as socio-economic development, governance structures, local cultural contexts and geographical and trade links are all important influencing factors in e-waste industry management, as the national regulations have different consequences in various local clusters, requiring careful consideration of specific regions.

4.3 Conclusion

Over the past 20 years, with the rapid development of technology, the global market for electrical and electronic equipment has grown rapidly. However, the lifespan of these devices has been increasingly shortened as goods become obsolete more quickly. E-waste is considered one of the fastest-growing waste streams in the world, and while it creates numerous job opportunities, it also brings about severe environmental pollution and health hazards. As one of the world's largest producers and recipients of e-waste, China has implemented many policies to restrict the import of e-waste and manage the industry, and these policies have had a profound impact on the global movement of e-waste. China's governance of the e-waste industry provides valuable insights for global e-waste management, particularly at the local level, but there remains a significant gap in understanding how these regulations are implemented and the effects they have on local clusters. Furthermore, the interactions between various agents within this new regulatory framework are not yet fully understood.

The concept of e-waste is ambiguous, much as the term 'waste recycling' combines scavenging and salvaging, containing a mixed attitude and definition of reclaiming materials and goods as waste and resources (Lepawsky and Mather, 2011; Kirby and Lora - Wainwright, 2015; Lepawsky, 2015). Many electronic products are discarded not because they are useless but due to obsolescence, lack of need or damage, which means that e-waste has material value as well as potential value for refurbishment and reuse. The e-waste industry can be divided into two areas: disassembly (material recovery and reuse) and reassembly (equipment repair, refurbishment and reuse). The development paths of these two distinct areas may be entirely different, and both require more detailed research.

This project, therefore, uses two regional case studies, Guiyu and Huaqiangbei. The first focuses on disassembly, and the second on reassembly. By comparing the developmental trajectories of the two e-waste clusters, the thesis explores the influence of different factors on the development paths of the two e-waste industry clusters, as well as the conflicts and negotiation processes among various agents in terms of policy management. Through a comprehensive analysis of cases involving different recycling paths in the e-waste industry, the study provides multifaceted perspectives as well as references for other countries and regions.

Chapter 5 Cluster Lock-in and Decline – The Case of Guiyu

> *'Hundreds of rivers present a pitch-black appearance due to the heavy metal substances; piles of e-waste are visible on the streets, with large trucks blocking the roads as they load and unload e-waste; outside the town, abandoned fields have turned into various dumping grounds, often emitting black smoke and releasing disgusting odours that cover the sky. This is not a description of the apocalypse but a depiction of the daily scenes in Guiyu, an ordinary town in the southern Chaoshan region of China (Ling and Su, 2007, P. 114).'*

Building on the previous chapter's overview of the e-waste industry, the focus of the thesis now shifts towards a case study conducted in Guiyu, which aims to investigate the evolution of the e-waste dismantling cluster. By examining the development trajectory of this cluster, the intricate relationship between e-waste and its various stakeholders and the factors influencing its development, the study seeks to enhance our understanding of change within the cluster and barriers to upgrading. Guiyu is renowned as one of the world's largest e-waste clusters and has attracted significant attention from foreign journalists and research scholars who have extensively documented and criticised the severe environmental problems caused by the local e-waste industry (Network, 2002; Watson, 2013). Numerous studies have focused on local environmental pollution, residents' health and policy management of the e-waste industry (Wu et al., 2008; Wang, Qian and He, 2022). Scholars have proposed strategies such as source control and producer responsibility to address the issue (Lin, Yan and Davis, 2001), but these efforts have had only a limited impact on alleviating Guiyu's challenges.

The problems confronting Guiyu's e-waste cluster call for a thorough analysis of its transformation as the area grapples with various issues, including environmental pollution, social equity and the need for industrial upgrading and restructuring. Following the implementation of regulatory measures by central and local governments on Guiyu's e-waste industry, aspects of the local landscape, such as industrial structure, economic development, employment conditions and social stability, have changed to varying degrees. These changes are closely linked to the development trajectory of the cluster and involve factors such as transformation, upgrading, path dependence (lock-in) or decline. This means that only by adopting a holistic perspective can we fully investigate the internal logic and external influences that shape the development of Guiyu's e-waste cluster. This approach will allow a systematic grasp of its evolutionary process and an examination of the root causes of current problems.

This chapter provides an in-depth exploration of the evolutionary trajectory of the e-waste cluster in Guiyu. It explains the factors that led to the emergence and subsequent development of the cluster, highlighting the distinctive characteristics observed at each stage of its evolution and the interactions between the various agents involved. A particular emphasis is placed on the reliance of residents on the e-waste industry and the influence of Guiyu's unique social and cultural fabric – including the business-oriented culture and the significance of clan affiliations – that played a significant role in fostering the prosperity of the e-waste industry in the region. As environmental concerns grew following the neglect of proper waste management practices, the government intervened during the 2010s, prohibiting e-waste dismantling activities in places other than the circular industry park in Guiyu, which led to the region adopting the most stringent e-waste control measures in China. This regulatory intervention presented a complex challenge, given that 90% of Guiyu's population depended on the e-waste industry for their livelihoods. The cluster did not diversify into new industries or facilitate industrial upgrading and transformation, leading to a tendency towards 'lock-in'.

During its development, the strong influence of local clan-based governance structures complicated the dynamics further, necessitating a delicate balance in the negotiation process between the government and regional stakeholders. The shift in power dynamics resulted in a transition from a scenario that was characterised by a strong clan influence, a vibrant market and a weaker government to a situation where the government gained more authority while the influence of clans weakened, leading to a less vibrant market. This chapter provides an in-depth exploration of the trajectory of Guiyu's e-waste cluster, tracing its emergence, development and the external shocks it encountered. It also critically examines the reasons behind the cluster's failure to diversify and its subsequent entrenchment in lock-in. It emphasises the intricate interactions between various agents, particularly in the context of stringent regulatory measures implemented by higher authorities.

5.1 Path Emergence, 1980s-1990s

According to some researchers, clusters follow the stages of birth, growth, maturity and decline, constituting a 'classic' life cycle (Storper, 1985). However, many economic entities do not follow specific or identifiable life cycle sequences (Robertson and Patel, 2007), and the Guiyu e-waste cluster is more like a complex adaptive system, as its evolution path demonstrates. The e-waste industry cluster in Guiyu can be divided into five phases and three different trajectories (Figure 5.1; Figure 5.2), based on emergence, exploitation and growth, conservation, decline and release and reorganisation and restructuring as an adaptive model described by Martin and Sunley (2011a). However, its decline and release stage followed three fragmented trajectories simultaneously and will continue to do so for a long time. These trajectories are the disappearance of the traditional cluster, its replacement by the textile industry and its renewal based on the Government defined e-waste industrial zone.

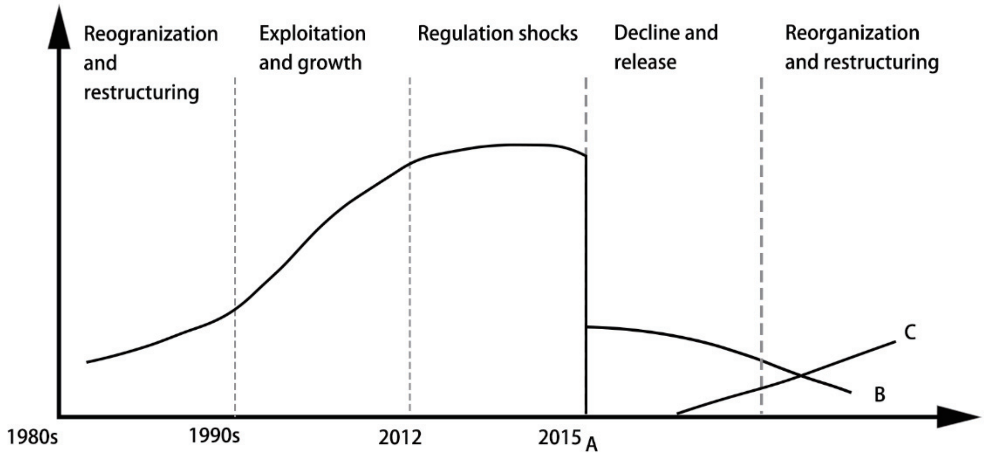

Figure 5.1 Phases of the e-waste cluster in Guiyu (Adapted from (Martin and Sunley, 2011a)

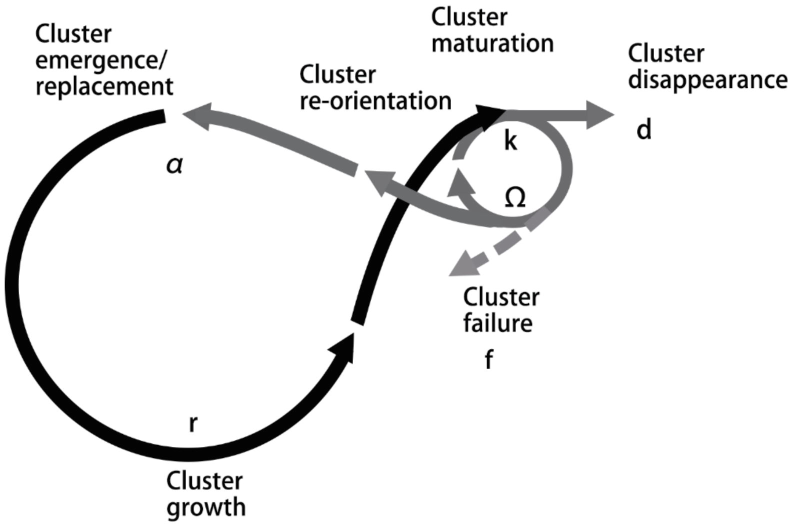

Figure 5.2 Guiyu e-waste cluster evolutionary model (Adapted from (Martin and Sunley, 2011a)

5.1.1 Related Industry and Path Dependency

Guiyu's e-waste cluster evolved from a historical foundation of traditional waste scavenging in an open and unregulated market. Its development was not accidental but rather represents a product of path dependency. The e-waste industry emerged in Guiyu during the 1980s and 1990s. Historically, Guiyu has faced significant financial challenges, which prompted local residents to engage in the waste industry (processing plastics, boxes, animal fur, etc.) as a primary livelihood strategy. Guiyu's geographical positioning in the centre of a low-lying area, with 13,864 millimetres of average annual precipitation, renders it particularly susceptible to severe waterlogging (Huang, 2019). This hydrological characteristic has consistently undermined agricultural viability in the region. As the former director of party history research in

Chaoyang District noted that: ‘Rainwater would flood into houses during the flood season in Guiyu, often taking days to soak in before fading away, so historically, the people in Guiyu seldom made a living from agriculture (Time-Weekly, 2009).’ This agricultural disadvantage was further exacerbated during 1959-1961, when China experienced extensive natural disasters resulting in widespread famine and economic hardship.

In response to these challenging circumstances, many Guiyu residents adopted waste scavenging as a subsistence strategy. They traversed streets collecting animal fur, feathers, boxes, and tins, generating modest profits that gradually established waste processing as the region’s predominant economic activity. By the 1980s, numerous Guiyu residents were deriving sustainable income from waste recycling operations. Consequently, Guiyu’s population became pejoratively labelled as ‘waste collectors’, and the area itself acquired the designation ‘waste town’ (Wong et al., 2007). This socioeconomic evolution fostered a distinctive local capability: Guiyu’s residents developed sophisticated skills in recognising value within discarded materials and demonstrated willingness to engage in this environmentally challenging industry.

The e-waste industry in Guiyu evolved from its traditional waste industry. Local residents, through their long-term engagement in traditional waste dismantling activities, accumulated extensive technical experience and resource networks, laying the foundation for the development of the e-waste industry. The e-waste industry can essentially be viewed as a technological upgrade and market expansion of the traditional waste industry. This evolutionary pathway explains why Guiyu residents were able to astutely identify economic value in e-waste when other regions still regarded it as worthless and highly polluting waste.

In the 1980s, China implemented its reform and opening-up policy, coinciding with the global transfer of low-end electronic industries to developing countries. Against this backdrop, substantial quantities of e-waste were transported to the Shenzhen, which will be elaborated upon in the next chapter. Some waste collectors from Guiyu discovered commercial opportunities in e-waste processing in Shenzhen, recognising that compared to traditional waste (such as plastics and cardboard), e-waste recycling could generate higher economic value. Under the leadership of these pioneers, the Guiyu region gradually transitioned from traditional waste to the e-waste industry. As one respondent explained:

> *‘E-waste was something that we, the people from Beilin, initially started doing. They brought it back for dismantling and discovered that the profits were much higher than other types of waste. Gradually, they started involving family and friends in the business (G37L).’*

This transformation process exemplifies the adaptive response of local industries to changes in global value chains and reflects the complex interactive relationship between local knowledge and global economic dynamics.Guiyu’s geographical location, away from major roads and far from the sea, made it less than ideal for collecting and distributing e-waste. However, this isolation made it an attractive site for grey industries seeking to evade regulation. Driven by the need to augment their income and the lack of a full industrial chain, the people of Guiyu initially accepted a diverse range of e-waste with no particular requirements or selection criteria. The local population was willing to accept and dismantle imported foreign e-waste as a primary raw material, whether it was large appliances, small electronic devices or plastics. The technological methods employed in family workshops were rudimentary and rough and involved fundamental dismantling and categorisation of e-waste to obtain valuable metals and plastics. E-waste that was deemed valueless was directly discarded, buried or incinerated to maximise profits. This gave rise to Guiyu’s primary industry – the disassembling of e-waste components and the gradual formation of an industrial chain involving the intake of materials, their dispersal to family workshops for disassembly, and the extraction and eventual sale of valuable components. During this period, the volume of business among family workshops remained constant, and due to the lack of environmental awareness or knowledge about electronic products, there were no provisions for wastewater and exhaust gas filtration and no protective facilities. Dismantlers worked without safety equipment, usually with their bare hands. Furthermore, government intervention was minimal, and Guiyu’s e-waste industry soon entered a phase of free and extreme expansion.

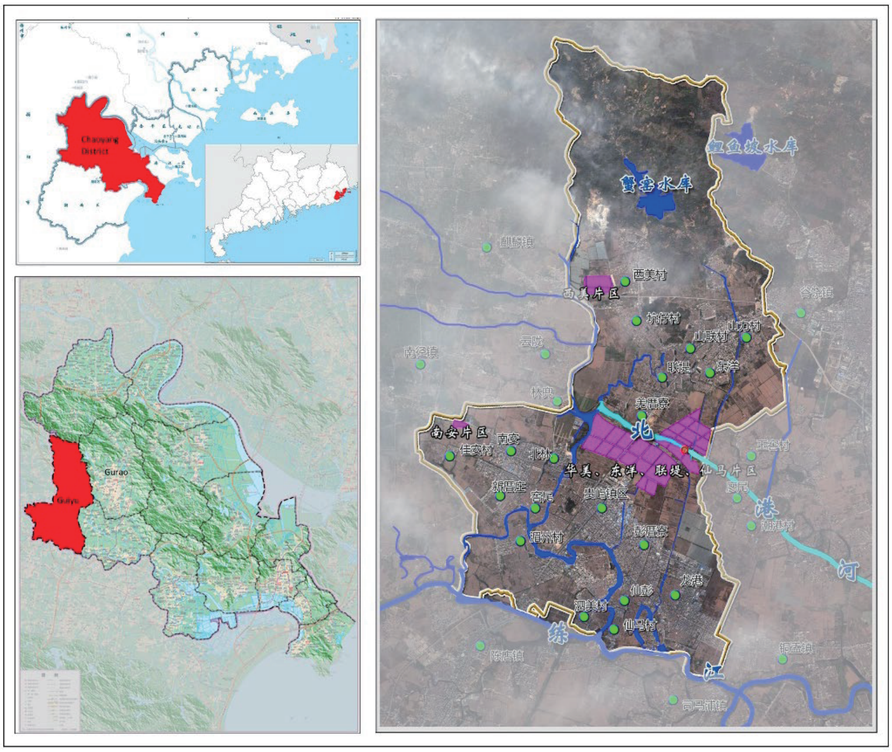

Figure 5.3 The geographical location of Guiyu (Author)

5.1.2 Regional Assets and Policy Stimulation

The shifts in China’s foreign policy and the establishment of Shenzhen’s electronic industry development strategy accelerated the transfer of e-waste to China at a global level, and these changes facilitated the transformation of Guiyu’s waste industry into a more specialised e-waste cluster. After the initiation of the ‘Reform and Opening-up’ policy in 1978, China loosened its control over foreign trade, expanding the import of goods from foreign countries. A significant amount of e-waste from developed countries began to enter China through Hong Kong and Taiwan, reaching various locations in mainland China, such as Shenzhen, Nanhai and Guangzhou (Shantou Chaoyang District People's Government, 2010). People from Beilin Village in Guiyu Town, who had previously been involved in collecting waste, were the first to bring e-waste back to Guiyu, where they dismantled it and quickly discovered that this endeavour yielded higher profits than dealing with other types of waste. This soon attracted the attention of others in Beilin and prompted by social networks of relatives and friends, more people from Beilin Village started to engage in the e-wate trade. At this initial stage, e-waste dismantling predominantly occurred within family settings, without factories. E-waste was accumulated and disassembled on the ground floor of the houses or in the streets outside (see Figure 5.4). However, because of the limited understanding of electronics, the dismantling process was rudimentary and unstructured, involving basic disassembly and the categorisation of the e-waste, which was then resold.

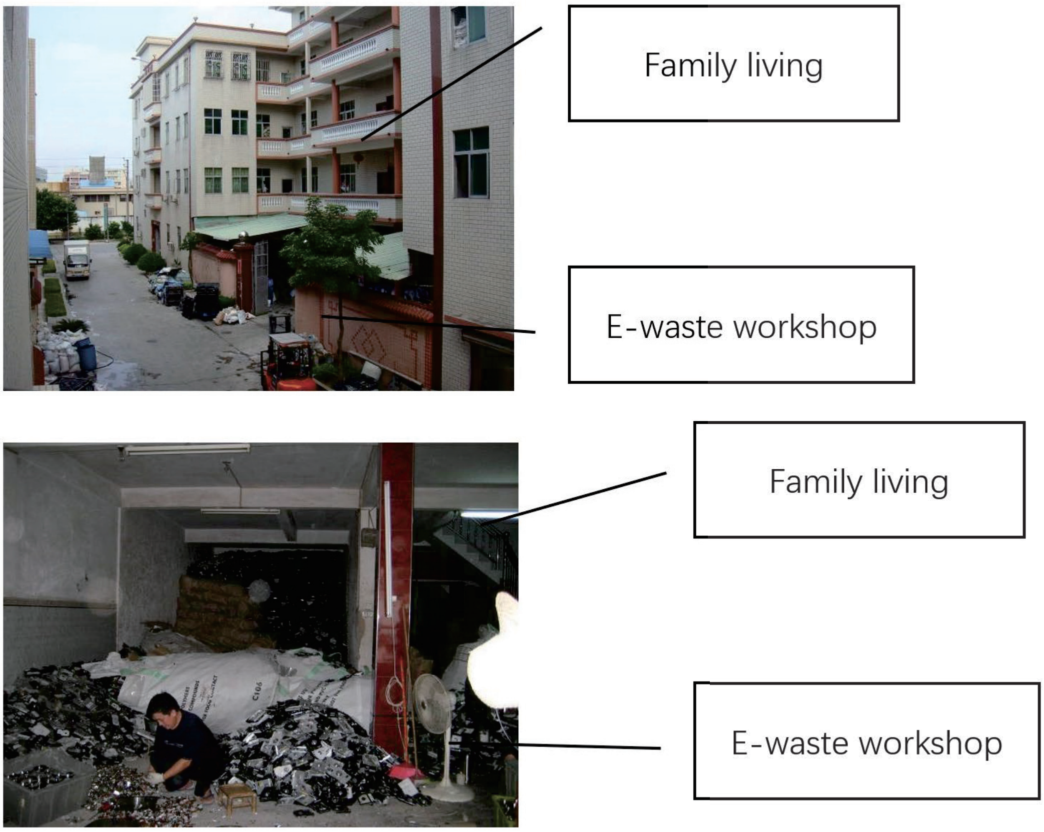

Figure 5.4 Family workshops in the Guiyu e-waste industry (Source: Interviewees)

During this stage, Guiyu gradually built an industrial chain characterised by the flow of materials into the area, their dispersal to various family workshops, dismantling and extracting valuable materials and eventual sale. However, due to the fledgling status of the industry during this period, resources were concentrated in the hands of a select few, and participants in this system were mostly limited to individuals who had access to vital information resources within the upstream or downstream segments of the supply chain. Outsiders faced significant challenges in entering this network. At this stage, the degree of accumulation and connectivity of the cluster was limited, and the level of resilience was high.

5.2 Path Development, 1990s-2012

The period from the 1990s to 2012 reflected a phase of rapid development for the e-waste industry. Driven by lucrative profits, Guiyu’s e-waste industry expanded rapidly, eventually evolving into a full e-waste cluster. According to official documents, at the peak of the e-waste industry, Guiyu had a population of more than 220,000, with around 160,000 residents and an additional 60,000 migrant workers who came for employment opportunities (Hu, 2016). 21 out of the 27 villages in the town were involved in the e-waste-related industry, with over 90% of households participating (Shantou Chaoyang District People's Government, 2010). In 2013, Guiyu was recognised by the Guinness World Records as the largest e-waste site in the world (Glenday, 2013). An interviewee (G38Z) with years of experience in e-waste said, 'I dare say that most Guiyu residents over 30 have worked in e-waste dismantling, and each of them is a millionaire.' Local government officials also claimed that nearly every household in Guiyu, apart from those in the more remote mountain villages, was involved in e-waste dismantling (China Solid Waste and Chemicals Management, 2016).

Given the large number of participants, the amount of e-waste dismantled in Guiyu was astonishing. According to Shantou Chaoyang District People's Government (2010), between the 1990s and 2012, Guiyu processed and recycled e-waste at a rate of over one million tons per year. The e-waste dismantled and processed in Guiyu is mainly comprised of discarded household appliances,[4] electronic products,[5] electronic device casings, circuit boards and other electronic products.[6] Between 1993 and 2005, Guiyu processed in excess of 20 million tons of e-waste, making it China and the world's biggest e-waste dismantling cluster (Shantou Chaoyang District People's Government, 2010). Despite a sharp decline in the dismantling of discarded electronic household appliances since China banned their import in July 2002, with the annual recovery amount dropping to only 20,000-30,000 tons (less than 20% of the original figures), the overall dismantling volume of e-waste remained high. According to Shantou Chaoyang District People's Government (2010), Guiyu received a total of 1.2728 million tons of discarded e-waste in 2008, including 0.0201 million tons (1.58%) of discarded household appliances, 0.1869 million tons (14.68%) of discarded electronic products, 0.9336 million tons (73.35%) of computer casing and circuit boards and 0.1322 million tons (10.39%) of other discarded electrical and electronic products. The total volume of e-waste processed in 2009 reached a staggering 1.94 million tons.

5.2.1 Deepening and Profitable Specialisation

5.2.1.1 A Rewarding Industry

E-waste contains a significant number of metals and has often been referred to as 'urban mining'. Generally, e-waste includes metals like copper and iron, while electronic chips contain metals like tin and gold that can yield substantial economic value from their extraction (Jiang, 2013). According to Worry-Free Solid Waste Network (2017), 1 ton of circuit boards can produce 130 kilograms of copper, 0.5 kilograms of gold, 58 kilograms of mercury, 24.6 kilograms of chromium and 340 kilograms of arsenic. Interviewees also noted that the older a mobile phone

[4] Televisions, refrigerators and air conditioners.
[5] Digital products and mobile phones.
[6] Wires and cables.

is, the more valuable it becomes. Phones from the 1990s contained a high number of precious metals, especially gold. Because of technological limitations in the early manufacturing phase, a significant number of precious metals were required to ensure the circuit board's conductivity and 'lock' the call signal. Interviewees told me that at the time, one ton of discarded phones could provide 200-300 grams of gold, 1-3 kilograms of silver, approximately 100 kilograms of copper, and varying amounts of palladium and platinum. In comparison, traditional mining operations target gold with a grade of 3 grams per ton, and even when processed, the ore typically yields only about 70 grams of gold per ton of refined concentrate. Thus, the gold content in one ton of discarded mobile phones far surpasses that of gold ore (Zhao, 2001; Time-Weekly, 2009).

According to official statistics from Guiyu, the local annual processing of various hardware materials is now 600,000 tons, equivalent to the mining 2 million tons of ore (Hu, 2023). During the peak period of e-waste dismantling, up to 15 tons of gold were extracted annually from e-waste, accounting for 5% of China's annual gold production (Lai and Li, 2017). Main gold dealers in Guangzhou, Shenzhen and other jewellery shops often sourced their gold from Guiyu (Li et al., 2014), and Guiyu had numerous precious metal testing shops to facilitate the resale of gold based on market conditions. Some workshops even had computers displaying the gold market prices from the Shanghai or London futures markets (International Green Economy Association, 2015). Interviewees proudly claimed that the gold they extracted from discarded e-waste at the time had the potential to influence international gold prices.

The rapid accumulation of wealth among the people of Guiyu through the dismantling of large quantities of e-waste transformed Guiyu into a prosperous town. At that time, a popular saying suggested that a single truckload of e-waste could make someone a millionaire (Lin and Zhuang, 2005). By the end of 2003, the savings deposits in Guiyu's rural credit agricultural banks and postal savings had already reached 570 million yuan. The town had 26,000 telephones, with installation numbers and telecom owner income dominating the Chaoyang District. In 2003, the town's power supply reached 140 million kilowatt-hours, making it one of the wealthiest towns in the region (Lin and Zhuang, 2005).

The E-waste industry became the backbone of the local community and served as the primary source of local revenue (Time-Weekly, 2009). In 2000, the total income of the enterprises in the town reached 700 million yuan, with income from recycling and utilising e-waste reaching 550 million yuan. Taxes amounted to 13.25 million yuan, constituting 84% of the region's tax revenue. Even in the face of the financial crisis in 2008, Guiyu's e-waste industry still generated an impressive output value of approximately 2.2 billion yuan, accounting for over 90% of the total industrial output value of the town and serving as the pillar industry of the local economy (Lin and Zhuang, 2005).

5.2.1.2 Specialisation in Disassembly

Driven by the lucrative profits to be made, e-waste dismantling techniques in Guiyu gradually developed specialisations, with a highly developed division of labour that covered almost all types and dismantling processes of e-waste. Local government officials and those engaged in the dismantling process proudly claimed during interviews that: 'There is nothing in e-waste that can't be dismantled in Guiyu. Things other places can't handle are shipped here (G31L).' According to interviewees, Guiyu received discarded fighter jets from foreign countries in the 1990s, which were also dismantled by locals. Guiyu soon became the best-known e-waste dismantling cluster in China. However, this was not because Guiyu's dismantling technology was using advanced techniques; in fact they used 'ancient' techniques, relying mostly on manual dismantling. There was a saying in Guiyu at the time: 'Using techniques from over 2000 years ago to handle things from the 21st century.' The fact that the people of Guiyu were so profit-oriented meant that they acted boldly and without considering consequences, ultimately leading to severe environmental problems.

The generally low standard of educational attainment in Guiyu significantly constrained the technological upgrading and transformation of its e-waste industry. According to Shantou City Chaoyang District Statistics Bureau (2021), only 2,552 individuals per 100,000 in Guiyu possess a degree or higher education. This educational structure has considerably influenced the long-term persistence of Guiyu's e-waste industry at a relatively low technological level and has impeded technological development. Guiyu's e-waste disassembly industry is still predominantly based on manual labour, characterised by low entry barriers and minimal requirements for educational qualifications or professional backgrounds. The transmission of knowledge and skills primarily relies on informal master-apprentice relationships and on-site practice, a process that lacks systematic training or educational channels. A common sentiment is: 'You can learn it after watching once or twice; even older people and children can master it. It's mainly about practice making perfect (G28Z).'

Figure 5.5 An old woman dismantling e-waste (Source: TIME (archive.org)

Guiyu's workers generally lack professional knowledge in electronics and have only a limited understanding of professional concepts such as chips and model numbers. They only knew that people frequently came to inquire about these items and that they could be sold at a good price, and it was this that drove their decision to dismantle them. This has led to a distinctive knowledge structure and market response pattern in Guiyu's e-waste industry, in which workers rely mainly on practical experience and market information to guide production activities rather than professional knowledge and technological innovation. While this model is adaptable to short-term market demands, it is likely to constrain the industry's technological upgrading and sustainable development in the long term. As one interviewee put it, 'Our understanding of electronic products is minimal. What these things are called and what they are used for – probably no one in the market knows (G2L).'

In the early stages, e-waste transactions in Guiyu were conducted using truckloads. Buyers could open the container doors to examine the cargo and then negotiate the price. This trading method carried significant risks but also offered considerable profits. If the entire truck contained inexpensive plastics, profits would be significantly reduced, but much more substantial profits could be made if it consisted of well-preserved electronic appliances. As the market matured and more regions engaged in the e-waste dismantling industry, more professional and tighter supply chain relationships became established between Guiyu's e-waste 'procurement' and upper-tier suppliers. Upstream suppliers began to pre-sort e-waste into various categories, such as large electronic appliances and mobile phones, before shipping it to Guiyu. The e-waste was then further categorised before being sold to different workshops. While this method reduced risks, it also meant that after the initial selection, many high-quality products had already been picked out, thus reducing opportunities for windfall profits.

After bringing the e-waste home, people in family workshops would initially categorise it by type, identifying appliances that could be directly used after simple repairs and those that could be used after basic repairs and reassembly. This portion of e-waste would be sold directly to the second-hand market in Chendian and Shenzhen. The remaining e-waste would then be dismantled by workshops specialising in various types, such as circuit boards and metal. At this stage, the e-waste dismantling process in Guiyu evolved from simple dismantling and categorisation in the first stage to a more diverse range of specialised processes.

Guiyu's e-waste dismantling industry resembles a large-scale horizontal disassembly line. Through long-term development, it has evolved into a highly specialised and finely divided system of labour, in which each family workshop or factory uses specific methods to dismantle particular materials or components. The dismantled materials are then sold to other specialised workshops, which continue with their own dismantling process, and the chain continues until the entire dismantling process is completed. The process relies heavily on initial raw materials and the final sales market. If the supply of raw materials is disrupted or cut off, the entire e-waste dismantling industry in Guiyu faces severe, even destructive, consequences.

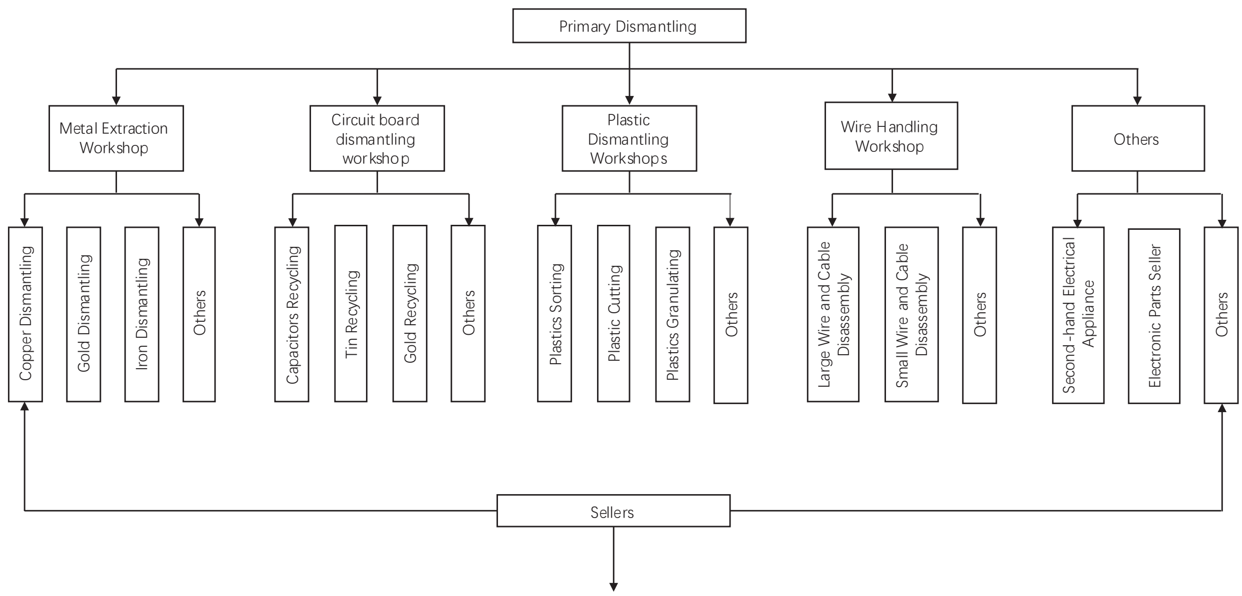

Figure 5.6 Classification of dismantling workshops in Guiyu (Source: Author)

The dismantling of e-waste in Guiyu can be broadly categorised into a three-tier dismantling industry chain. The first tier involves the dismantling of integral e-waste appliances. Upon arrival in Guiyu, various workshops specialising in different types of appliances, including computers, air conditioners and digital devices, dismantle the e-waste. The plastics, circuit boards, wires and metal dismantled during the first step are then passed on to the second-tier dismantling workshops. The empty circuit boards, electronic components, and metals are dismantled at the second tier and then transferred to the third tier for metal extraction. The detailed steps and methods for dismantling e-waste are shown in Appendix F.

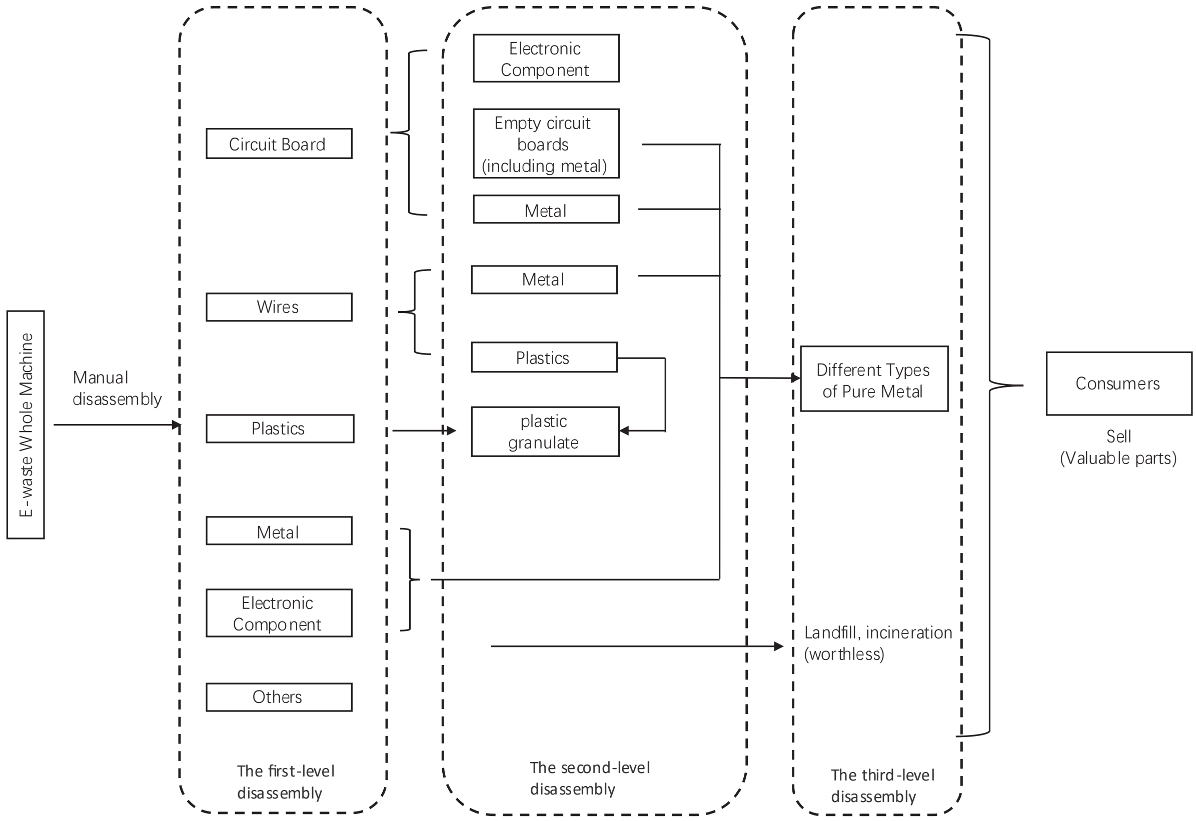

Figure 5.7 Guiyu e-waste industry dismantling chain (Source: Author)

5.2.2 Clan Networks Accelerate Wider Specialisation

Guiyu’s horizontal dismantling model relies heavily on the upstream and downstream chains, rendering it extremely vulnerable. Access to information on the source of goods is crucial for participation in the e-waste dismantling industry, and this has led Guiyu to erect high information barriers that prevent outsiders from entering the sector. Meanwhile, due to the sensitive nature of e-waste – much of which is smuggled illegally, especially after China banned e-waste imports in 2002 – procurement transactions are conducted with a great degree of secrecy (Gregson and Crang, 2019). By using its close-knit clan organisation, Guiyu has established a well-organised and tightly run grey network (Wang, Qian and He, 2022), and transactions occur entirely within this network of relationships. Significant barriers exist between locals and outsiders even within Guiyu, creating what Zhou (2000) terms a ‘binary community'.[7] Despite sharing the same geographical space, locals and outsiders appear to inhabit very different social worlds as they engage in different occupations and levels of consumption. Residential segregation is evident, with locals occupying newly constructed buildings while outsiders living in old, dilapidated houses. Apart from work and business interactions, there is minimal social exchange between the local and outsider communities.

There are also evident internal divisions within Guiyu, contributing to a distinctive regional division within the e-waste dismantling industry. The clustering of the e-waste dismantling industry in Guiyu is not just an economic agglomeration effect, and its regional distribution is highly correlated with clan structures (Greenpeace, 2003). Guiyu is a typical clan-based economy with a powerful and tightly-knit clan-based[8] social network that facilitates the rapid spread of the e-waste industry cluster. Starting from Beilin Village, the e-waste dismantling industry expanded through Nan'an Village and Huamei Village to almost all of Guiyu, and 21 out of 27 villages engaged in e-waste-related industries (Shantou Chaoyang District People's Government, 2010). The clan-based structure serves as a foundation for this specialisation, creating a unique socio-economic fabric that links familial ties with industrial organisation.

To avoid intensifying competition, different clans have always prevented members of other clans from engaging in the same business. In the early stages of Guiyu's e-waste dismantling, numerous inter-clan conflicts arose from disputes over securing sources and business development. At this time, the intense networks helped people get into the industry quickly and build a fence to prevent imitation or entry from outside and to preserve the industry within Guiyu. Ultimately, each village engaged in identical or comparable recycling practices, and a sophisticated geographical division of labour was developed at the village level. The central areas of Guiyu town, such as Huamei and Beilin Villages, are primary regions for dismantling electronic circuit boards, while villages like Longgang and Dutou in the southern areas mainly engage in the recovery of discarded plastics, and the northern area of Nanyang focuses mainly on dismantling integral electronic appliances. Such specialisation not only enhances efficiency but also fosters the accumulation and intergenerational transfer of tacit knowledge within these clan-based industrial units, which resemble the localised production pattern observed in Lancashire's cotton industry in the nineteenth century, as described by Marshall (1919).

[7] Eryuan shequ 二元社区 in Chinese

[8] People with the same surname tend to live together within the same village. For instance, in Beilin Village, most residents share the surname 'Li', while in Xianpeng Village, the predominant surname is 'Peng', and in Yujiao Village, the majority have the surname 'Zhuang'. This structure signifies a shared ancestry, with each surname forming a distinct clan. Each village and surname combination has its own ancestral hall, and within the same region, clans with the same surname may collectively establish a large ancestral hall for joint worship.

From the 1990s to 2012, Guiyu's e-waste dismantling cluster experienced extremely rapid growth and became well-established, mature, and stable. Interconnections and interrelationships within the system were high, and this reduced the system's resilience, making the cluster less adaptable to external environmental changes or shocks (Martin and Sunley, 2011a). However, driven by high profits, the local population saw no need to change this pattern, which kept the Guiyu e-waste dismantling industry in a 'conservation' development stage for a considerable period.

5.3 External Shocks and Agents' Reflections

5.3.1 Pollution and Scandals

During the peak period of e-waste in Guiyu (the 2000s), the town suffered from severe environmental pollution. The Handbook of Environmental Chemistry classified Guiyu as the world's largest and the second most severely polluted area and Guiyu was often referred to as 'the world's most toxic place' (Suciu et al., 2013; Qin et al., 2019; Huang, Shi and Wu, 2021). The level of environmental degradation is particularly evident in the Beigang River section of Guiyu, where acid-washing sheds were once widespread, causing the river's acidity to reach levels close to those of strong acids. In 2010, the PH value of the Beigang River was measured at 3.24, and the sediment in the river bed showed severe heavy metal contamination, with copper levels approaching 1%, akin to copper ore concentrations (Che and Zhan, 2015). Numerous studies have documented Guiyu's pollution, and sampling studies on Guiyu's air, soil, and water revealed alarming results. Surface water samples from Guiyu showed a significant excess of metal content, with lead levels double those of European safety levels (Puckett et al., 2002). Sediment samples from the riverbanks contained concentrations of barium, a harmful metal to organisms, that were 10 times the threshold set by environmental protection agencies, tin levels 152 times higher, chromium 1338 times higher and lead 212 times higher (Walters and Santillo, 2008; Li, 2020a). Air pollution is also severe, with lead, copper and nickel contents in the dust on certain streets surpassing levels at non-dismantling sites 8 kilometres away by over 330 times (Leung et al., 2008). Soil and sediment samples exhibited significant excesses of lead, zinc and copper (Walters and Santillo, 2008). These pollutants have now spread to plants and animals in Guiyu. Tests on vegetables, poultry, fish, snails and water snakes revealed excessive levels of heavy metals and organic pollutants (Li et al., 2014).

Figure 5.8 Pollution in Guiyu (Source: IBTimes UK, 2015)

A study by the Medical School Laboratory of Shantou University found that lead levels in the blood of Guiyu children were significantly above the permissible limit (Li, 2009; Monbiot, 2009). According to the Youth League Committee (2017), in a kindergarten in Guiyu, there were five to six hundred lead-poisoned children between 2006 and 2009, and more than 90% of the children had blood lead levels that exceeded the standard. Furthermore, newborns in the e-waste dismantling area had chromium levels in the umbilical cord blood that were as high as 303.38 micrograms per litre, while in the Chaoyang urban area, the corresponding figure was 20.30 micrograms per litre (Ni et al., 2014; Kim et al., 2019). Residents who have engaged in the e-waste industry for many years always have black teeth, and wealthy people in Guiyu, including the local town government’s canteen, do not purchase their food locally because of the pollution. During the author’s fieldwork in 2022, local people still cautioned me not to eat at the local restaurants and avoid tap water.

5.3.2 Conflicts and Negotiations

This severely polluted environment in Guiyu initially drew the attention of international organisations and media. In 2001, the Basel Action Network documented Guiyu’s environmental and health issues in its *Exporting Harm* documentary, triggering significant concern from international organisations (Puckett et al., 2002). Subsequently, major media outlets such as CNN and TIME reported on Guiyu’s pollution issues, criticising the environmental harm caused by the e-waste industry (Castillo, 2011; Watson, 2013).

These scandals compelled the Chinese government to enact policies to regulate e-waste in Guiyu. In 2003, the Guangdong Provincial government approved the implementation of the first provincial-level ‘Solid Waste Pollution Prevention and Control Plan’, specifying the responsibilities of local governments to manage e-waste and the e-waste industry, which was previously regulated solely by market mechanisms. On January 7, 2004, the Guangdong Provincial Environmental Protection Bureau approved the establishment of a Domestic Waste Metal and Electrical Appliance Dismantling Centre in Guiyu, and on November 8, 2004, the Ministry of Information and Industry approved the establishment of a Waste Electronic Information Product Dismantling Demonstration Project. On October 27, 2005, six ministries, including the National Development and Reform Commission, approved Guiyu as a Pilot Unit for the Recycling and Utilisation of Waste Household Appliances in the Circular Economy. On December 9, 2005, the Provincial Science and Technology Department approved Guiyu as the Guangdong Provincial Technical Innovation Professional Town. At the same time, Guiyu’s circular economy pilot projects were included in the key provincial, municipal and district projects of the Eleventh Five-Year Plan. Accelerating the construction of Guiyu Circular Economy National Demonstration Base was also identified as an important aspect in the work reports of the ninth Party Congress of Shantou City, the second Party Congress of Chaoyang District and at the dual-level governments of the city and district, emphasising the development of the circular economy as a new growth point for the economic development of Shantou City (Wang, Qian and Liu, 2020). Under these policies, the local government in Guiyu was forced to rectify high-pollution dismantling workshops. However, due to the wide range of areas involved and the disruption to local livelihoods, the local government’s enforcement power has been weak, and efforts have been more of a response to directives from higher authorities, while the regulation work has remained largely at the level of slogans at the early stages of e-waste management implementation (Gregson and Crang, 2019).

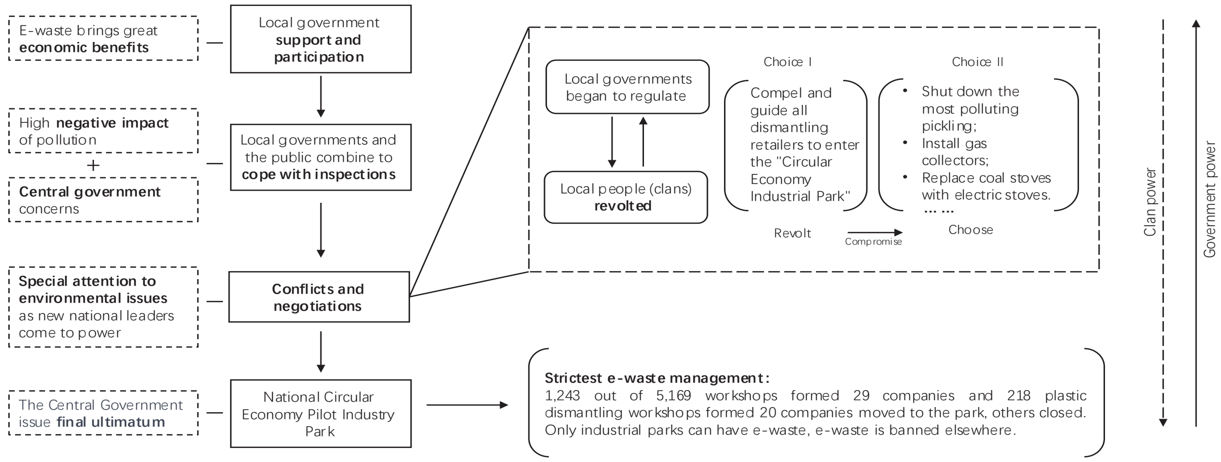

Figure 5.9 Guiyu e-waste remediation process (Source: Author)

Governance within the e-waste cluster has been a prolonged process of conflict and negotiation. Historically, Guiyu has always been highly impoverished, and the local government supported the growth of the e-waste industry to lift everyone out of poverty and promote economic development. The promise of significant and rapid profits attracted many government officials and their family members to participate in this industry. Guiyu also has a history of being in a regulatory vacuum, as it is located at the intersection of Chaoyang City, Pu'ning City and Jieyang City. Before Chaoyang City was reorganised into Shantou City in March 2003, the three cities often shifted responsibility for managing Guiyu among themselves, with a tendency to ignore it. This administrative vacuum led to a lack of effective governance in Guiyu, and the lax regulation of the market provided the grounds for the emergence of the informal and high-pollution e-waste industry in Guiyu (Weber and Friedrich, 1929). One interviewee said: 'In the past, even killing someone wasn't a big deal here. Illegal activities like gambling, drugs and prostitution were prevalent (G33J).' Even China's previously strict 'One-Child Policy' was ineffective in Guiyu, where the traditional belief in the importance of having many sons for prosperity and prestige led to widespread violations of the national family planning policy. Due to lax enforcement in Guiyu, many people from other regions intentionally went there to give birth, taking advantage of the lenient regulations (Greenpeace, 2003). In this context, Guiyu rapidly became a paradise for the development of the e-waste industry.

Instead of government management, an influential power structure operated in rural society and economy, and clans were the central power for residents in Guiyu. Village self-governance under this rural power structure was the operational mode in Guiyu for a long time, gradually forming the basic power structure that comprised town government, village committees, clan influence, economic elites and prominent cultural figures (Wang, Qian and He, 2022). Compared to the clan influence in Guiyu, the role of the local government was rather awkward. In the past, due to their lack of enforcement power, local government played the role of an assistant, and village affairs were essentially handled by local clans. Local government only needed to maintain a relatively stable environment while providing land, electricity and other support to the e-waste industry without directly intervening in social and economic operations (Wang, Qian and Liu, 2020).

In Guiyu, the lifestyle organised around clans meant that almost every village was dominated by a single surname, and only people who had that surname could be elected as clan leader, village chief and village party secretary.[9] Historically, clan leaders had significant power and authority, deciding major matters and settling disputes or fights in the village. They could even

[9] Government administrative leader of village.

impose punishments on clan members. Clan leaders also had significant influence, and many government policies and projects were difficult to implement without their endorsement. As China's economy developed, economic elites became an influential force within the clan, and it was common in Guiyu for the wealthiest economic figure to be both the village party secretary and the most prominent figure in the clan. Although he may not have been the clan leader, his support was crucial for major decisions – particularly economic ones – in the village and the clan. There were rumours that leaders appointed by the higher-level government usually had to visit the main forces (the clan leader and elites) in each village first to obtain their support and assistance (G12L). The formulation and implementation of policies also required their opinions and approval, without which policies were almost impossible to implement. As one respondent put it: '... In the past, those who didn't do this didn't last long and eventually left' (G3G). At that time, the power of the clans far exceeded that of the government at the local level.

For a long time, the local government's e-waste management remained superficial or was used as a way of coping with inspections by the higher-level authorities due to significant economic interests and the difficulty of the government's power to counterbalance clan influences. Usually, before inspections by higher-level leaders, government officials would disclose the news to locals and ask them to move illegally dumped e-waste from streets and farmlands into warehouses and suspend operations temporarily in the highly polluting dismantling workshops until after the inspection. A research report by Greenpeace (2003) on Guiyu recounted a story that illustrated this practice; to cope with inspections by higher-level leaders, the local government temporarily planted seedlings in dozens of acres of rice paddies on both sides of the road from Guiyu to Nanyang that had already been contaminated and were unsuitable for cultivation.

For a long time, residents did not take regulations from higher-level governments seriously, viewing them as empty words and slogans. This mindset significantly influenced Guiyu residents' attitude toward the e-waste dismantling industry, stopping them from shifting or upgrading the industry. From their perspective, e-waste was limitless, and the local government would not manage this industry rigorously. Their dismantling model was already mature and lucrative, so there was no need for further upgrades or transformations. As one interviewee asserted: 'Almost everyone in the entire town is involved in e-waste. They dare not stop us (G39Z).'

5.3.3 Developing Regulation

The central government has been urging the local government in Guiyu to regulate the e-waste dismantling industry since the early 2000s. In 2003, the Guiyu government proposed the establishment of a National Circular Economy Pilot Industry Park, but it was not until 2013 that construction began. During these 10 years, the plans remained only on paper, indicating a lack of will to put them into practice. Local government officials also admitted that their previous efforts were little more than passing inspections. When higher-level government officials came to inspect the area, they would be shown the planned drawings. In 2005, when Guiyu obtained national government approval to build a demonstration project for dismantling e-waste appliances that would use an area of up to 3,800 acres[10], it hastily constructed the Guiyu Electronic Market, covering a mere 30,000 square meters. Locals ridiculed this act as 'lip service, and no one took the issue seriously.

Until 2012, when Jinping Xi became China's new leader, the construction of an ecological civilisation was proposed in the eighteenth Party Congress Report, and environmental issues in China were elevated to an unprecedented level, with sustainable development acting as the fundamental pillar of economic development (Gregson and Crang, 2019). In March 2012, the Deputy Minister of the National Environmental Protection Ministry had discussions with the Guangdong Provincial Governor about the pollution issue from e-waste in Guiyu. E-waste pollution control was listed as one of the 'Three Major Battles' in the 2012 Environmental Protection Ministry Pollution Prevention and Control Campaign, and the Guangdong Provincial Environmental Protection Department announced the implementation of special supervision of the pollution from e-waste in Guiyu. A member of the Political Bureau of the Central Committee of the Communist Party of China and Secretary of the Guangdong Provincial Party Committee delivered two consecutive important instructions on the reduction of e-waste pollution in Guiyu and the acceleration of the construction of Guiyu's Circular Economy Industrial Park (CEIP). The Guangdong Provincial Governor proposed formulating specific rectification plans as soon as possible, specifying a timeline for governance. Under this pressure, Shantou City established a leadership group at the highest level, with the Secretary of the Shantou Municipal Party Committee and the Mayor serving as the leader of the Guiyu Pollution Control Leadership Group, and seven members or deputy mayors serving as deputy leaders and leaders of five specialised groups. Shantou City, Chaoyang District and Guiyu Town's three-level governments mobilised more than 200 cadres to enter the villages and households, setting up checkpoints at the nine main entrances and exits of Guiyu Town. They conducted 24-hour joint law enforcement operations in which all imported wastes were weighed, and all containers were opened for inspection. Meanwhile, the public security organs in Shantou, together with the Safety Supervision Bureau, formed a specialised team to combat the illegal activities of the 'three acids', conducting in-depth investigations into Guiyu Town and holding those engaged in

[10] Around 2,130,000 square meters.

illegal acid washing criminally responsible under suspicion of illegally purchasing and using precursor chemicals for drug production, vigorously cracking down on the most severe environmental violations. Guangdong Province and Shantou City pushed for the comprehensive governance of e-waste pollution in Guiyu with hitherto unprecedented efforts.

Under this extreme pressure and with help from higher levels of government, the local government in Guiyu began to take action. However, considering that the e-waste dismantling industry was the livelihood of most people in Guiyu, an overly aggressive approach would have provoked strong opposition from the residents. Faced with powerful clan influences, when the local people did not accept the government's decisions and actions in the past, they organised resistance and resorted to violence to solve problems. However, Guiyu only has 12 policemen, making it difficult to confront large and aggressive crowds. Interviewees (G28Z) described instances in the 2000s where residents protested against improper policies by blocking roads. They also described an incident in 2001 in which villagers destroyed seven police cars to prevent the inspection of a factory that was operating illegally.

Guiyu's dismantling industry mainly comprises household workshops which operate without business licenses and do not pay taxes, which makes it difficult for the government to regulate. One government official told me:

> *'Enterprises can be constrained through regulations and fines, but family workshops driven by financial interests cannot be controlled through economic sanctions or moral pressure. If they cannot continue in one place, they will move to another or continue dismantling behind closed doors at home (G42Z).'*

However, in this instance, the local government was forced to initiate rectification actions because the higher government was beginning to penalise many local officials, resulting in frequent leadership changes in Guiyu.

Under dual pressure from higher-level government and local clans, the Guiyu government decided firstly to crack down on the 'acid washing' and 'burning boards' practices which caused the most pollution while urging other less-polluting workshops to implement their own rectification measures, which included requiring sites to prevent wastewater from contaminating the soil, installing gas collection hoods to reduce air pollution and providing workers with masks, gloves and other equipment. Only after successful rectification would the government offer temporary environmental permits, business registration and tax registration for the workshops, which meant that they could only obtain dismantling licenses when they had complied with these requirements. Previously, most dismantling workshops operated without business licences or tax registration, making it difficult to determine their specific scale and data. The uncertainty about the industry's scale also reflected the disorderly and unbridled development of the market at that time.

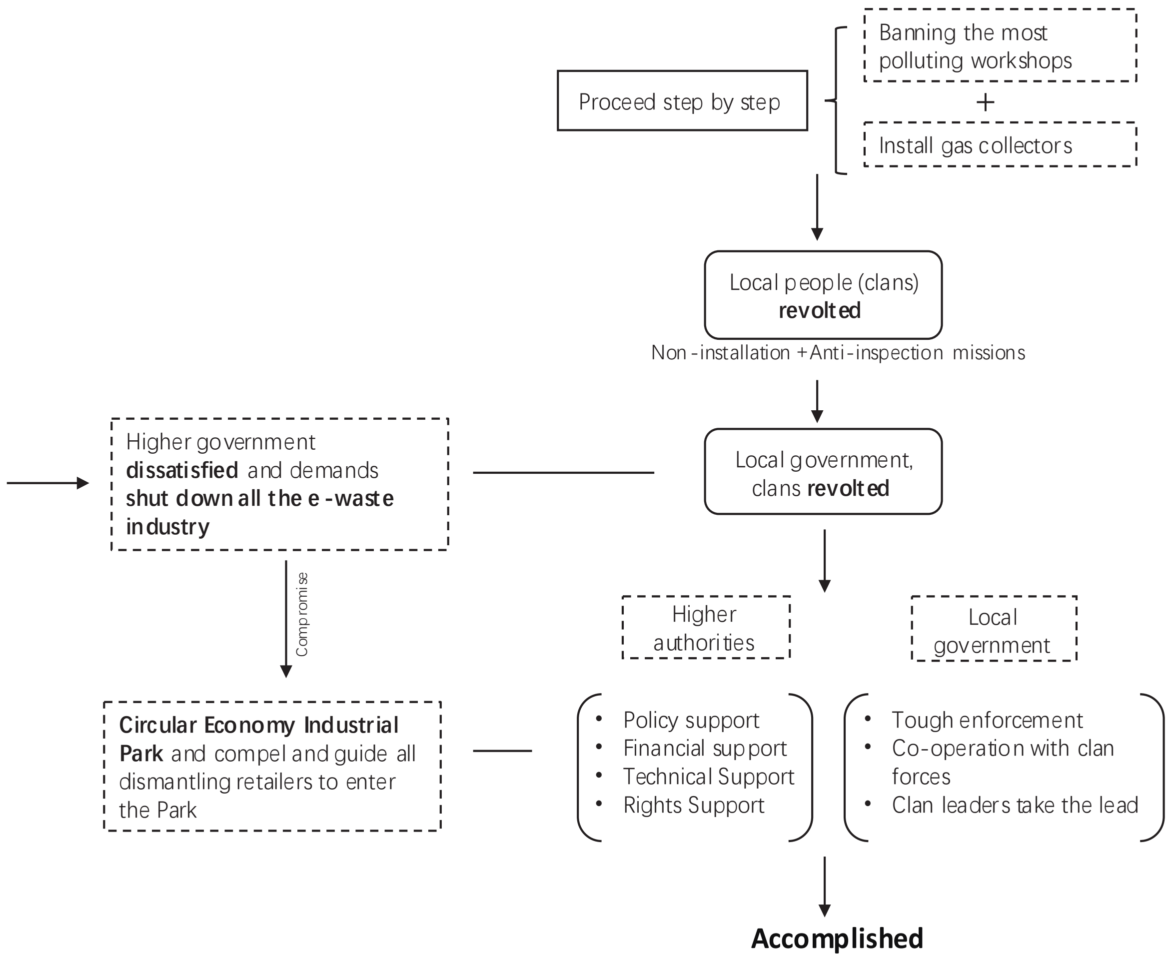

Figure 5.10 Conflict and negotiation processes between the Government of Guiyu and local operators (Source: Author)

However, these measures proved to be ineffective. Faced with government inspections, residents shifted their working hours from daytime to nighttime and relocated from conspicuous areas to the mountains. Some villagers even spontaneously organised 'anti-inspection teams', gathering information about upcoming inspections in order to respond more promptly to them. Meanwhile, the uptake installation of gas collection hoods was relatively low. Guiyu's government required each hood to be priced at over 18,000 yuan, and they had to be procured centrally by the local government. The additional electricity costs incurred when operating them were heavy for local dismantling households, making them unpopular. Even when installed, the hoods were seldom used, typically only during times of certification and inspection. Many interviewees stated that high costs and scepticism about the effectiveness of the hoods were reasons for not installing them and not using them. Since the government purchased the hoods, installing them independently would not pass government inspections, leading to suspicions that government officials were receiving bribes.

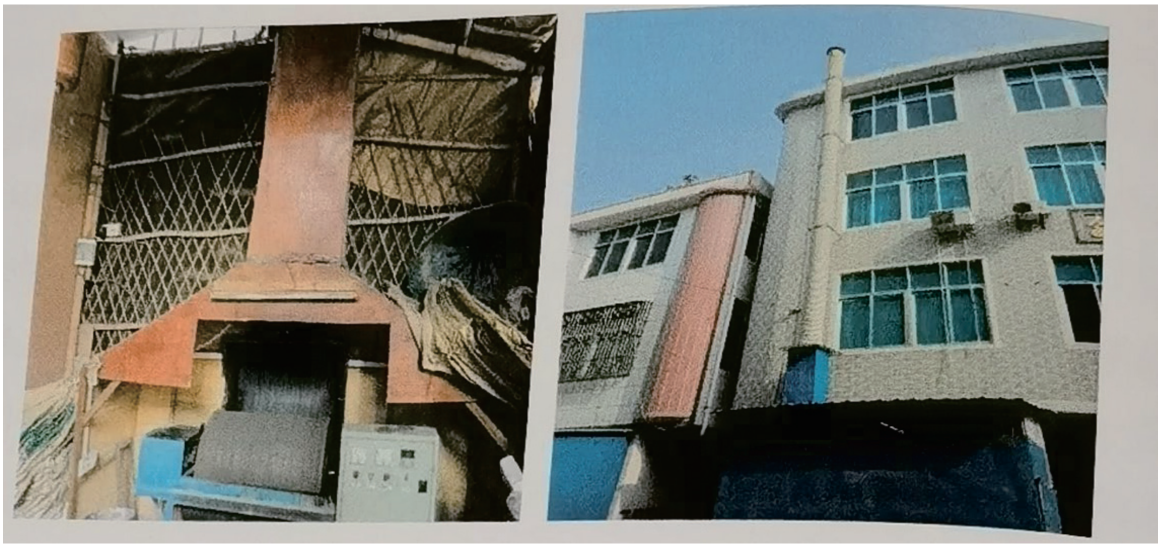

Figure 5.11 Gas collection hoods (Source: Guiyu Government)

Figure 5.12 Protective measures for workers (Source: Author 30/03/2022)

At that time, Guiyu did not have a dedicated centre for exhaust gas and waste disposal. Even with measures such as using gas collection hoods and toughening regulations governing the sites, exhaust gases, wastewater and solid waste were still directly discharged, leading to ineffective remediation. However, these were only some of the methods used by local governments to enact policies of higher-level government. To accelerate the cleanup process, inspection teams from the provincial party committee, provincial government and provincial environmental protection departments visited Guiyu every month starting in September 2014. According to the Shantou Chaoyang District People's Government (2015), from 2012 to 2015, a total of 151 cases of environmental pollution were investigated and dealt with. Government forces demolished 57 illegally operated workshops engaged in activities like acid washing and electrolysis, dismantled six furnaces for burning circuit boards, seized 64 tons of illegal ‘three-acid’ substances, confiscated approximately 57,384 tons of goods and sentenced 5 individuals to imprisonment. Some interviewees told me that: ‘people are inspected every day, and everyone began to realise that this is no longer a small issue. The country is taking it seriously now (G40Z).’

Some higher-level leaders suggested directly shutting down all e-waste workshops to address the problem at its source. However, local government officials considered the significance of the e-waste dismantling industry in Guiyu. Having developed for many years and grown to involve the employment of most of the town's population, this issue wasn't just an environmental or industrial concern; it was also a social and political matter. Implementing the extreme measure of a blanket shutdown of all dismantling workshops would cause local social instability, so instead, the local government proposed planning a circular industry park and relocating all workshops into the park for centralised emissions and management.

However, almost no household workshops were willing to relocate. Moving from household workshops to a circular industry park not only increased the cost of renting workshops but also posed inconveniences relating to management, logistics and labour. Another challenge was that the local government lacked sufficient funds and the necessary authority. Constructing an industrial development park would require occupying large amounts of farmland, residential land, and village collective land, and it would also entail changing the land designation from agricultural to industrial use, a challenging process for the local government to accomplish independently.

To reform the cluster, several policy measures were implemented. Firstly, the higher-level government provided comprehensive policy, financial, technical and authoritative support. For example, according to statistics, since the Twelfth Five-Year Plan, 2011, various levels of government at the provincial, municipal and district levels have cumulatively invested nearly 1 billion yuan in Guiyu's rectification[11] (Ministry of Ecology and Environment, 2019). The Guangdong provincial government approved the land use change for the Guiyu CEIP, while the provincial environmental protection department coordinated with central ministries and research institutes to specify technical routes and solutions for the park and provide on-site guidance for constructing environmental protection facilities. Meanwhile, the higher-level government facilitated various administrative processes for Guiyu, and everything was conducted in accordance with the requirements of emergency projects, expediting approvals and advancing project construction beyond routine procedures. Some processes were even initiated before the necessary formalities were completed, and the Guiyu CEIP was officially commenced in 2013. Meanwhile, strict accountability measures were taken for units and individuals that displayed dereliction of duty or misconduct. Between 2012 and 2016, 173 individuals in the Chaoyang District were held accountable for their roles in environmental

[11] The provincial government directly allocated 156 million yuan and borrowed 3 billion yuan, the municipal government allocated 46.3 million yuan and borrowed 3 billion yuan, and the district government allocated 95.16 million yuan and borrowed 3.46 billion yuan for the rectification of Guiyu's e-waste dismantling industry.

governance.[12] As one interviewee asserted: ‘The leaders of Guiyu have changed several times because of the e-waste. Some of them even have gone to jail (G4L).’

In addition, to combat illegal and high-pollution e-waste dismantling activities more effectively, the higher-level government also established an Environmental Protection Sub-bureau in Guiyu. Guiyu is the only township in Chaoyang District with such a bureau, which significantly improves the local government’s law enforcement authority and execution capabilities, as the local government’s environmental law enforcement teams were able to conduct regular patrols and inspections in collaboration with the district public security sub-bureau. They cut off power to workshops that refused to pay taxes, operated illegally, or did not complete the required entry into industrial parks or on-site renovations. Low-altitude chimneys and gas hoods were dismantled. Between 2013 and 2015, under the authority of the district and township governments, 2,469 unqualified e-waste dismantling family workshops were shut down, and 3,245 sets of exhaust chimneys and gas hoods were dismantled (Shantou Chaoyang District People's Government, 2015). During the legalisation of e-waste family workshops, the local government, no longer under pressure from clans and the public, took a tougher stance in dealing with conflicts. In 2012, a dismantling household member was sentenced to five years in prison for assaulting administrative personnel (Interview G42Z).

However, most of the population still could not accept being shut down or relocated to the industrial park. Firstly, as Guiyu residents operated as families, they enjoyed various operational bonuses. For instance, they were not required to pay taxes. For a family workshop with an annual income of over a million yuan, the yearly fees paid to the government might only be three to four thousand yuan. They also did not need to contribute to any insurance for workers or provide additional benefits beyond wages, and they employed a flexible labour force that started or stopped work based on the availability of e-waste. Moreover, firms did not offer any compensation for occupational diseases caused by pollution. Once they moved into the park, they had to provide all of these, and standardising production meant a doubling of costs.

Government officials adopted a cooperative approach with the clans, initially targeting influential figures such as clan leaders, village chiefs and village committee secretaries for propaganda and persuasion. They analysed the pros and cons and provided certain benefits, such as offering shares in the industrial park or giving appropriate incentives for enterprises that moved into the park. Currently, the family of the committee secretary of Huanmei Village has shares in many significant projects in the CEIP. Clan leaders were incentivised to take the lead

[12] Among them, one person was criminally prosecuted by the district prosecutor’s office, 40 individuals faced party and government disciplinary actions, and 133 individuals received other forms of admonishment.

in shutting down their dismantling workshops, moving into the CEIP and then persuading relatives and friends to relocate to the park. These individuals were held in high regard by the public, and with their persuasion, Guiyu quickly achieved the goal set by the higher-level government. In the end, 1,243 electronic dismantling workshops were transformed into 29 companies, and 218 plastic dismantling workshops were consolidated into 20 companies, entering the industrial park under unified management. Interviewees claimed that the most influential clans cooperated with the government, closed their workshops and moved to the industrial park. Others had no choice but to follow them because they had no power (Interviewee G31L).

5.4 Path Fragmentation, 2015-Present

The sudden policy shock showed the rigidity and inflexibility of the firms in the Guiyu e-waste cluster (Martin and Sunley, 2011a). Monolithic industrial composition, tight social networks, low-end technology and short-sighted perspectives had left the Guiyu e-waste cluster poorly resilient and adaptable, which eventually brought it into the 'decline and release' (or 'Ω' phase) from around 2015. However, unlike other industrial clusters, Guiyu's cluster has fragmented into three different paths.

5.4.1 Path Renewal

The first path has been the government's renewal of the e-waste industrial zone renewal since 2015 (path B in Figure 5.1). As discussed above, the government established a CEIP in Guiyu and implemented zone management, and the e-waste dismantling industry in the park adopted a unified approach for trading, dismantling and overall management. However, the industrial park has not yet been able to form a fully functional industrial cluster. The park occupies an area of less than 500 acres, with a considerable portion allocated to office spaces, resulting in an inadequately developed industrial chain configuration. Due to management issues and other multifaceted problems, numerous enterprises face shortages of raw materials for waste processing, prompting some companies to relocate to other province. During the researcher's field investigation, interviewed business executives indicated that the park currently has a high vacancy rate. They mentioned having received invitations from an e-waste industrial park in Hubei province and are considering relocation, while several of their industry peers have already completed their move. These enterprise representatives believe that the park resembles more of a government vanity project and has essentially lost its market vitality.

Although the industrial park engages in e-waste processing activities that are substantively similar to previous operations, its management model and operational methodology have undergone a fundamental transformation. The development and operation of the park have fully adopted a government-led advancement model. Within this framework, the e-waste dismantling industry has achieved an integrated management process characterized by ‘unified trading, dismantling production, and business operations’. Regarding the management mechanism, the park comprehensively implements the ‘five unifications’ principle: unified planning, unified construction, unified operation, unified pollution control, and unified supervision. This government-led management model, while conducive to enhancing environmental compliance and industrial standardisation, simultaneously faces challenges such as insufficient market vitality and reduced efficiency in resource allocation.

The area designated for e-waste dismantling work was minimal and was utterly incapable of accommodating the 5,169 dismantling workshops and over 100,000 dismantling personnel reported in May 2012 for the town (Che and Zhan, 2015). Despite the park’s planned area of 2,262 acres, the constructed area has not yet exceeded 500 acres at the time of this research (Shantou Chaoyang District People's Government, 2015). This area includes over ten functional, trading and office areas, and the park can accommodate only a tiny proportion of the traditional cluster. There are numerous requirements for relocating into the industrial park, and not all workshops are eligible for entry. Firstly, it required government environmental impact assessments and the completion of tax and business registration. Ultimately, workshops had to enter the park in the form of a company. Previously, most of the dismantling work in Guiyu existed in family workshops, with small-scale and decentralised dismantling units that were challenging to manage in a uniform way. The park planned to move from individual to collective economic operations, promoting the transition to corporate management. Households were offered guidance on how to integrate and form companies based on industry type, kinship relationships and geographical proximity, but forming a company was challenging, and some interviewees mentioned that having a specific relationship with the village or clan leaders was necessary to join, with many small workshops lacking such connections. Additionally, the park management is stringent and rigid. Specifically, all transactions involving the trading of e-waste products in the Guiyu town area must be registered and conducted at the park’s centralised trading and unloading zone. Any circulation and trade in e-waste outside the park is strictly prohibited, and multiple checkpoints have been set up in Guiyu to inspect the sources of e-waste, while entry and exit cards are also required within the park. Vehicles must stop for inspection at the entrance to the park, and all goods vehicles have to present the trading card and weigh-in for entry. Interviewees also mentioned that it is impossible to bring any e-waste back home – a policy that was still being strictly enforced during the author’s fieldwork period.

To trace the flow of e-waste, the park has introduced a ‘centralised trading card’. All transactions within the park must go through this card, without which it is not possible to buy or sell any e-waste. Meanwhile, the e-waste trading in the park is reliant on specific companies to obtain quotas to enter the park for transactions. This means that e-waste entering and leaving the park relies on obtaining the trading company's park entry and exit permit, which involves additional fees, significantly increasing dismantling costs. During the fieldwork period, I repeatedly inquired about the work of trade companies, only to find that their function was only to provide 'entry and exit permits', and all trade company offices were empty at the time of the fieldwork (Figure 5.14). Some dismantlers speculated that: 'This kind of company is just pure money-spinning. They don't need to do anything; they give you a licence and take the fees (G17L).'

Figure 5.13 Empty trading company offices (Author 08/04/2022)

Any e-waste materials entering the park are first transported to the centralised trading zone, where buyers from workshops select and negotiate purchases. The materials are then transported to dismantling workshops that have been purchased for the dismantling process. After fundamental manual dismantling, relatively good quality products, components and metals are directly traded in the electronic market within the park. Ordinary waste generated during the process is transferred to a landfill, while hazardous waste is taken for specialised treatment. Dismantled items such as circuit boards and electronic components are processed centrally at the park's circuit board pyrolysis plant, pickling smelt plant (for acid treatment), and physical processing plant to extract valuable metals such as copper, gold and silver. Finally, the dismantled items are sold through companies in the centralised trading zone. All the processes must be completed within the industrial park.

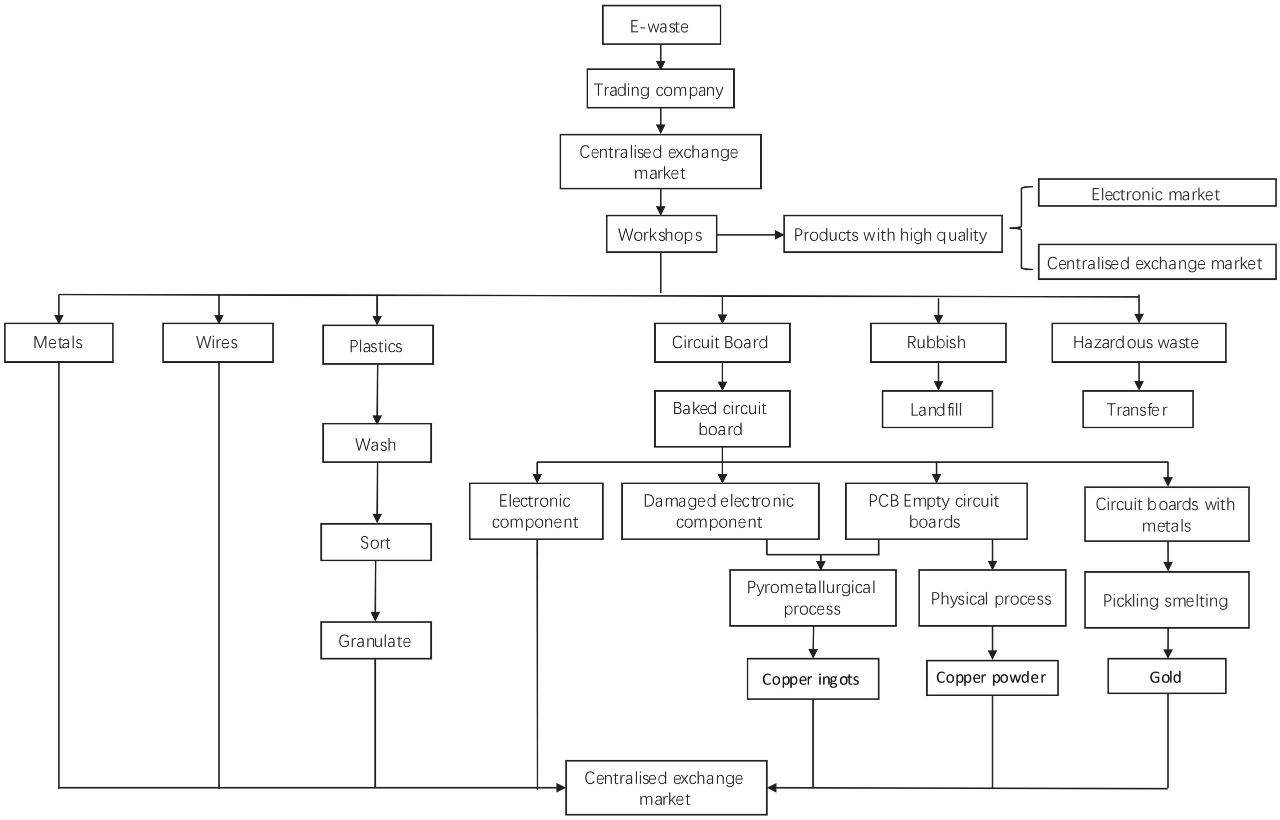

Figure 5.14 E-waste treatment process in Guiyu CEIP (Source: Author)

Thes strict control measures in the park have almost detached the e-waste industry in Guiyu from ‘market-oriented’ operations. The dismantling volume, process and sales of e-waste are regulated rigorously, causing the e-waste dismantling industry to lose much of its market vitality and value. The daily dismantling volume of e-waste entering the park is also strictly controlled. According to the interviewees, the daily volume of e-waste entering the park in 2022 was limited to around 20 trucks, while in 2005 more than 100 truckloads of e-waste entered Guiyu every day (Liu, 2005). This amount is significantly lower than the dismantling capacity of the workshops within the park, and to obtain enough e-waste, some workshops have had to raise prices and squeeze profits, forcing many to shut down due to a lack of materials.

The extracted circuit boards have to be transported to the park’s circuit board pyrolysis plant, pickling smelt plant and physical processing plant to extract precious metals. This step represents a crucial source of profit for the e-waste industry, but the processing capacities of these plants are insufficient. The pyrolysis plant processes only 20,000 tons annually, and the pickling smelt plant processes just 5,000 tons, falling far short of the park’s potential e-waste dismantling volume. Many dismantled circuit boards can therefore only be stored in warehouses, forming a backlog. Once warehouses are full, the park’s dismantling workshops face a ‘deadlock’, leading many operators to shut down or relocate to other places, such as Hubei Province. One interviewer asserted: ‘I have been out of work for almost a week now because there is nothing to dismantle. Many workshops in the park have also stopped working (G31L).'

Residents consistently hold a negative opinion of the Guiyu CEIP. Some interviewees even claim that its continued operation relies entirely on government support, or it would have closed down long ago. Despite the government's introduction of the TCL Electronics Waste Recycling Company, the e-waste dismantling industry in Guiyu has not developed a model in which a 'leading enterprise' drives industry growth. The operation of large companies is relatively independent, with little connection to workshops. Firstly, these large enterprises and dismantling workshops are spatially separated, with the government allocating them independent plots of land that are completely isolated from the dismantling areas in the park. In terms of business and technology, the TCL Dismantling Company has almost no interaction with the small workshops in the park, and no dismantling industry chain has been formed. Even the transportation of e-waste to the TCL Dismantling Company is independent, as they do not need to go through the park's centralised trading centre. The company transports the e-waste directly to its factory for dismantling and then transports the dismantled products out. In terms of technology, TCL uses relatively low-end recycling processes, relying mainly on manual dismantling. However, since it is nationally authorised, it receives subsidies from the government each year and the company's management claims that dismantling is not profitable without government subsidies. Meanwhile, over 80% of TCL's employees are outsiders who cannot provide significant technical assistance or upgrades for the e-waste dismantling industry in Guiyu. The small workshops that have moved into the park still use traditional and familiar technology despite the government's centralised air and water treatment facilities. Most of the technology remains unchanged, so pollution can only be controlled through the restriction of quantities of e-waste.

Figure 5.15 Manual dismantling process in TCL company (Source: Author)

The industrial park's shortcomings and the residents' pessimistic views mean that some predict its closure within five years under its current model. However, the political nature of Guiyu

Industrial Park suggests that the government will continue to support and sustain its operation, so despite the low connectedness of the e-waste park and its failure to accumulate resources, resilience is high. That is because the government always has been able to provide financial support to keep the park running. Almost all the significant companies in the park receive investments from the government, and when problems arise, the government seeks new assets to keep the park alive. Therefore, although the e-waste dismantling industry in the park is declining, it will continue to survive.

5.4.2 Path Disappearance

The second trajectory was cluster disappearance (path A in Figure 5.1). The impact of the policy shock on the Guiyu e-waste cluster was not slow and was particularly devastating. As mentioned above, in the 2010s, the government asked the people to move their businesses to the CEIP and threatened them with closure if they did not move. However, the park was just a tiny plot of land in Huaimei village that could accommodate less than 5% of existing firms. Furthermore, certain conditions were required to enter the park, under which most companies were eliminated immediately. Most importantly, the government restricted the daily amount of e-waste coming in and out of Guiyu, cutting off the industry at source and causing the e-waste cluster to disappear. The rigorous regulation of the e-waste business led to the closure of over 90% of small e-waste workshops and the layoff of many recyclers. Given the decline in employment prospects, many migrant workers were forced to leave the city. Many villages in Guiyu became 'hollow villages' with empty streets even in the middle of the day. As one interviewee said:

> *'Guiyu used to be very prosperous, the streets were full of people, and more than 100,000 migrants were coming to work at its peak. Since the policy, e-waste is not allowed to be done, they have all left, and there are no more migrants. 90% of the local people here are out of work now. E-waste industry in Guiyu as if it had disappeared ' (G12L).'*

Local e-waste workers had become accustomed to 'easy money' and were unwilling to consider other industries. Several interviewees expressed that 'earning money in other industries is too slow; they won't do it (G11Z) ', so they stayed where they were, waiting for the day when the e-waste dismantling industry in Guiyu would revive. Some denied the pollution caused by e-waste or turned a blind eye to it and insisted that e-waste dismantling was just a little primitive in its process, claiming that dismantling had an unpleasant smell but wasn't severely polluting. They argued that Guiyu's water quality was already poor and undrinkable and that it was not affected by e-waste.

While the pollution caused by e-waste is now acknowledged, it is seldom seen as a significant concern compared to issues of livelihood and survival. Several interviewees admitted that they were aware of the pollution from e-waste dismantling but had no choice in their livelihoods. If it weren't for this industry's dirty, tiring and polluting nature, they wouldn't have the opportunity to do it and make money. Without it, the local people would still be poor and struggle to put food on the table by farming. Locals still feel significant animosity towards certain media and environmental organisations, blaming them for the disappearance of the e-waste industry and giving them no chance to earn money. They believe it was irresponsible of these agents to exaggerate Guiyu's facts with hyperbole and then abandon the town after stirring it up. After Greenpeace's report on Guiyu's e-waste was published, the local government quickly contacted the director of Greenpeace to seek solutions, but the offer was rejected, with the explanation that it was beyond their capabilities. As one interviewee said:

> *'They come here, create chaos, and then leave. If you ask them how to solve the problem, they say they're only responsible for exposing it. They aren't doing anything positive (G12L).'*

Certainly, residents acknowledge that through the government's efforts, the environment has been improved significantly. The sky is bluer, the water is clearer, and they can even breathe fresh air outside. However, due to these improvements, they can no longer engage in the e-waste industry, leading to a complete loss of their source of income. With low technical skills, limited education, a closed social network and the habit of earning quick money, they are reluctant to explore new businesses and find it challenging to transition to other occupations. Currently, many of them are unemployed. One interviewee sarcastically said, 'Now that the environment has improved. When we're hungry, we go out to eat the wind and feel full (G32L).'

Residents believe that plenty of e-waste is generated globally and nationally and are still convinced that it is a good industry and that in order to dispose of the waste, the government will sooner or later let them start the e-waste industry again. However, when asked if they are preparing for this by making technological upgrades, their answer was negative, and they are still planning to use the old methods that the government banned. In their view, the government should deal with the environment and the upgrading of the e-waste industry. As one interviewee said: 'It is the government's responsibility to deal with pollution, not ours (G39Z).' It is likely that their wait for an upturn in e-waste activity will continue for a long time.

5.4.3 Path Replacement

The third fragmented path since 2015 is a new replacement cluster with a different identity and function (Figure 5.1 Path C). The e-waste business is failing economically, and in terms of jobs, resident and migrant workers are looking for new opportunities. The Nanyang area has formed a new textile cluster distinct from the e-waste industry, but this still takes the form of family and low-skilled workshops. However, unlike the e-waste industry, which is predominantly male, the textile industry is primarily female-dominated, and in many households, I observed in the fieldwork that women worked while men were unemployed at home.

Nanyang village is near Gurao, one of China's famous textile towns. Almost everyone in Gurao is engaged in textiles (mostly lingerie). Before the COVID-19 pandemic, 90% of its lingerie was exported abroad. The geographical proximity, close networks, open-mindedness and the accumulation of previous capital in the e-waste industry have made it relatively easy for Nanyang to transfer to textiles, and Nanyang's transition is profound, with more than half of the workforce employed in the textile sector. Currently, this district is also one of the wealthiest in Guiyu.

Figure 5.16 Textile industry in Nanyang Area (Source, author)

This stage strongly resembles the phase that occurred when the e-waste business was first formed. People in Nanyang village were led into the textile trade by strong networks of friends and relatives in the industry. Although the textile industry differs from e-waste in terms of technology and access to various resources, and the new system cannot incorporate elements and components left over from the old one, the textile industry emerged quickly in Nanyang village and was soon accepted, developed and expanded by its people, mainly because of accessibility. The textile industry is a low-end industry with narrow technical barriers, which means that workers can easily access specialised knowledge, draw on their neighbours' mature operating models and take advantage of established industry chains. More significantly, most textile workers have completed the most crucial accumulation of specialised productive capital through the e-waste industry. With the connectedness of the system components and the increase in the accumulation of resources, the cluster grew fast to form a new cluster.

5.5 Conclusion

This chapter conducted an in-depth examination of the developmental trajectory of the Guiyu e-waste cluster, with a particular focus on the interaction and negotiation processes among multiple agents that followed external shocks. The research analysed why the cluster failed to achieve technological and industrial upgrading and transformation and became trapped in path lock-in and decline. The study shows that the evolutionary path of the Guiyu e-waste cluster did not strictly adhere to specific life cycle sequence models (Robertson and Patel, 2007). Instead, it resembled a more complex adaptive system. In its initial stages, the cluster's development path aligned with the adaptive model proposed by Martin and Sunley (2011a), but the cluster fragmented into three coexisting evolutionary paths following external shocks: path disappearance, renewal and replacement. Through empirical research, this study suggests that cluster evolutionary paths can be multifaceted, especially during the reorganisation and restructuring phases that follow shocks. The adaptation strategies of different agents to the new context led to the simultaneous emergence of multiple evolutionary paths, a phenomenon that has often been overlooked in previous research. To some extent, the findings of this study complement and expand the adaptive model proposed by Martin and Sunley (2011a).

This study argues that the formation of the Guiyu e-waste cluster represents a typical case of path dependency. Guiyu's prior experience in traditional waste recycling laid the foundation for its rapid adaptation to the e-waste industry. As it developed, the cluster exhibited characteristics of deepening specialisation, accompanied by distinct labour divisions, gradually forming a complete industrial chain, leading Guiyu to become the largest e-waste site in the world. To some extent, this phenomenon corroborates the theoretical viewpoints of economists such as Marshall (1890), who suggested that as agglomerations develop specialisations, their internal differentiation becomes finer and more complex. However, this study further argues that the agglomeration phenomenon of Guiyu's e-waste industry cannot be explained solely by agglomeration effects, as the distribution of the e-waste industry coincides strongly with the geographical distribution of local clans, highlighting the significant role of regional culture and social structure in the process of industrial agglomeration. The study, therefore, advocates that when analysing industrial agglomeration, due attention should be paid to the influence of regional culture, social networks, local politics, and economic factors.

The process of e-waste regulation presents a complex, long-term conflict and negotiation process that involves multiple stakeholders, with the conflict between environmental sustainability and economic development at its core. Significant conflicts of interest exist between different agents, leading to obstacles in formulating and implementing regulatory policies. The coexistence of traditional clan governance structures and modern administrative systems has made interactions more complex in the Guiyu region, necessitating delicate balancing of interests and continuous negotiation, during which the power structure has undergone significant transformation. The initial pattern of 'strong clans, strong market and weak government' has gradually evolved into a new configuration of 'strong government, weak clans and weak market'. This process reflects multiple tensions in industrial governance: the collision between traditional social structures and modern governance models, the conflict between economic development and environmental protection and the coordination between central policies and local practices.

In the face of severe external policy shocks, Guiyu's e-waste cluster struggled to respond effectively due to its high internal corporate interconnectivity and low levels of adaptability and resilience. This led the cluster to fall into path lock-in and decline. This study suggests that the Guiyu e-waste cluster represents a typical low-end industrial cluster, with its production modes relying primarily on manual dismantling. While this approach lowered industry entry barriers and accelerated industrial diffusion, it simultaneously constrained the potential for technological upgrades and sustainable development. In the modern industrial era, the global and local divisions of labour have become more complex and refined, with industrial clusters often specialising in specific industries (Krugman, 1991). Although this unified and specialised production model improves supply output and chain efficiency, it is also vulnerable to external threats, especially for low-tech industries where unpredictable risks can lead to industry decline or disappearance (Parmentola, Ferretti and Panetti, 2021). The Guiyu e-waste cluster is a typical representative of old industry specialisation, the characteristics of which include a singular industrial composition, high homogeneity among enterprises and the formation of a refined horizontal inter-enterprise labour division. Enterprises are tightly connected because of raw material demands, and the industrial structure makes it difficult for enterprises to change their specific roles, technologies or products, resulting in insufficient innovation capacity and poor adaptability to shocks. Theoretically, the Guiyu case provides significant empirical evidence for understanding vulnerability and adaptability challenges of low-end industrial clusters.

The Guiyu e-waste cluster exemplifies the detrimental effects of excessive interdependence on long-term adaptive capacity, as theorised by Grabher (1993). The cluster's stable industrial chain relationships, while initially beneficial for reducing transaction costs, ultimately resulted in path dependency and a lack of boundary-spanning functions (Grabher, 1993). This configuration impeded external information exchange and attenuated the cluster's learning and self-organisation capabilities, culminating in a state of functional lock-in (Grabher, 1993). The cluster's strong clan-based social structures further reinforced internal network cohesion while simultaneously limiting external connectivity in order to safeguard its e-waste industry. This insularity severely compromised the cluster's ability to effectively respond to exogenous shocks, hindering information, technological, and cultural exchange with external entities and impeding the development of new evolutionary pathways. This phenomenon was particularly relevant to Guiyu's central region, which still remains in a state of industrial stasis due to minimal external interaction. Conversely, the Nan'an area, situated on Guiyu's northern periphery adjacent to the Gurao textile cluster, has been forced by its geographical position to forge stronger external linkages. This area has successfully assimilated information and established cooperative ventures with Gurao's textile industry, thus initiating new trajectories for industrial development and stimulating a fresh cycle of economic growth.

It is worth noting that low-end technology clusters like Guiyu, which are characterised by limited technological accumulation and human capital, face greater challenges in transitioning to related industries in comparison to their high-tech counterparts. For such clusters, the primary avenue for transformation often involves other low-end industries with minimal technological barriers but substantial capital requirements. This study corroborates the critical importance of maintaining a relatively loose network of structures within industrial clusters in order to mitigate the risk of lock-in (Sabel *et al.*, 1989). Its findings underscore the significance of balancing internal cohesion with external connectivity in order to enhance adaptive capacity and foster sustainable industrial development.

This vicious cycle that was initiated by functional lock-in is further reinforced by 'cognitive lock-in' (Grabher, 1993). Morgan (1986) points out that close long-term relationships tend to form 'groupthink', a mindset that reinforces the group's worldview and determines how cluster members collectively perceive or overlook certain phenomena. In the case of Guiyu, this cognitive lock-in is particularly evident. Residents generally insist that their e-waste dismantling technology is fine as it is and requires no further upgrades or improvements. More importantly, they firmly believe that the e-waste industry is the most suitable occupation for locals. Despite being unemployed, this deeply rooted belief makes many residents unwilling to consider new areas of work despite a decade of government regulation. Furthermore, cognitive lock-in is also manifested in local people's cognitive bias towards government regulation. They generally did not believe that the government would implement strict management of e-waste, reasoning that it was the livelihood source for 90% of the population and that the government would not take measures that could affect such widespread livelihoods. This cognitive bias led locals not to take the government's proposal to manage or ban the industry in 2003 seriously. This form of groupthink played a crucial role in the cluster's early restructuring process and put in place hidden dangers for future transformation and adaptive changes (Schlieper, 1986).

The political and administrative system plays a crucial role in regional development, effectively keeping a region on the 'right' path, even if this path has led to a dead end (Grabher, 1993). The case of Guiyu's e-waste industry illustrates this phenomenon well. Before the intervention of higher-level government, the industry had formed a highly symbiotic relationship with the local political system. This relationship was primarily manifested in two aspects, based on the idea that local tax revenue heavily depended on the e-waste industry, and many government officials and their families were directly involved in the industry. This led to a strong alignment of interests between the local government and industry, forming a particular community of interests. This symbiotic relationship between government and businesses hindered the timely restructuring and transformation of the Guiyu e-waste cluster (Kunzmann, 1986), and this lock-in was eventually broken with the intervention of the central government.

Chapter 6 Multiple Paths and Diversification – The Case of Huaqiangbei, Shenzhen

This chapter examines the evolutionary trajectory of Huaqiangbei's e-waste reassembly cluster. Huaqiangbei, Shenzhen is renowned for its thriving second-hand electronics industry and boasts China's largest second-hand mobile phone resale market (Xu, 2023). According to the definition in the 2019 Global E-waste Monitor report, second-hand electronic products fall into the category of e-waste (Forti et al., 2020). Unlike Guiyu's traditional e-waste dismantling, Huaqiangbei's second-hand electronics industry centres on the repair and reuse process, so it can be termed as reassembly, as opposed to the highly polluting metal extraction processes prevalent in Guiyu. However,Huaqiangbei's e-waste reuse industry still faces issues including pollution, smuggling and intellectual property infringement. Furthermore, as the city developed, conflicts arose between the city's pursuit of 'high-end' emerging industries and the presence of the e-waste industry. Consequently, the central and Shenzhen municipal governments have formulated a series of regulations to control the e-waste industry.

When faced with external shocks and changes in context, Huaqiangbei's e-waste cluster has continuously moved forward and adapted, achieving upgrades, in contrast to Guiyu's e-waste cluster, which fell into a lock-in and eventual decline, and its flexible cluster has not become stagnant. Although Huaqiangbei's e-waste industry possesses specific characteristics, the flourishing development of Shenzhen's high-tech industries – such as electronics, information technology and cultural creativity – academic attention to its e-waste industry has been notably lacking. Besides, Huaqiangbei's e-waste reassembly industry is closely linked to the city's rapidly growing electronics industry, and the two sectors demonstrate significant overlap and integration in various aspects, including but not limited to shared markets, technological exchange, overlapping supply chains and even the movement of labour resources. As a result, Huaqiangbei's e-waste industry is often classified as a subset of the electronics industry, resulting in its oversight.

This chapter reviews the development trajectory of Huaqiangbei's e-waste cluster, exploring its operating model, industrial chain, characteristics and relationship with the electronic industry. It also analyses why the industry avoided lock-in and achieved incremental upgrading when confronted with external shocks and an evolving context. The evolutionary process of Huaqiangbei's e-waste industry cluster did not conform to a typical life cycle development path, nor did it fall into a lock-in and subsequent decline. Instead, it exhibited resilience that was characterised by the coexistence of multiple pathways and continuous adaptation and adjustment (Bonaccorsi and Giuri, 2000; Robertson and Patel, 2007). This specific evolutionary trajectory is closely linked to Shenzhen's role in the vanguard of China's reform and opening-up policy and as a joint product that was shaped by the central and local governments. As China's first Special Economic Zone and a testing ground for the transition from a planned to a market economy, Shenzhen received substantial policy, funding and talent support from the central government during its development process. It was also granted considerable autonomy and privileges. Many practices initially that were considered capitalist ideas – such as attracting foreign investment, land auctions and securities trading – were piloted in Shenzhen before being implemented nationwide. The development of Shenzhen's industrial clusters showed that the government played a core role in guiding market-oriented economic growth.

Huaqiangbei, due to its locational advantage within a metropolitan area, has benefited from significant policy support, favorable environmental conditions, and comprehensive external effects including diverse industrial agglomeration. Thanks to this metropolitan location, associated externality resources, and the adaptive capacity fostered thereby, Huaqiangbei has been able to demonstrate remarkable resilience and transformation potential when confronted with external shocks. By examining this specific case study, we can, therefore, gain valuable insights into the role of government in guiding the development of industrial clusters and the impact of central/local interactions on shaping the adaptability and flexibility of these clusters. This will enrich relevant theories and provide empirical lessons for industrial upgrading in other regions.

This chapter elaborates on the evolutionary trajectories of the e-waste cluster in Huaqiangbei, dividing it into three sections. The first covers the path emergence stage from the 1980s to the 1990s. With the implementation of China's reform and opening-up policy, Shenzhen, as China's first special economic zone, established the goal of developing an electronics industry, which led to the emergence of the e-waste industry. During this emergent stage, Huaqiangbei primarily served as a simple dismantling, sorting and transhipment hub for e-waste. Overseas e-waste was taken to Huaqiangbei, where it underwent preliminary dismantling before being sold to Guiyu for more refined dismantling before being shipped back to Huaqiangbei for sale. With the vigorous development of the electronics industry in Shenzhen and the spillover effects of technology and knowledge, the e-waste industry then entered a developmental phase, which is discussed in the next section. In this stage, Huaqiangbei's e-waste industry began to focus on specific types, brands and models of products, using the electronics industry's technology for reassembly. The evolution of the e-waste industry closely followed the popularity and updating of electronic products, such as pagers in the 1990s, mobile phones in the 2000s and the widespread adoption of iPhones in the 2010s. Driven by global and domestic electronics industry technologies, Huaqiangbei established an integrated and specialised industry chain that encompassed collection, dismantling, refurbishment, reprogramming, packaging and sales, becoming a renowned e-waste reassembly and reuse industry cluster.

The third section pertains to the period of government policy intervention and industrial transformation and primarily explores the effects of regulatory changes, technological advances and policy shifts on Huaqiangbei's e-waste industry. As the e-waste reuse industry developed in Huaqiangbei, issues such as smuggling, counterfeiting and intellectual property infringement grew, prompting the government to increase regulatory oversight while providing supportive policies to facilitate industrial upgrading and transformation. During this stage, innovative enterprises emerged, with some companies moving towards producing domestic electronic products. However, certain entities continued to avoid government scrutiny in pursuit of self-interest, while the development of related industries – particularly electronic information technology – impacted Huaqiangbei's e-waste industry profoundly. The electronics industry provided the latest technologies, products and supporting equipment for the reuse of e-waste, significantly facilitating the upgrading and transformation of Huaqiangbei's e-waste sector.

This study examines the evolutionary path of Huaqiangbei's e-waste cluster. Most literature in EEG focuses primarily on specific industry scenarios, delineating the various life cycle models for their evolutionary paths (Belussi and Sedita, 2009). However, the coexistence of multiple industries is more prevalent in reality, though current research on this phenomenon remains limited (Bergek and Onufrey, 2014; Frangenheim, Trippl and Chlebna, 2020). Unlike most evolutionary studies in economic geography that concentrate on single industry clusters, Shenzhen represents a multi-industry cluster, of which the e-waste industry constitutes only one part. The development of Huaqiangbei's e-waste industry is closely intertwined with the co-evolution of related industries such as electronics and information technology, and it was precisely this synergistic development of multiple industries that enabled Huaqiangbei's e-waste industry to transform and upgrade when faced with external shocks such as policy constraints. The multi-industry cluster environment provided Huaqiangbei's e-waste industry with strong adaptability and resilience, allowing it to avoid lock-in traps smoothly and continuously innovate and upgrade (Bathelt and Storper, 2023). This case study breaks away from the single-industry perspective prevalent in traditional evolutionary economic geography research to show how an industry can interpenetrate, influence and co-develop with other industries, thereby resisting external shocks and incremental changes and achieving sustained evolution and upgrading. This not only enriches the theoretical foundations of evolutionary economic geography but also provides valuable insights for industrial cluster transformation and upgrading in other regions.

6.1 Path Emergence, 1980s-1990s

Huaqiangbei's e-waste industry emerged between the early 1980s and the early 1990s. Although no precise data indicates the exact year of its inception, it is evident that Huaqiangbei's e-waste industry developed in conjunction with China's reform and opening-up policy and the implementation of the 'Three-plus-one Trading Mix' policy[13]. During this period, Huaqiangbei's e-waste industry primarily served as a transit and a final sales destination. After the importation of e-waste into Shenzhen, it was transported to the nearby town of Guiyu for disassembly, classification and metal extraction before being sold again in Huaqiangbei. This process was relatively straightforward and had minimal technical requirements.

Before the 1978 reform and opening-up policy, Shenzhen, then Bao'an County, was a poor agricultural region with a population of around 360,000, of which 92% were farmers earning about ￥150 annually (The Institute of Migration Studies, 2014) and had a significant wealth disparity when compared to nearby Hong Kong (Liu, 2019). This economic hardship triggered four waves of population outflows between 1955 and 1979, with many residents illegally migrating to Hong Kong, leaving 'hollow villages' behind (Smart and Smart, 2008). The rigorous state control over economic activities and foreign trade under the planned economy system exacerbated local poverty, precipitating widespread famine and social distress, which intensified the exodus of people seeking refuge in Hong Kong (Chen, 2010).

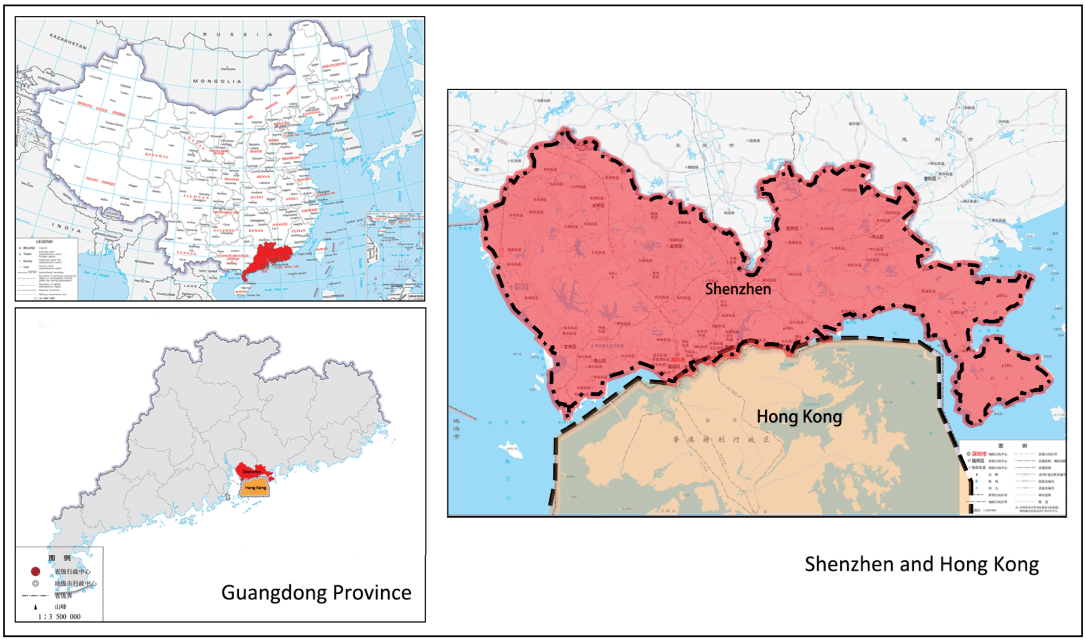

Figure 6.1 Location map of Shenzhen (Author)

[13] This involved processing with imported materials, assembly with imported components, processing with imported materials and compensation trade.

The ongoing practice of escaping to Hong Kong directly led to the introduction of the Chinese Economic Special Zone Policy and the Reform and Opening-up Policy, which involved internal reforms and external openness (Chen, 2010). Enterprises were no longer state-owned, private ownership was allowed, and policies that permitted foreign investment were introduced. Simultaneously, overseas enterprises were allowed to enter the Chinese market, and Chinese enterprises were encouraged to explore overseas markets. Shenzhen was designated China's first special economic zone, implementing free port policies. This included simplifying import and export procedures, improving customs efficiency, reducing trade costs and attracting significant international trade (Chen, 2018). Subsequently, Shenzhen became a primary gateway for foreign e-waste to enter China.

In order to attract foreign investment and introduce advanced technology, talent and scientific management methods, Shenzhen implemented the Three-plus-one trading mix policy[14], which can be understood as a 'front-shop, back-factory' approach, where foreign investors took the 'shop' role in the industrial division of the labour system. They were responsible for financing, management, product design, sales, and other high-end processes and for providing equipment, raw materials, and samples. Shenzhen used its advantages of land and labour costs to play the 'factory' role in the industrial division of labour by using foreign capital for factory construction and taking charge of product production, assembly and other low-end processes. This period coincided with industrial restructuring in the late 1980s and early 1990s in developed countries and regions such as Europe, the United States, Japan, Hong Kong and Taiwan, in which numerous labour-intensive and high-pollution industries with high energy consumption shifted to developing countries. The central government of China quickly identified the electronic industry as the primary direction for economic development for Shenzhen (Wang and Lin, 2020).

Many businesses from Hong Kong, Taiwan and Japan established electronic enterprises in Shenzhen, contributing to a significant accumulation of e-waste. Meanwhile, some foreign investors transported e-waste from their own countries or other regions to Shenzhen. Initially, these investors lacked awareness of the 'value' and proper treatment methods for e-waste. They exploited Shenzhen's low land prices and government incentives, such as tax breaks and funding support for foreign enterprises, and used e-waste for 'land enclosure.' The e-waste was merely stockpiled with no knowledge of how to manage or process it. Residents of Guiyu, who made a living by scavenging, came to Shenzhen and transported e-waste back to Guiyu at lower

[14] this involved processing supplied materials, processing supplied samples, assembling supplied parts, and compensatory trade.

prices for dismantling (see Chapter 5). Shenzhen was at first little more than a collection point for e-waste, with virtually no industrialised e-waste processing. As one interviewee said:

> *'At the beginning, these Taiwanese bosses brought some e-waste here [...] they didn't know how to deal with it [...] In the beginning, some even paid us to take it.' (G28Z)*

In 1998, the SEG Electronics Group established the first specialised electronic component trading market in Huaqiangbei. This initiative marked the beginning of a market-oriented service platform for the electronics industry during China's transition from a planned to a market economy. Huaqiangbei soon emerged as a key centre for the resale and reuse of dismantled and recycled e-waste, establishing itself as a primary hub for the redistribution of discarded electronic products and components. Before the establishment of the SEG Electronic Market, under China's planned economic system, electronic component quotas were allocated through annual conferences organised by the Planning Commission, but Shenzhen's electronic enterprises, which operated outside the plan, struggled to obtain their component quotas. Even if they were allocated quotas, the import process involved multiple layers of approval, taking at least six to twelve months (HQBMuseum, 2020). After these approvals were granted, the market situation changed.

In 1998, Huaqiang Electronic World opened, with a business area of 43,000 square metres and over 2,800 stalls, primarily selling electronic accessories and second-hand electronic goods (HQBMuseum, 2020). As mentioned above, used electronics destined for refurbishment, reuse, resale, salvage, recycling through material recovery or disposal are also considered e-waste (Kahhat et al., 2008; Perkins et al., 2014), which meant that Huaqiangbei's second-hand electronic products fall into the e-waste category. The subsequent development of the e-waste industry in Huaqiangbei – focusing on refurbishment, reassembly and reuse – represented a different aspect of the e-waste industry that was different from Guiyu's disassembly e-waste industry. During China's early transition from a planned to a market economy, electronic components, metals and plastics were scarce, and secondary materials derived from dismantled e-waste became crucial substitutes and the main products sold in Shenzhen's electronic market (Tong and Wang, 2004).

The establishment of Shenzhen's electronic market not only addressed the timely supply and demand of electronic components for China's new electronic enterprises but also strengthened the recycling pathways of the e-waste industry. Foreign businesses transported e-waste generated in developed countries to Shenzhen, where it was resold to Guiyu for dismantling, sorting and metal extraction. Reusable electronic components and products were then sold back to Shenzhen for resale in the electronic market. The dismantling and use of e-waste in Guiyu generated substantial economic benefits, highlighting the inherent value of e-waste. The refinement of the e-waste industry chain, market demand and the pursuit of significant profits facilitated the rapid development of the e-waste industry in Huaqiangbei.

During this stage, with the support and approval of the central government, Shenzhen introduced a series of preferential policies in taxation, land and talent, attracting numerous foreign electronic enterprises – particularly from Hong Kong, Taiwan and Japan. This allowed Shenzhen to transition rapidly from agriculture to industry in a leapfrog development that bypassed intermediate stages. The interconnection of system components was further strengthened, leading to the establishment of a core industrial system that was centred around electronics, electrical appliances and telecommunications. Through Hong Kong, Shenzhen developed a commercial network along the east coast of the Pearl River Delta that included raw materials, sales networks, global technological connections and logistics. By the end of 1985, Shenzhen's electronic industry, which had started with a single county-owned enterprise in 1979, had grown to over 170 enterprises producing radios, colour televisions, telephones, calculators and components, along with advanced software development and component manufacturing technologies. The workforce expanded from 108 people to over 17,000, and the factory area increased from a few simple buildings totalling around 100 square metres to dozens of standard industrial buildings with a total area exceeding 500,000 square metres (Tang, 2020).

By 1985, the annual output value of Shenzhen's electronics industry had reached ￥1.375 billion, accounting for approximately 49.7% of the city's total industrial output, an 113.5-fold increase compared to 1979. By this time, Shenzhen's electronics industry had risen to seventh position nationally among the electronic industries of 28 provinces and cities. The range of products expanded from fewer than 10 in 1979 to over 400 (Guangdong Provincial Party Committee, 2022).

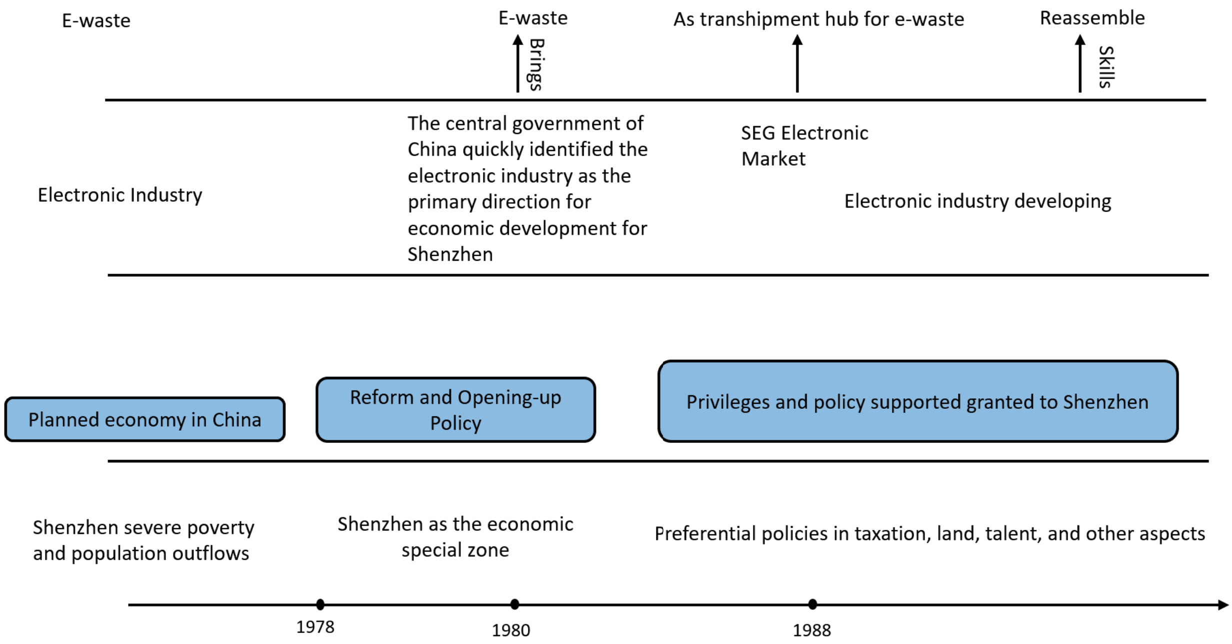

Figure 6.2 Path emergence of the e-waste industry in Huaqiangbei, Shenzhen (Author)

In summary, the emergence of Huaqiangbei's e-waste industry was closely related to national policies and the global shift in the electronics industry to developing countries and can be viewed as an incidental outcome of a sudden change in the external policy environment rather than a path-dependent result (Porter, 1998a). The impact of external policies facilitated the formation and transformation of the e-waste industry in Huaqiangbei, although e-waste, as only a small part of Shenzhen's industries, was often overlooked. In the early stages of development, Huaqiangbei served primarily as a transit point from which imported e-waste was sent to be dismantled in Guiyu. However, with the establishment of the Electronic Market and the recognition of the value of e-waste, some dismantled electronic components were transferred back to Huaqiangbei for resale. During this phase, supported by favourable policies for the electronics industry, Huaqiangbei bypassed intermediary stages and rapidly accumulated capital, talent, information networks, technology and the necessary elements of the industry chain. Although these policies primarily targeted the electronics industry rather than e-waste, industries do not exist in isolation and are often closely interconnected (Martin and Sunley, 2011a). Given the strong relationship between the e-waste and electronics industries, the accumulation of policies, technologies, knowledge and talent in the electronics industry has also provided a crucial foundation for the upgrade and development ofHuaqiangbei's e-waste sectors (Bathelt and Storper, 2023).

6.2 Path Development, mid-1990s-2020s

The period from the mid-1990s to the 2020s was a period of rapid development for Huaqiangbei's e-waste industry. Building upon the foundation of the first phase, which involved the transit and resale of e-waste, Huaqiangbei's e-waste industry gradually established a full e-waste reassembling supply chain that included specialised recycling, dismantling, refurbishing of components, programming, packaging and selling. It formed an industry cluster which eventually became the largest national centre for the trade of second-hand electronic products (Xu, 2023). Since second-hand electronic products are essentially a form of e-waste reuse, it can be argued that Huaqiangbei has developed an e-waste cluster that is primarily focused on e-waste reassembly.

During this phase, the cluster no longer indiscriminately accepted all types of e-waste products shipped from the West. Instead, using information and technical resources it had accumulated previously, it responded flexibly and adapted to the constantly evolving market and technological environments. The industry adapted itself based on the demand for new electronic products, actively and purposefully seeking out specific types and brands of e-waste products and showing an apparent selectivity and specialisation in the types of e-waste it was prepared to recycle. At this stage, the cluster did not lock in the mature mode of establishing a strong network and accumulating resources around a particular specialisation. Instead, it remained in the exploration and growth phase of the adaptive cycle model, gradually evolving in a path-dependent, self-adaptive manner (i.e., an evolutionary path of α-r-r'-r''..., (Martin and Sunley, 2011a). This section examines three typical cases of e-waste reassembly in Shenzhen: pagers in the 1990s, mobile phones in the early 2000s and iPhones that became more widely popular in the 2010s, to demonstrate the adaptive processes of Huaqiangbei's e-waste industry during different periods, revealing the inherent logic behind its adaptive development.

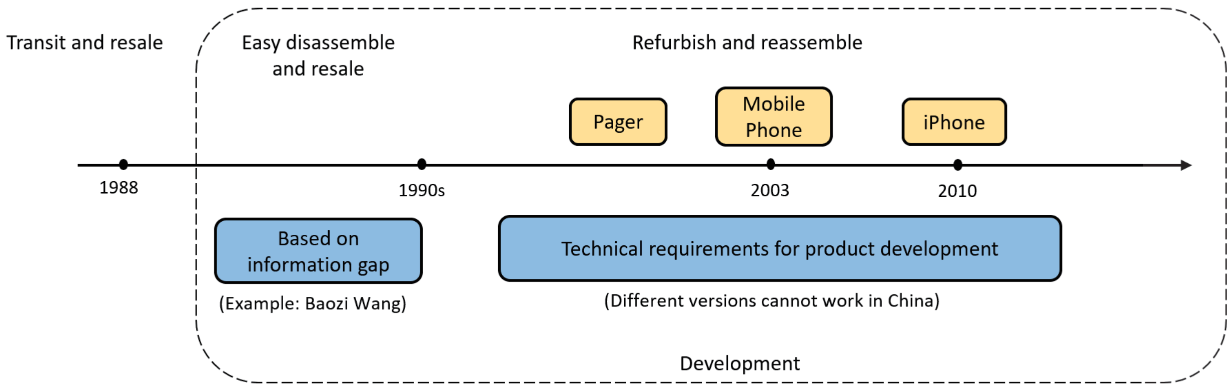

Figure 6.3 The development trajectory of e-waste in Huaqiangbei, Shenzhen (Author)

As the leader of China's electronics industry, Shenzhen benefits from its proximity to Hong Kong, which allows it to access the latest technologies and products rapidly. Interviewees highlighted that Shenzhen was China's initial gateway to the outside world, serving as the entry point for new technologies and products abroad and ultimately becoming a benchmark for the country's domestic electronics and information industries. Technologies and products were absorbed and adopted in Shenzhen before spreading to mainland China, with some products being several versions ahead of those used on the mainland. In the early stages, Huaqiangbei's e-waste industry profited significantly by capturing and using information disparities.

An example widely mentioned by interviewees (S9N) is the case of a business owner in Huaqiangbei named Baozi Wang, who made substantial profits by reselling discarded chips. In 1993, he purchased 30,000 electronic components from hands-free phones at an extremely low price of ￥0.2 each from Motorola's obsolete stock in Hong Kong. Two years later, after Motorola ceased to produce these components, Wang, having selectively refurbished them, sold them for ￥27 each. At that time, an ordinary person's monthly salary in Shenzhen was only ￥38, and Wang made a great deal of money from this deal. He then purchased a batch of chips to be disposed of in Hong Kong for ￥15[15] each and later sold them for $200 each, generating substantial profits.

The Huaqiangbei e-waste cluster historically generated profits by exploiting price disparities between identical products across different countries and capitalising on its information lead over the mainland Chinese market. In the 1990s, China's electronic technology was underdeveloped, with low production rates and high prices for electronic products. Additionally, it was experiencing high rates of obsolescence and a rapid turnover of electronic products. This created an opportunity for Huaqiangbei's e-waste industry, which profited primarily by importing discarded electronic products from abroad, refurbishing them and reselling them within China. This process created a process by which Hong Kong businessmen bid for, auctioned and purchased e-waste, then smuggled them into Huaqiangbei for resale. Typically, this e-waste was shipped to Hong Kong by sea, using Hong Kong's status as an international free trade port, which allowed goods to enter without paying tariffs. Crossing from Hong Kong to mainland China, the goods needed to go through customs and comply with all regulatory requirements, and items that exceeded the permitted limits were subject to additional fees or even fines. Huaqiangbei entrepreneurs often used smuggling to bring goods back to Shenzhen to reduce costs. After winning the bid in Hong Kong, Hong Kong companies would coordinate with Shenzhen entrepreneurs to contact the smugglers, and bosses only needed to confirm the location of the transaction with them. The parties involved typically did not interfere with or even understand each other's work. According to interviewees (S31Z), over 90% of e-waste transactions involved smuggling, as it was the only viable method of generating profits and remaining competitive in the market. These smuggling activities were illegal, and around 2020,

[15] Approximately $2 US at current exchange rates.

the government intensified efforts to combat them, significantly impacting the Huaqiangbei e-waste industry, as will be shown in the following sections.

6.2.1 The Rise of Electronic Information Products and the Technological Crisis

As well as basic manual techniques such as simple dismantling, sorting and cleansing, the Huaqiangbei e-waste industry also borrowed innovative technologies from the electronics industry, such as programme modification and code writing, to achieve a higher level of refurbishment and reassembly. Huaqiangbei's e-waste industry was primarily focused on reusing and refurbishing discarded electronic products from overseas markets. However, the rapid growth of information and communication technology (ICT) products posed significant technological challenges to Huaqiangbei's traditional e-waste reuse model. Unlike conventional electronic products, which could generally be used across countries, ICT products relied heavily on specific communication standards and regulations that were mandated by individual nations due to different communication functionalities.

This technological barrier posed a significant challenge to the traditional reuse model of Huaqiangbei's e-waste industry. The previous approaches of simple dismantling and reassembly were ineffective when dealing with ICT products with complex hardware, software and communication standard differences. This compelled Huaqiangbei's e-waste industry to engage in communication, learning and technological innovation with the electronic industry, adopt new technologies and undergo innovative upgrades to meet the new requirements of reusing overseas electronic information products in China.

6.2.1.1 The Rise of the Pager

The refurbishment and reuse of discarded pagers is a good example of this. The emergence of pagers stimulated the development of character transliteration and simplification [16] technologies in the e-waste industry. Pagers are wireless communication devices that receive and display alphabetic, numeric or voice messages (Agar, 2013). They were developed in the 1950s and 1960s and were widely used in many countries. However, they were only officially introduced in China in 1983, when Shanghai established its first paging station (Dong and Wei, 2019). Initially, basic analogue signal pagers were used, by which users could only receive messages when someone called. Specific callback numbers had to be obtained by contacting the paging station and then using telephones on the streets to return the call. Although this process appeared cumbersome, it solved the problem of being unable to reach someone

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[16] Converting traditional Chinese characters to simplified Chinese characters.

through landline phones (Luan, 1993). With technological advances, local companies collaborated with Motorola to develop Chinese pagers that allowed users to understand the caller's intent despite the pager's small screen. However, because of economic conditions at that time, the average income of the Chinese people was very low. A pager could cost as much as two to three thousand RMB, while many individuals earn only four to five hundred RMB per month (Dong and Wei, 2019). As a result, people had to save for several months to buy one. In contrast, pagers were relatively inexpensive in developed regions, where local people enjoyed higher incomes. This led to a significant number of pagers being discarded as waste.

Huaqiangbei's businessmen recognised this opportunity, collected discarded pagers from Hong Kong and smuggled them to Shenzhen. However, since the font on Hong Kong pagers was traditional Chinese, it resulted in garbled characters when used on the mainland. To address this issue, entrepreneurs in Shenzhen learned from Hong Kong programmers, read numerous books and eventually developed technology to translate and simplify the character library. They purchased a substantial number of discarded pagers from Hong Kong or overseas at relatively low prices and smuggled them into Shenzhen. Then, based on the quality of the pagers, they classified the lower-quality ones for disassembly based on the shell, board, screen and battery and sold the corresponding accessories. The higher-quality pagers underwent program modification, transliteration and simplification and were then repackaged and sold to domestic consumers at prices that sometimes reached up to ten times the costs. As one interviewee mentioned:

> *'In Hong Kong, pagers were sold by weight; you can imagine how inexpensive they were. However, they were unusable. Later, we learned from programmers in Hong Kong and realised that it was due to font issues [...] This system was quite lucrative at the time, and, in the end, this system sold for several hundred thousand RMB (S22X).'*

Figure 6.4 Traditional Hong Kong pager and mainland China simplified pager (Source: Google Images)

滬-沪	畫-画	劃-划	懷-怀	壞-坏	歡-欢	環-环
還-还	穢-秽	會-会	匯-汇	獲-获	擊-击	雞-鸡
極-极	擠-挤	幾-几	際-际	繼-继	殲-歼	監-监
堅-坚	艱-艰	檢-检	鹼-碱	鹼-硷	薦-荐	鑒-鉴
講-讲	膠-胶	澆-浇	驕-骄	嬌-娇	階-阶	節-节
傑-杰	潔-洁	結-结	屆-届	緊-紧	僅-仅	進-进
燼-烬	盡-尽	勁-劲	驚-惊	競-竞	廄-厩	舊-旧

Figure 6.5 Comparison of traditional and simplified Chinese characters (Source: https://www.acfun.cn/a/ac20026383?from=video)

6.2.1.2 The Rise of the Mobile Phone

With early mobile phones coming into more widespread use in the 2000s, pagers gradually lost their market and were phased out (Fong, 2009). The attention of the e-waste industry in Huaqiangbei shifted towards mobile phones, bringing innovation to the Chinese version of mobile phone system technologies. Because of the different standards for mobile network signals in various countries, discarded phones from South Korea, Japan and the United States, despite being fully functional, could not be used in China. Before 2003, discarded phones imported from abroad were sold by weight in Huaqiangbei, and the processing involved little more than primitive disassembly.

In 2007, a university student named Fuqing Fan, who was engaged in dismantling discarded phones in Huaqiangbei, successfully developed a technology known as ‘number burning’[17] (Liu and Liu, 2017). This innovation enabled overseas phones to be modified for use on Chinese networks. Fan, through his connections, met a telecommunications professional at a phone card vendor inHuaqiangbei. He obtained the source codes for 10 telecommunications numbers and then asked a technician to embed these source codes into discarded South Korean phones. Fan then took the system from the phone and enlisted the help of a Korean-speaking friend to translate the system’s text into Chinese. Finally, he imported Nokia’s Chinese character library into the system for editing Chinese text messages, creating a Chinese version of the system for the modified phone. Using the same technology, Fan then introduced Chinese phone systems to phones from other regions (Liu and Liu, 2017).

Following the popularisation of these technologies, discarded foreign phones were no longer just disassembled. Instead, a range of new practices emerged, including repair, reassembly and

[17] Shaohao 烧号 in Chinese.

refurbishment. These advances enabled the reuse of discarded phones, leading to a significant upsurge in the e-waste industry. As various brands, models, and versions became popular, the Huaqiangbei e-waste industry adapted by continuously evolving its refurbished products in response to shifting product trends.

6.2.1.3 The Rise of the iPhone

After 2010, the rise of the iPhone spurred the development of new technologies within the e-waste industry. Unlike traditional mobile phones, iPhones feature more complex software and hardware systems, stricter security protocols, diverse system versions and different carrier services. To reuse discarded iPhones, Huaqiangbei's e-waste enterprises needed to develop new technologies. In this context, a series of new techniques emerged, such as 'jailbreaking' [18], 'activation lock removal' [19] and 'phone card grafting'. [20]

As the iPhone began to dominate the global smartphone market, some e-waste enterprises in Huaqiangbei began to shift from other mobile phone brands to the iPhone. This transition was driven by two main factors. Firstly, because of significant price differences for iPhones across various countries and regions, the Chinese market initially fell into the higher price zone. Companies could, therefore, achieve considerable profits by reassembling discarded iPhones overseas. Secondly, as previously mentioned, the protective ecosystem of the iPhones' systems necessitated substantial specialised technology for reuse, [21] thereby raising entry barriers. Peter Schindler, the founder of the US electronic recycling and refurbishing company The Wireless Alliance, stated that due to Apple's activation lock, between 4,000 and 6,000 iPhones are destroyed every month (Craig, 2019). However, the e-waste companies in Huaqiangbei used unofficial and illegal methods to unlock iPhones, allowing their refurbishment for reuse.

Almost all iPhones that are difficult to unlock in China and globally – including many stolen phones – find their way to Huaqiangbei. Users from various countries have noted on X that when traced, their stolen phones often end up in Shenzhen. In June 2022, a user from London tweeted, 'My iPhone got stolen in London. Now it is back in China.' Hundreds of comments followed indicating similar experiences, with some even joking and referring to Shenzhen as the

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[18] The 'jailbreaking' technique bypasses Apple's restrictions on the IOS system, granting root access. 越狱 in Chinese.

[19] Activation lock removal can unbind the iPhone from its previous user account.

[20] Phone card grafting allows discarded iPhones without SIM cards (like eSIM technology) to be equipped with new SIM cards for continued use on new carrier networks.

[21] iPhones present challenges for refurbishment and reuse due to features like activation locks and serial numbers. Activation locks link the iPhone to the owner's login ID, making the system protection dependent on that specific ID. As a result, unlocking the activation lock requires entering the corresponding ID and password. Without the necessary unlocking technology, the iPhone cannot be activated, rendering the device's logic board useless. In such cases, the phone can only be disassembled and sold as individual components, although selling the entire device generates significantly higher profits compared to the revenue from disassembly.

'hometown' of iPhones. Even during the COVID-19 pandemic, when many international flights to China were suspended and imports were severely restricted, iPhones stolen in London quickly reappeared in Huaqiangbei. A user posted on Chinese social media: 'When I couldn't get a ticket back to China because of COVID-19, my iPhone beat me to it.' (User in Little Red Book[22])

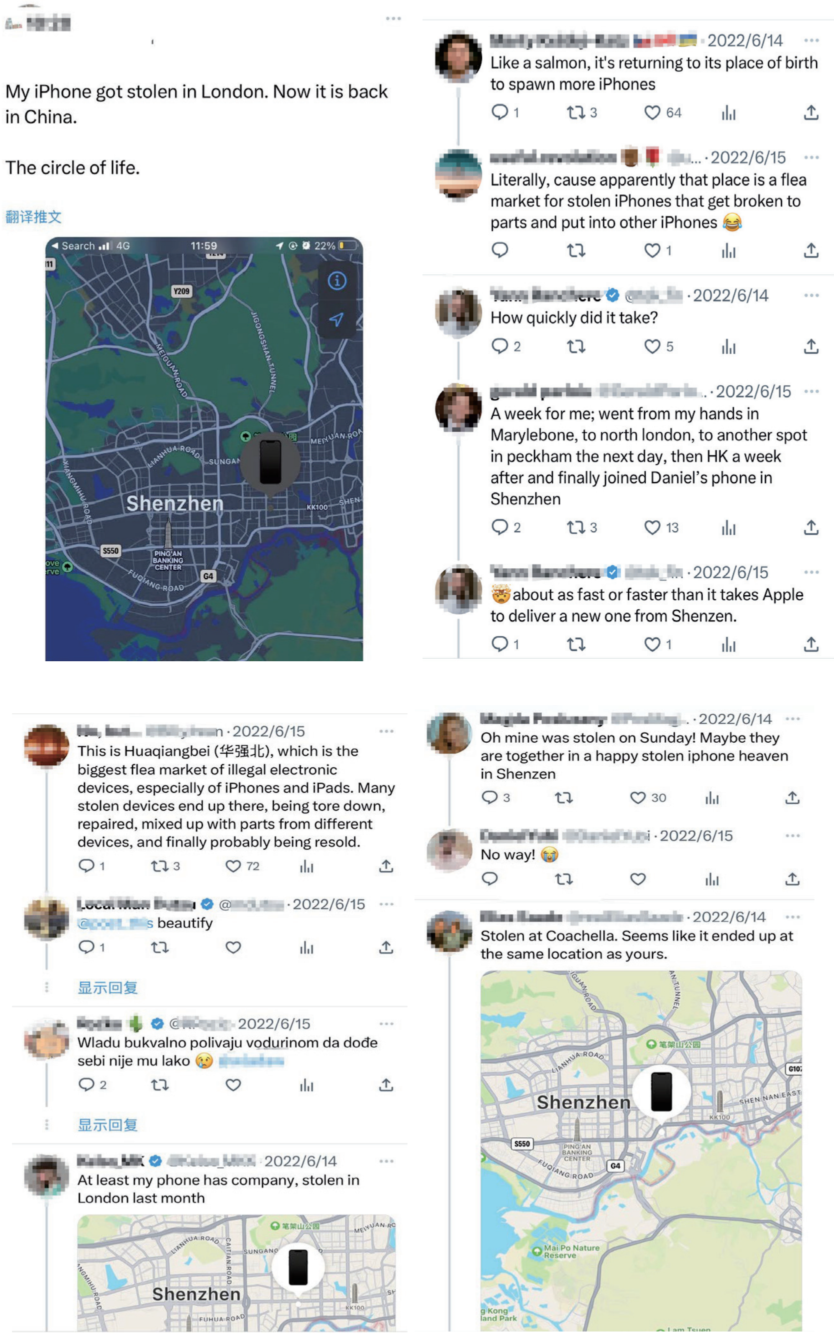

Figure 6.6 Posts about iPhones that were stolen and ended up in Huaqiangbei, Shenzhen (Source: 'X')

Huaqiangbei has consistently innovated with each new generation of iPhone upgrades, developing technologies such as IMEI modification, deactivation of activation locks, unlocking

[22] A Chinese social media platform.

procedures and the addition of SIM card slots[23]. For example, each iPhone has a unique IMEI code, which can be used to verify its authenticity, place of manufacture, production date, original memory and colour. Huaqiangbei can provide technology to 'jailbreak' Apple's iPhone board and change the original IMEI code to a new one, allowing the device to be sold as a new phone. An employee at an iPhone refurbishing workshop[24] told me that changing the IMEI code costs only ￥10Huaqiangbei can also provide unlocking and SIM card add-on technologies. Some American versions of iPhones are carrier-locked, necessitating the use of specialised software to unlock the IMEI and add a SIM card adapter to the board. Only after such modifications can these iPhones accept domestic China Unicom and China Mobile SIM cards. The latest American version of the iPhone 15 with eSim can also be quickly modified to become an iPhone that can use SIM cards in China, as eSIM cards cannot be used there. However, these processes are illegal, which is why the Chinese government has now implemented regulations to manage them.

Figure 6.7 iPhone refurbished before and after comparison (Source: Douyin)

In Huaqiangbei's e-waste industry cluster, screens and frames can be polished, battery efficiency can be improved, single SIM card slots can be converted to dual SIMs, national versions can be altered, and 64GB memory can be expanded to 128GB, 256GB, or even 512 GB. iPhones like the XR can be transformed into iPhones 11, 12, or 13, and some more extreme cases involve turning iPhones with cracked screens into seemingly new devices that are sold online. Joi Ito, the director of the MIT Media Lab, expressed amazement after visiting Shenzhen. In a blog post, he wrote:

[23] In some countries, the iPhone 14 series has eliminated the physical SIM card slot, replacing it with an eSIM card. However, in China, an eSIM card cannot be used so a SIM card slot must be added.

[24] The methods they used are 'unofficial' and 'illegal'.

> *'What surprised me is that they don't use any vision-assisting tools to solder circuit boards the size of fingernails. No microscope, no magnifying glass. Perhaps they usually do it by feeling and muscle memory. In the United States, even with vision-assisting tools, workers can only do a fraction of such work (Ito, 2014).'*

As one respondent explained:

> *'Shenzhen is at least two years ahead in terms of technology compared to other places in mainland China. If you can't figure out how to deal with a phone, it eventually ends up in Shenzhen (S30X).'*

Figure 6.8 Details of iPhone refurbishment (Source: From interviewees)

Undoubtedly, the appearance of the iPhone has brought the Huaqiangbei e-waste industry to its peak in terms of both quantity and technology. According to Guohui Hu, the chairman of Foxconn, Apple's second-hand equipment sales company, in 2015, between 40,000 and 50,000 used iPhones were resold in Shenzhen every day, with a conservative estimate of at least tens of thousands of people engaged in the business of refurbishing discarded phones in Shenzhen (Peng, 2015b). According to merchants involved in recycling iPhones in Shenzhen, the annual turnover of the Shenzhen iPhone recycling industry has long exceeded a hundred billion RMB, and these are just the B2B numbers, excluding online transactions (Nan, 2017). Mobile phone reassembly workshops are typically located in ordinary residential buildings in Huaqiangbei, mainly operating as family workshops (Peng, 2015a). They are secretive because refurbishing phones involves smuggling, counterfeiting and other issues, and workshops often install hidden cameras on their doors to avoid police inspections. It is, therefore, extremely challenging to provide exact statistics, but during its most prosperous period, the Shenzhen electronic market was almost entirely dominated by send-hand iPhones.

Figure 6.9 iPhone bulk purchasing (Source: From interviewees)

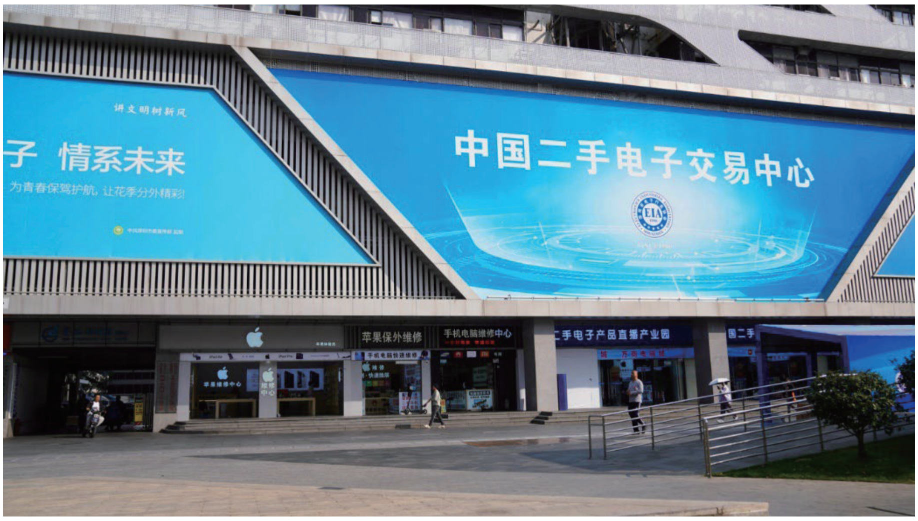

Figure 6.10 One of Shenzhen's second-hand mobile phone trading markets (Source: https://www.sohu.com/a/743877738_751260)

6.2.2 Interactions Between the E-waste and the Electronic Industry

Since the 1980s, from pagers to the latest iPhone 15, Huaqiangbei's e-waste industry cluster has established a sophisticated refurbishment and reassembly supply chain. During this period, refurbishment techniques have continually evolved and improved in response to product and market demands. Although tracing the origin of each technique is challenging, the e-waste industry cluster in Shenzhen is not isolated, and external industries and environmental factors have strongly influenced its development. The activities of companies within the cluster also have a significant impact on the competitive environment of the entire industry (Porter, 1998a; de Haan, 2006).

The e-waste industry and the electronics industry are closely linked and mutually influential, and e-waste can be seen as a vertical extension of the electronics industry. Disassembling and refurbishing e-waste requires a certain level of electronic and information technology knowledge, and due to the principle of extended producer responsibility, the electronics industry has to consider and bear subsequent management responsibilities after their products become waste. It is, therefore, difficult to discuss the e-waste industry independently from the electronics industry.

The relationship between Huaqiangbei's e-waste and electronics industries is particularly intimate, to the point of being interwoven. They co-exist in the same region, sharing production supply chains, information networks and even specific labour resources. The development of Huaqiangbei's e-waste industry has undoubtedly benefited from knowledge spillovers and exchanges with the local electronics industry. Specifically, the electronics industry's rapid development has shortened the lifecycle of electronic products, forcing Huaqiangbei's e-waste industry to continuously update and innovate its refurbishing technologies in line with ever-evolving electronic products to avoid becoming obsolete. Since Shenzhen has always been positioned as China's reform and opening-up demonstration zone, its e-waste industry cannot engage in large-scale, highly polluting e-waste dismantling and metal smelting activities as happens in Guiyu. Instead, it focuses more on refurbishing and reassembling discarded products. Compared to simple disassembly, reassembling requires more stringent technical requirements and a deeper knowledge of and expertise in electronic products to complete the disassembly, refurbishing and reassembly processes.

The early participants in Huaqiangbei's e-waste industry were predominantly migrants from the Chaoshan region, particularly those with close ties to Guiyu. These individuals were generally low in formal educational attainment but maintained strong clan-based social networks. Unlike Guiyu, where the e-waste cluster is largely controlled and organised through tightly knit kinship structures, Shenzhen represents a contrasting case. As one of the most prominent immigrant cities in China since the era of economic reform and opening-up, Shenzhen exhibits a highly diverse and mobile social structure. To attract talent and labour, the municipal government implemented a range of inclusive policies, including the well-known slogan, 'Once you come to Shenzhen, you are a Shenzhener.' According to the Shenzhen Municipal Bureau of Statistics (2021), the city had a migrant population of 12.44 million in 2020, accounting for 70.84% of the total population. This high degree of mobility and demographic diversity significantly undermined the formation of tightly bounded clan networks like those in Guiyu. While some regional migrant communities may have formed chambers of commerce to consolidate resources and coordinate interests, these associations functioned more as strategic alliances rather than entities exerting systemic control over the broader commercial landscape of Shenzhen. This distinctive 'weak clan–strong market' social configuration constitutes a crucial foundation for the differentiated evolution of industrial clusters in Shenzhen. This structural feature has created favourable conditions for the introduction of external knowledge and technology. More significantly, the flourishing electronics industry within the same geographical space has generated substantial knowledge spillover effects, providing critical human resources and technical support for the e-waste industry. Multiple interviewees (S30X) stated that initially, they only knew that foreign low-priced recycled electronic products could not be reused in China due to version differences, and they did not know how to overcome these barriers.

Therefore, through communication and learning from local and neighbouring practitioners in the electronics industry (such as those in Hong Kong), they gained information, techniques and knowledge, thereby enhancing the industry's adaptability. This enabled them to continuously learn and innovate techniques that kept abreast of updates in electronic products. The cases of pagers and mobile phones mentioned earlier exemplify this point well. The founder of the pager character transliteration and simplification system stated that, at first, he had no idea how to use Hong Kong's pagers in mainland China. However, through frequent interactions with electronics industry personnel in Shenzhen and Hong Kong's electronic market, he eventually developed the system by consulting them and through self-study. As one interviewee said:

> *'They select components, trade products, communicate and share ideas here. Some foreign merchants even share technical ideas and inform us of their domestic standards, facilitating our production of products that are compliant with their national standards, which, of course, also helps us to improve the techniques of our e-waste industry (S25D).'*

Simultaneously, the huge profit potential of the e-waste industry drove Shenzhen's electronics industry to prioritise its technical demands. Shenzhen has numerous electronic companies focused on technological research and development for the e-waste industry, and these companies can rapidly research solutions based on the e-waste industry and market demands, such as screen polishing and mobile phone jailbreaking. Many refurbishing techniques and instruments that are widely used in the e-waste industry originate from these electronic companies, with e-waste merchants only needing to purchase machinery and learn the techniques from electronics manufacturers. For example, Shenzhen has many companies that specialise in technology and product R&D for Apple, maintaining close ties with Foxconn. Through specific informal and illegal transaction channels, Shenzhen's electronics manufacturers can obtain schematics of the latest product designs. Every year, before Apple's launch events, Shenzhen can unveil the appearance of new Apple products prematurely and produce copycat models, albeit through non-compliant practices that have gained Shenzhen renown in this domain. This 'ahead of the curve' information provides Huaqiangbei's e-waste industry with the potential for advanced deployment, updating, transformation and rapid capture of the market share. With the influx of highly educated technical talent joining the e-waste industry, barriers to technical exchange have been reduced, technological updates have been accelerated, and the adaptability of the e-waste industry has improved, avoiding functional lock-in.

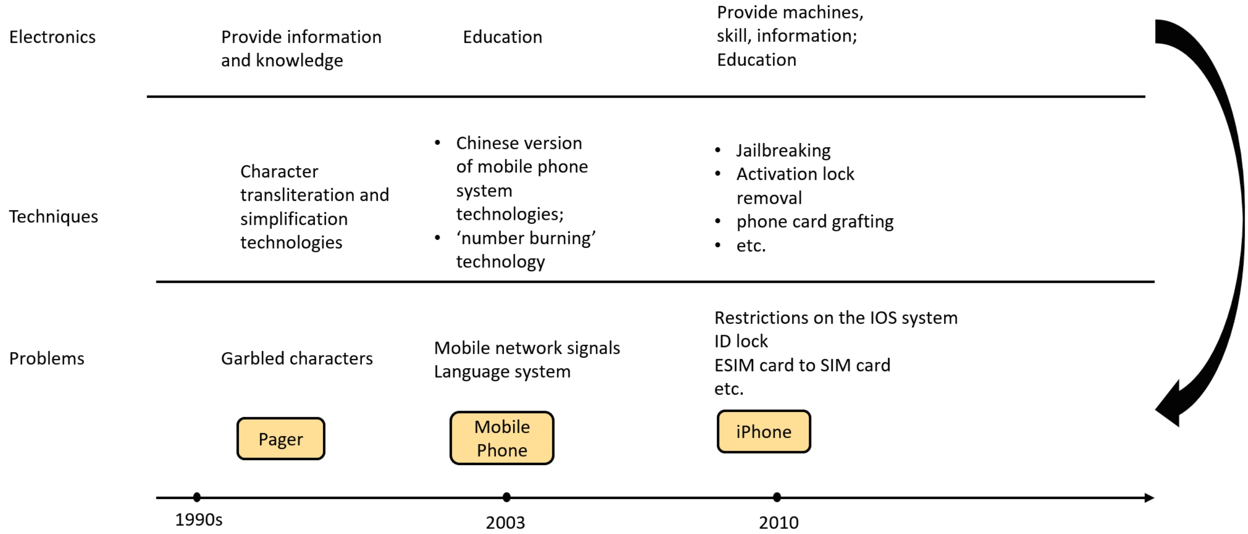

Figure 6.11 Interactions between the e-waste industry and the electronic industry (Author)

Overall, the rise of electronic information products presented a technological disruption to Huaqiangbei's traditional e-waste industry model, driving an adaptive industrial transformation. Benefiting from geographic proximity and agglomeration effects, Huaqiangbei's e-waste and electronics industries became interconnected through formal and informal market mechanisms, facilitating the dissemination of technology and knowledge through official and unofficial channels, thus promoting innovation (Jensen et al., 2007). Through close collaboration with the local electronics industry, Huaqiangbei's e-waste industry was able to undertake technological innovation and industrial upgrading, gradually expanding its capabilities to reuse electronic products. This enabled Huaqiangbei to become the nation's largest refurbishing and reuse cluster for discarded iPhones, thereby avoiding lock-in.

6.3 Incremental Adaptations and Path Diversity

Huaqiangbei's e-waste cluster is not an isolated entity but is part of a complex industrial ecosystem comprising a network of geographically concentrated and interconnected companies, specialised suppliers, service providers, related industry enterprises and associated institutions (Martin and Sunley, 2011a). The cluster exhibits significant flexibility, with its development trajectory continuously shaped by multiple external factors, including changes in policy and regulations, developmental dynamics of related industries and soft environmental factors such as local culture. It is worth noting that these external influences are not sudden, major shocks but incremental transformational forces that play a role in the evolutionary process of the e-waste cluster, reflecting the dynamic process of the industrial cluster adapting to the external environment. Changes in policy have gradually altered the operational model of the industry, and technological advancements in related industries have slowly but continuously influenced the methods of e-waste reassembly, while cultural factors have had long-term effects on the organisational structure and operational modes within the cluster. Huaqiangbei's e-waste industry has been constantly adapting and upgrading, resulting in a diversified trajectory of evolution, denoted as α-r-k-k', α-r-k-α, α-r-r-α, and α-r-k-Ω, with some paths overlapping in time. This section will examine some of the key periods of transformation and adaptation.

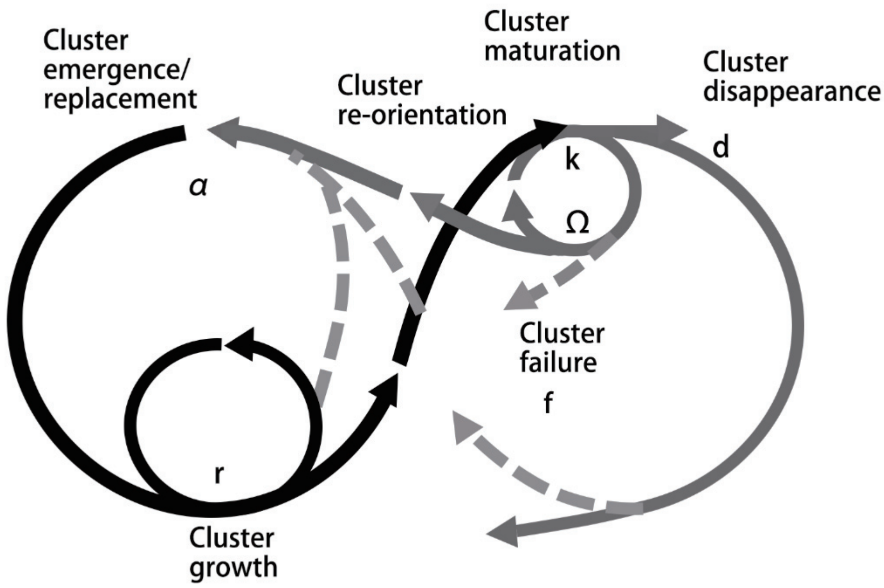

Figure 6.12 Huaqiangbei's e-waste industrial cluster evolutionary model (Source: Adapted from (Martin and Sunley, 2011a)

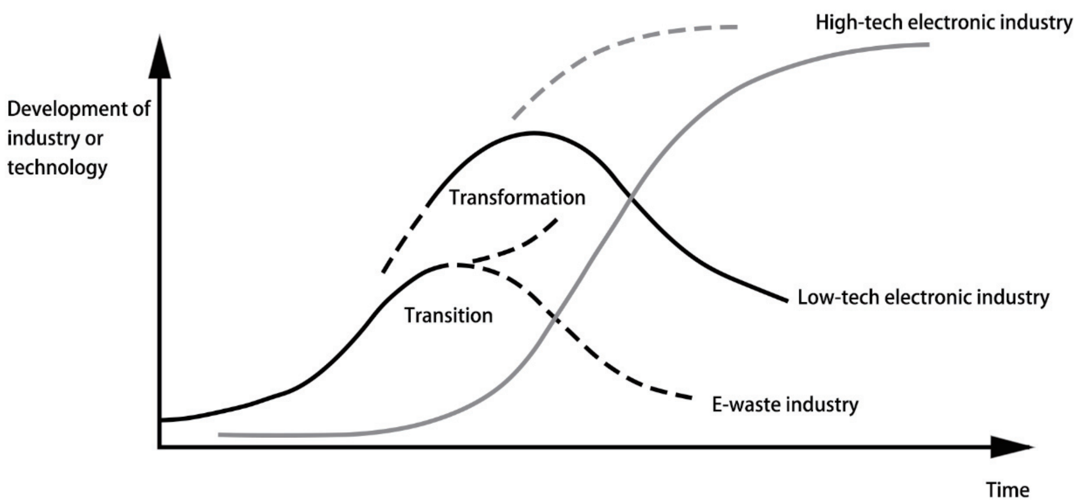

Figure 6.13 Phases of the e-waste industrial cluster in Huaqiangbei, Shenzhen (Source: Adapted from (Howarth, 2016)

6.3.1 Regulatory Changes

Huaqiangbei's e-waste industry is characterised by numerous illegal activities, including smuggling, intellectual property infringement and consumer deception. There are also potential risks in the source of goods, as e-waste in Huaqiangbei comes from user-initiated disposal and a significant number of stolen items. Due to its substantial profits, Huaqiangbei has long been dominated by the e-waste industry, primarily focused on phones, earning it the title of 'China's largest second-hand electronics centre'. This informal industry gradually attracted government attention, and from around 2010, government departments in Shenzhen, including the Market Supervision Administration and the Industrial and Commercial Bureau, began frequent inspections of the Shenzhen electronic market, aiming to formalise the industry. Slogans such as 'Combat theft, robbery and write-offs', 'Crackdown on illegal smuggling', and 'Strictly combat the sale of products that infringe on others' patents, trademarks, copyrights and other intellectual property rights' were everywhere in the markets (Figure 6.15).

Figure 6.14 Slogans in huaqiangbei electronic markets[25] (Author)

According to the General Administration of Customs, in March 2012, customs seized over 4,800 suspected smuggled mobile phones and tablets and more than ￥2 million in cash and froze bank accounts containing over ￥4 million (Li, 2012). Several top-rated secondhand iPhone sellers on Taobao,[26] including Lanyou Digital and Feifan Mobile, collectively posted notices that they were 'going on vacation'[27] (Qi, 2012). Under regulatory pressure, e-waste businesses had to temporarily cease commercial activities to avoid inspections. Nonetheless, they did not completely shut down and remained watchful, waiting to see if the intensity of the crackdown would ease or if there were other potential operating spaces (such as through bribery). In May

[25] Translates as: 'Protecting Intellectual Property Rights and Safeguarding Legitimate Rights and Interests'; 'Cracking down on counterfeiting and commercial fraud'.
[26] The biggest online shopping platform in China.
[27] Closing the shop.

2013, more than 500 customs anti-smuggling police and 180 border defence armed police formed 65 action groups to investigate and apprehend the targets of smuggling networks, sales outlets and warehouses. They successfully dismantled 43 private warehouses and stalls distributed in the Luohu, Futian, Huaqiangbei and Yantian residential areas of Shenzhen, confiscating suspected smuggled Samsung, Sony, and other brand phones, as well as a batch of high-end wines such as Lafite, and seizing a large amount of cash used for private trading. On-site investigations led to the identification of 105 suspects, with 66 criminally detained, 11 released on bail pending trial, and suspected smuggled phones valued at over ￥1 billion (Yang, 2013). From May to September 2017, Shenzhen police destroyed 37 centres selling stolen goods, detained 81 people and seized large amounts of stolen goods (Meng and Bi, 2017).

In 2022, Shenzhen launched a comprehensive industry-wide crackdown on smuggling and other illegal activities. This operation intensified efforts to combat illegally imported goods without legitimate sources, rigorously inspecting channels of procurement or express delivery items and dealing sternly with the sale of goods without legal import sources. All businesses were forced to provide formal procurement certificates, and the process was regarded as the most stringent measure of the last ten years (Wang and Wu, 2022). Many stores were forced to close temporarily, posting signs advertising subleases to avoid inspection. Some counters were empty, or contained only a few models scattered here and there, making it difficult to see the actual goods. Some large wholesalers frequently changed locations to avoid inspections, and stalls in the market were only responsible for quotation, billing and collection. Generally, they took customers to the warehouse to pick up the goods after negotiating a price. During the author's research period (2022), the Market Supervision Administration conducted inspections.

The government's management of Huaqiangbei's e-waste industry is a long-term process as the law is lagging behind industry developments, the economy is growing too quickly, and the emergence of many new products catches law enforcement units off guard. Meanwhile, the prevalence of the e-waste industry in Huaqiangbei is an economic phenomenon driven by the market and interests, which means that it is difficult to eradicate it thoroughly using only laws and regulations. When the government initially cracked down on the e-waste industry, the industry generally disapproved, and electronics markets often tipped off shops to avoid inspections. Many interviewees typically believed that the government at that time mainly punished visible and profitable cases to obtain revenues from fines. Some even believed that the government only took action when it needed to demonstrate its performance at a political level or pursue its performance indicators (KPIs). Interviewees (S37S) asserted that the government tends to let companies develop before shutting them down and only takes action after allowing profits to reach a certain level, paying less attention to the arrest of small traders.

6.3.1.1 The ‘α-r- r- r-…’ Evolutionary Path

The implementation of regulatory policies has had a significant impact on Huaqiangbei’s e-waste industry, precipitating profound structural transformations within the sector. This shift is particularly evident in discarded iPhone processing, propelling the industry chain towards a more specialised division of labour. During this transition, the number of comprehensive enterprises engaged in full-chain operations (smuggling, repair and sales) has decreased significantly and has been replaced by a more refined and delineated industry chain system. This transformation process underscores the importance of industrial adaptability. In the face of regulatory pressures, Huaqiangbei’s e-waste industry has demonstrated a strong capacity for self-adjustment and adaptability, thus maintaining its position at the vanguard of global e-waste recycling and utilisation.

A major penalty case in 2011 served as a pivotal catalyst for the transformation of Huaqiangbei’s e-waste industry. A company called Lanyou Digital took over the entire industrial chain for the iPhone, from procurement to refurbishment and sales, becoming one of China’s largest secondhand mobile phone sales companies in 2007. Lanyou Digital, headquartered in Shenzhen, primarily sold Apple’s iPhone and iPad products through nearly a hundred physical stores nationwide. Its supply mainly came from Shenzhen, with over 200 suppliers in Shenzhen’s Huaqiangbei district. In 2011, the company faced customs scrutiny for selling smuggled iPhones, iPads and other electronic products in excess of 100,000 units, with a case value exceeding ￥5 billion. Customs apprehended over 60 members of smuggling gangs and seized a large quantity of unsold iPhones and iPads. The company’s Taobao store was also shut down (Li, 2012).

Since then, Huaqiangbei’s e-waste industry has been characterised by a highly specialised division of labour. Each company focuses on a specific segment or task while remaining mutually independent from yet closely interlinked with other segments. As well as the vertical specialisation of functions, a horizontal division of labour exists based on relationship networks. To pursue greater profits, some entrepreneurs, upon accumulating sufficient capital and resources, recommended relatives and friends into the industry and assigned them to different segments. This practice not only promoted industrial diversification but also constructed an interdependent industry chain, maximising control over resources within the relationship networks, achieving maximum profits while minimising risks. As one respondent explained:

> *‘This industry has always operated in a grey area, not allowing any trace of light. Once an organisation wants to industrialise, it will inevitably disrupt the originally balanced*

'ecosystem' of the e-waste industry, and the government will inevitably shoot the leading bird, a headshot (S9N).'

In 2020, China's largest online shopping platform, Taobao, explicitly banned the sale of non-mainland versions of mobile phones. Subsequently, other e-commerce platforms, such as JD.com and Suning, also enacted restrictive regulations (Sun, 2022). This led e-waste manufacturers to turn to personal platforms like Douyin,[28] Xiaohongshu and Xianyu[29] to avoid dependence on fixed online stores. This transaction model does not rely on established online stores and requires no documentation; transactions can be conducted solely through personal accounts. This approach is more flexible and makes it easier to evade government supervision.

Despite regulatory constraints imposed on the e-waste industry, its high-profit margins and expansive market potential continue to attract participants to engage in sustained operations. As electronic products undergo iterative updates, the types of e-waste and associated processing technologies are also evolving constantly. This dynamic developmental process can be characterised by an evolutionary path represented as (α-r-r-r-…). The pattern reflects the constantly changing nature of the e-waste industry, driven by technological advancements and market demands.

6.3.1.2 The 'α-r-k-Ω' Evolutionary Path

As regulatory enforcement intensified and industry transparency increased, the e-waste industry experienced a decline in profit margins, driving numerous enterprises to undertake strategic transformations. These transitions demonstrated the characteristics of diversification and complexity, reflecting the adaptive responses of businesses to market changes. Primarily, a segment of enterprises pivoted towards the recycling of domestic brand mobile phones, striving to explore new market opportunities within a compliant framework. At the same time, other firms opted to enter the Apple accessories market, attempting to reposition themselves within the industry chain, while other businesses transitioned into the smuggling and counterfeiting of imported cosmetics. These operations shared similarities with the e-waste industry, leveraging price disparities across national borders and informal channels to generate profit. However, these emerging business models swiftly became the targets of government crackdowns, forcing the majority of participants to readjust their operational strategies or move into underground operations.

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[28] TikTok in China.
[29] A personal second-hand trading platform.

Shenzhen's proximity to Hong Kong and its well-established cross-border trade networks and smuggling operations provided enterprises with the capacity to identify and enter new markets rapidly. When faced with stringent regulations in one sector, businesses demonstrated the ability to pivot rapidly to alternative domains. For instance, during the author's research period, the imported and counterfeit snack food market was thriving, exemplifying this adaptive behaviour. This pattern of evolution can be characterised by an (α-r-k-Ω) pathway, and this evolutionary model reflects the adaptability and resilience conferred upon the industrial ecosystem by Shenzhen's specific market conditions and institutional environment. It not only demonstrates the flexible strategies of enterprises in the face of regulatory pressures but also highlights the complex interplay between government policies and market dynamics.

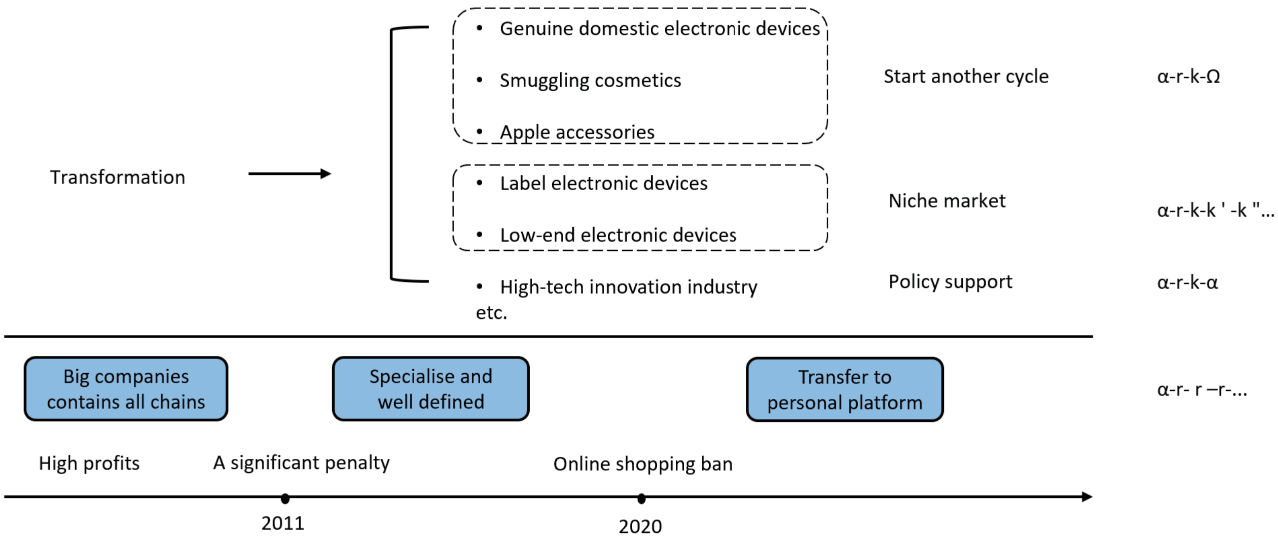

Figure 6.15 The adaptation process and the diversity of paths (Author)

6.3.2 Technology Shocks

The continuous adaptation and upgrading of Huaqiangbei's e-waste reassembly industry has benefited greatly from the influence of external technologies. Unlike Guiyu's traditional disassembly-based e-waste industry, Shenzhen's refurbishment and reassembly processes require substantial support from the electronic and information technology sector, necessitating consistent technological updates that align with product iterations and renewals. However, as mentioned above, the educational and cultural level of Huaqiangbei's initial e-waste workforce was relatively limited. Technological advances in the global electronics industry, particularly the modularisation of the Turnkey solution, significantly lowered the technical barriers to entry into the electronics industry, providing possibilities for the e-waste industry to move towards the electronics industry. Modular designs broke complex electronic systems down into relatively independent units, with each unit's functional logic being relatively simple and accessible to untrained operators. Meanwhile, the Turnkey solution integrated and standardised these modules into a unified solution, allowing system design and operation without the need for deep-rooted professional knowledge. These technological shifts effectively allowed Huaqiangbei's e-waste practitioners to acquire the necessary electronic and technical expertise, driving the industry's technological upgrading and adaptive transformation, presenting an α-r-k-k'-k"... evolutionary path.

The traditional production system for electronic products follows a vertically integrated model, encompassing chip design, software and system design, engineering development and production. Although later developments involved outsourcing aspects such as chip design, engineering development and production, the core software and system design production system remained, constituting a high-tech industry with a high entry threshold. New entrants struggled due to a lack of expertise. In the 1990s, some chip companies in Taiwan, imitating European and American chip companies, began outsourcing chips to electronic enterprises in mainland China. However, they found that many mainland enterprises lacked adequate software and system design capabilities, making it either impossible to design the chip or requiring a significant amount of time. In 2003, the Taiwanese company MediaTek (MTK) broke through the chip technology monopoly held by companies like Nokia and Motorola to introduce a single-chip mobile phone solution that included a communication baseband, Bluetooth, camera, touchscreen and other processes. MTK bundled the key components of the phone – chip, OS and application software – into a three-in-one packaged marketing solution (the Turnkey solution), which provided a simplified one-stop solution for phone manufacturers. This drastically lowered the technological threshold for mobile phone manufacturing, and with this semi-finished Turnkey solution, customers only needed to perform simple engineering development processes or even none at all. They could directly organise material procurement and production, significantly reducing the cost, time and risks of downstream manufacturers' technological development.

Typically, Turnkey solutions are more about standardisation and platformisation in terms of technology, particularly in software, allowing the shared use of technology. Public boards and loose moulds help to achieve the standardisation and platformisation of hardware and materials, enabling shared procurement and production. Based on the Turnkey solution, downstream manufacturers only need to customise and develop the motherboard according to final functional and appearance requirements, design moulds and add components such as batteries, shells and screens to mass-produce electronic products such as phones, MP3 players and Bluetooth speakers.

The emergence of the Turnkey solution in the electronics industry helped to promote the formation of Shenzhen's refined and modularised production model. Many specialised manufacturers of motherboards, moulds, casings, batteries and screens settled in Shenzhen, constructing a comprehensive industry chain that included design, component production, testing, assembly and recycling. This encouraged the formation of professional market clusters for various electronic products as well as a robust product distribution system, supporting all upstream and downstream processes as well as ancillary services, earning Shenzhen a reputation as the 'Silicon Valley of Hardware' and the 'World Capital of Hardware' (Economist, 2014). Shenzhen became the preferred base for many R&D teams, where teams could efficiently transform designs into products in the early stages of hardware development. One interviewee stated:

> *'We can rapidly acquire various component solutions here, with upstream suppliers in the vicinity. Moreover, Shenzhen's Huaqiangbei electronics market provides a window to global demand for electronic products (S6L).'*

In this area, based on just one idea, it was possible to procure all necessary components from the electronics market using a one-stop approach to realise hardware innovation. In subsequent production stages, Shenzhen was also able to complete product sampling, assembly, manufacturing and shipping efficiently, swiftly converting ideas into products. Canadian entrepreneur Jothesh, who participated in the HAX program in Shenzhen, said:

> *'In North America, three months is typically sufficient only for component sourcing and testing, but in Shenzhen, an entire project lifecycle can essentially be completed. Here, you can access the entire industry chain, find partners, and produce prototypes rapidly and inexpensively while preparing for large-scale production (Li, 2015).'*

This 'foolproof' production process has made electronic products analogous to assembling Lego blocks. In theory, with sufficient capital, even someone who is completely technologically illiterate can, with the help of three people (one responsible for purchasing the MediaTek solution, one to find an OEM factory, and one to handle sales and receipts), engage in the production and operation of smartphones. This simplified model significantly lowered the entry barrier for Huaqiangbei's e-waste industry to transition into the low-end electronics sector. As one interviewee said: 'After MTK's chip came out, basically, anyone could make a phone. You don't need to understand it; in fact, we don't ourselves (S6L).'

In 2003, with the rise of mobile phones, pagers gradually became obsolete. At that time, mobile phone 'number burning' technology had not yet been developed, so discarded mobile phones could only be dismantled and could not be refurbished for reuse. Driven by the stimulus of the Turnkey solution and the pursuit of profits, the Huaqiangbei e-waste industry experienced a significant wave of transformation towards the electronics industry, facilitated by simple production models and low technical barriers. In the 2000s, numerous small enterprises emerged producing low-end electronic products and components, with mobile phones being the most prominent. These products, characterised by their exaggerated designs, fragile intellectual property protections and use of Turnkey solution production methods, became known as *shanzhai* (counterfeit)[30] phones, another explanation for the sudden increase in mobile phones produced in Shenzhen (Qian, Lyu and Guo, 2021). This 'assembly' style of production came to be known as the *shanzhai* production system, and it is still used to produce many low-end electronic products in Shenzhen today, such as VR glasses, Bluetooth speakers and wireless headphones.

The essence of *shanzhai* lay in its ability to cater to the lower industrial technology levels of emerging countries and the lower consumption levels of emerging markets, thereby forming a specialised production system. The system was characterised by its accessibility, with relatively low financial and technical barriers, making it particularly suitable for e-waste enterprises that wanted to transition into this field. During the early 2000s, consumer and technological levels in China were generally low, with almost no domestic mobile phone manufacturers, and international brands such as Nokia and Motorola were prohibitively expensive for most Chinese consumers. In 1999, for example, when Nokia's global mobile phone sales reached 280 million units, there were only 700,000 mobile phones in China, where mobile phones were considered luxury items that were unaffordable for most people. The combination of a vast low-end consumer market, potential high profits and low technological barriers encouraged the large-scale transformation of the e-waste industry. According to reports, in 2008, Shenzhen's Huaqiang North district had more than 5,000 large cottage phone businesses (Dou, 2018). Interviewees mentioned:

> *'The cost of a shanzhai phone ranges from just over 100 to 400 yuan, while their prices range from 400 to 1000 yuan. The profit margin is high (S8C).'*

In recent years, Apple's smart wearable devices have caused a stir in the industry, with Apple Watches and AirPods experiencing phenomenal sales figures in the billions annually. The enormous consumer market has given rise to the Huaqiangbei 'white-label electronic device' grey industry chain. The term 'white-label' refers to unbranded counterfeit goods, the main advantages of which are low prices and a striking resemblance to AirPods. Compared to the

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[30] Clone/knockoff/copycat as an exact or almost exact replica of an original device, albeit with a different branding. A clone or knockoff is a copy of the design or function of an original device, sold as a clone copy, and fully disclosed as "not the original." An example of a clone/knockoff phone is a "Nokia" clone that was once produced with the name "Nokla." Also, a Chinese knock-off brand called HDC makes a phone that's a pure clone of One M8. (https://www.lemmymorgan.com/avoid-buying-fake-knockoff-phones/#:~:text=Furthermore%2C%20a%20clone%20or%20knockoff%20is%20a%20copy,phone%20that%E2%80%99s%20a%20pure%20clone%20of%20One%20M8.)

daunting prices of AirPods, white-label headphones priced between 50 and 200 yuan seem to better align with consumer expectations. Not only do they resemble AirPods in appearance, but white-label headphones produced in Shenzhen even manage to support functions such as 'name change positioning, pop-up connection and in-ear detection,' mirroring the standard features of Apple's AirPod Pro. Inexpensive and similar appearance and functionality to AirPods, these white-label headphones have become the industry's leading sales products. According to data from the Shanghai Securities Institute, in 2020, the shipment volume for white-label headphones reached 292 million units, accounting for a staggering 49% of shipments. In contrast, Apple AirPods had a shipment volume of 78 million units, accounting for 21% of shipments (Sun, 2022). Shenzhen's well-established electronic industry chain, coupled with the ongoing close relationship between the e-waste and the electronic industries, enables the relatively smooth realisation of industrial upgrades and transformations in the e-waste industry. However, constrained by the inadequate research and development capabilities of the e-waste industry itself, the transformation direction often leans towards niche markets in widespread mass-market consumption.

Figure 6.16 'White-label' iPhone and airpods[31] (Source: Interviewees and Taobao)

Due to its long-term presence in the low-end market, the e-waste cluster in Huaqiangbei retains a modest degree of resilience, remains stable and maintains its self-circulating model at the K-stage evolution path (α-r-k-k'-k''...) (Martin and Sunley, 2011a). Meanwhile, innovation centred around users facilitates interaction between user culture and technological innovation. Although manufacturers may not be able to compete with established technology companies in fundamental innovation, their proximity to consumers enables them to develop technologies that are tailored to consumers' daily use, stimulating everyday creativity. This is achieved by gaining a deeper understanding of mass contextual needs and lifestyle cultures and leveraging technological niches (Anderson, 2012). However, as the cluster belongs to a low-end

[31] The shopping platform Taobao lists genuine AirPods and the Shenzhen version at a price difference of nearly 10-fold, with the pirated version boasting that it is 'the official original one'.

technology sector, it possesses high requirements and depends on external information technology and internal information cooperation. The internal and external connections within the cluster are strong, and there is a high degree of flexibility. As the cluster continues to develop, the high and continually rising costs of the workforce, along with land, congestion, transaction costs and external shocks, result in a relatively weak system resilience, leaving the cluster potentially vulnerable to decline (Marshall, 1919). Consequently, industries are shifting towards lower-cost locations in their later stages of evolution. However, because of the vast size of the low-end market and its prolonged existence, the industry is expected to persist in the long term.

6.3.3 Policy Changes

Huaqiangbei's rapid transformation towards high-tech industries can be mainly attributed to strategic government support. While high-tech industries are characterised by high added value, they also face significant risks. Relying solely on spontaneous corporate behaviour is insufficient to generate appropriate economies of scale and establish a comprehensive industrial system. Consequently, state intervention has become crucial in accelerating local industrial transformation.

To break free from the constraints of a low-end industrial structure, the Shenzhen municipal government has used its macroeconomic regulatory role to its fullest extent. The government has formulated comprehensive development plans, industrial policies and investment guidelines to direct domestic and foreign investors towards Shenzhen's high-tech industries. Notably, it has proposed an industrial policy framework that positions 'high-tech enterprises as the vanguard, advanced manufacturing as the foundation, and modern service industries as the pillar' (Guangdong Provincial Party Committee, 2022). The policy explicitly calls for 'gradually replacing low-end industries to create space for high-end industries,' thereby promoting the development of high-tech industries (HQBMuseum, 2020). Meanwhile, the government has implemented wide-ranging policy deployment in areas such as talent recruitment, research support, financial investment, optimisation of the business environment and intellectual property protection (Li, 2020b).

Driven by these policies, Huaqiangbei's industrial structure has undergone significant changes. The low-end traditional e-waste dismantling industry has relocated almost entirely, retaining only the electronics refurbishment, reassembly and sales segments that are closely related to the electronics industry. These segments continuously upgrade their technology in tandem with electronic product innovations, fostering a positive interaction with the electronics industry. Meanwhile, high-tech industries led by the electronics and ICT sectors, along with their supporting industrial clusters, have rapidly emerged in Huaqiangbei to form a new industrial ecosystem.

Shenzhen regional governments have also actively attracted and cultivated the electronic innovation industry by establishing maker spaces and creating incubation bases. In 2017, the Shenzhen Futian District Government issued the ‘Huaqiangbei Innovation Development Action Plan (2017-2019)’, which comprehensively implemented the ‘1222 strategic initiative’: investing 1 billion yuan in special funds over three years to carry out ten major projects, creating more than 200,000 square meters of innovative industrial space, building more than 20 maker spaces, incubators and accelerators and cultivating more than 2,000 innovation and entrepreneurship teams (HQBMuseum, 2020). With the rise of global intelligent hardware and maker movements, Shenzhen has attracted global innovative capital through the efficient electronics supply and sales chains to become a concentrated space for innovation, which includes the Huaqiang International Maker Centre, the Seager Maker Space and the Futian District Artificial Intelligence City Innovation Centre. More than 100 international maker teams have successively settled in, transforming ideas into products, raising funds through global financing platforms and then returning to Shenzhen for industrialised production (HQBMuseum, 2020). In 2012, the world’s largest hardware incubator company, HAXLR8R, settled in Huaqiangbei, reflecting the recognition of its innovative environment. Some Shenzhen merchants have also attempted to use new business approaches, forming independent design and development teams and nurturing large projects such as DJI drones.

With policy support, the electronics industry has developed rapidly in Shenzhen, and its size continues to increase. With the support of relevant policies, the Huaqiangbei e-waste cluster has been able to bypass the lengthy exploration and resource accumulation process, promoting the adaptive restructuring and upgrading of the cluster and allowing it to enter a new potential development stage (α) relatively directly and quickly, forming an α-r-k-α evolutionary trajectory.

In summary, Shenzhen is a special case both in China and globally. Its rapid development has benefitted from centralised resources and policy support characteristic of an activist state, and its growth reflects the free operation of a market economy. According to Chiping Yuan, Director of the Hong Kong and Macao Economic Research Centre, Shenzhen has adopted a proactive rather than reactive approach to industrial upgrading by not waiting until an industry shows signs of decline or is on the verge of collapse to transition. Instead, it begins to prepare for upgrading and transition to new or substitute industries while the current industry is still thriving (Zhang, Tao and Zhang, 2019). Using the support and impetus of government policies, Huaqiangbei was able to transition from low-end to high-end innovative electronic industries. The forward-looking development path and decisive implementation measures accelerated the determination of the direction of growth of its industrial cluster and the accumulation of key resources, while the connections and interactions between the constituent parts within the system became more robust. Supported by the government, the industrial cluster developed a relatively strong ability to withstand external shocks and possessed a high level of adaptability and resilience (Martin et al., 2021). Even during the 2008 international financial crisis, which led to a worldwide economic recession, Shenzhen's local GDP still maintained a growth rate of 12.1% that year. In a setting of efficient government policy execution, the development path of its industrial cluster not only had a certain degree of predictability but also the potential for planning ahead.

6.4 Conclusion

This chapter presents a study of the Huaqiangbei e-waste industry cluster, highlighting its flexibility. The cluster has continued to evolve and upgrade and has exhibited a strong degree of adaptability. To explain this phenomenon, this chapter explores the development path of Huaqiangbei's e-waste industry, examining the incremental changes that have taken place over the years to explain how and why the cluster has maintained its adaptability. The case study shows that the emergence of Huaqiangbei's e-waste industry was an incidental outcome driven by policy incentives that coincided with China's economic reforms and global industrial shifts. The development of Shenzhen's electronic industry and the establishment of a full industrial chain provided substantial technological support to the e-waste industry, leading it down a reassembly-based recycling path that was distinctly different from Guiyu's.

By the mid-1990s, Huaqiangbei's e-waste industry had developed rapidly and formed a significant cluster, and Huaqiangbei was recognised as China's largest second-hand electronics market. During this phase, the types of e-waste reassembling in Shenzhen showed distinct temporal characteristics driven by economic interests. The types of e-waste changed to reflect the popularity of various electronic products, and the technological requirements for different products also varied, leading to continuous technological updates. These updates ranged from character transliteration and simplification technologies for pagers to the development of a Chinese version of the mobile phone system and 'number burning' technologies for mobile phones. Huaqiangbei then went on to include multiple technological advancements for iPhones, including jailbreaking, activation lock removal and SIM card grafting.

This study concludes that policy and technological shocks, as well as other incremental changes, have had a significant impact on the development trajectory of Huaqiangbei's e-waste industry. As China's first Special Economic Zone and a testing ground for the country's transition from a planned economy to a market economy, Shenzhen has received a great deal of policy support from the state to facilitate its industrial development, leading to the formation of a full electronics industry chain. The advancement of electronic industry technologies, particularly the emergence of the ‘modular’ production mode, has significantly lowered the entry barrier for the electronics industry, promoting the technological upgrading and transformation of Huaqiangbei’s e-waste industry. However, this e-waste industry has included numerous illegal operations, prompting the state to introduce relevant policies to regulate and manage it. In response to this, the market began to transform, moving to domestic electronic brands or shifting their business focus towards low-end electronics to target niche markets, while local government implemented relevant policies and provided financial support to facilitate the transformation and upgrading of the industry. Driven by the strong impetus of government policies and influenced by the electronics industry, Huaqiangbei’s e-waste cluster was able to bypass the lengthy process of exploration and resource accumulation, avoiding a prolonged period of decline and release, and rapidly achieved industrial upgrading and transformation. Meanwhile, the e-waste cluster maintained strong levels of adaptability and resilience, effectively withstanding external environmental changes and shocks.

Industrial clusters do not exist in isolation; their evolutionary paths are influenced not only by other clusters within the same industry and external competitive environments but also by the activities of other firms within the cluster, which shape the competitive landscape of the entire industry (de Haan, 2006). As a representative of a multi-industry cluster, Huaqiangbei’s e-waste and electronics sectors have influenced each other, jointly constructing a specialised and diversified linked industrial cluster. The electronics industry provided the e-waste industry with products, information, and technological resources, enabling the latter to adjust its development path promptly according to market demands, thereby avoiding lock-in. Simultaneously, the enormous profit-driven power of the e-waste industry has prompted many electronics companies to address and meet the needs, promoting the development of relevant technological fields within the electronics industry and the improvement of their industrial chain.

This study also suggests that policies can have different impacts on the development of industrial clusters, potentially generating either negative or positive stimuli. Long-term regional resilience and adaptability require universally applicable top-down policy support and assistance that is grounded in local contexts (Hu and Hassink, 2017). Meanwhile, it is crucial to tailor policies to local circumstances, relying on effective and proactive local decision-making and implementation to coordinate adaptability and adaptation (Martin et al., 2021). The high level of adaptability of Shenzhen’s industrial clusters has resulted from the collective operation of various spatially targeted and place-based policies. This case study validates Martin et al.’s (2021) perspective on policies, which asserts that successful policies must consider specific local resources and their development potential while setting up long-term vision and planning as well as proactive capabilities for local execution.

Meanwhile, based on the theoretical framework of the adaptive cycle, this study also examined interaction and mutual influences between the electronics industry and the e-waste industry cluster at different stages of the cluster's development. Compared to the upgrading and transformation of a single-industry cluster, the exchanges and interactions between different industries – especially related industries within a multi-industry cluster – are more conducive to facilitating rapid industrial transformation and upgrading, thereby improving the cluster's adaptive resilience, providing multiple development path choices and avoiding path lock-in. Through an empirical approach, this study has validated the positive effects of related industries on cluster development by exploring the short- and long-term impacts of disruptive technological changes, thus compensating for the shortcomings of traditional quantitative research in this regard (Bathelt and Storper, 2022), although the variety described here is limited to e-waste, consumer electronics and ICT. The study also incorporated a dynamic perspective in its analysis, investigating how related industries interact during different developmental stages. To a certain extent, this addresses the critical observation of evolutionary economic geography that the study of related industry lacks a dynamic perspective in existing research and does not, therefore, provide sufficient detail on how the concept of relatedness itself changes over time (Juhász, Broekel and Boschma, 2021; Kuusk and Martynovich, 2021).

Chapter 7 Lock-in or Upgrading: A Comparative Analysis of the Guiyu and Shenzhen E-waste Clusters

This chapter provides a comparative analysis of the empirical evidence derived from the case studies, thereby addressing the demand for enhanced comparative assessment in the realm of EEG research (Boschma and Frenken, 2006; Gertler, 2010; Coe, 2011). By comparing the disparate trajectories of industrial evolution in response to external shocks between the two case studies, qualified and cross-referenced analytical observations can be drawn from the empirical evidence. The different trajectories unfolded within distinct regional contexts, navigating space and time while adopting divergent developmental pathways (Pike et al., 2016). This chapter explores the reasons for the divergent development trajectories of the e-waste industries in Guiyu and Huaqiangbei, one of which was characterised by lock-in and the other by upgrading. The research emphasises the influence of knowledge and technological networks on the creation and upgrading of industrial paths. Guiyu, as a mono-industrial cluster specialising in e-waste disassembly, developed low transaction costs based on the close and stable connections between its industrial sectors, but it was susceptible to constraint by existing technological trajectories, leading to ‘functional lock-in’ and ‘cognitive lock-in’ (Grabher, 1993). In contrast, as a multi-industry city with e-waste reassembly close to other sectors, Shenzhen facilitated information and technology exchange between different institutions, improving its understanding of regional industrial complementarity and facilitating the transition of industries towards more promising markets, thereby achieving industrial upgrading (Grabher, 1993).

Given the comparative nature of this chapter, it is necessary to consider the role of regional sociocultural and institutional environments when examining the industrial development paths of each case study. Guiyu’s relatively conservative ideologies and social relationships resulted in tightly-knit and strict inter-enterprise connections, whereas Shenzhen’s inclusive and diverse urban culture resulted in a more loosely connected system (Grabher, 1993). This chapter will also discuss the ways in which institutional environments and the regulatory capabilities of local governments promote or constrain path creation and upgrading (Dawley et al., 2015). The comparative methodology employed here adopts the perspective of EEG, which suggests that path evolution is a continuous process of change and continuity (Martin, 2010; Steen, 2016; Evenhuis, 2017). The struggle between continuity and change can generate different causal events within the period of path creation itself, identifying a more contingent, open and intermittent process (Martin, 2010). Traditionally, EEG has focused on gradual and incremental changes within industries, often overlooking the impacts of shocks and disruptions. This study addresses this gap by examining the role of shocks and disruptions in industrial evolution, thus providing a more comprehensive understanding of the evolutionary dynamics within industrial systems.

This chapter begins by examining cluster adaptability from the perspective of functional and structural assets and relationships. Although businesses in both study regions primarily take the form of small family workshops, significant differences exist in terms of cluster diversity composition (Guiyu's specialised industry cluster versus Shenzhen's diversified industry cluster), business environment, and network characteristics. This section will first conduct an in-depth exploration of the industrial structure and related variety of the two clusters. By investigating these aspects, we can examine their economic environments and external relationships, which play a crucial role in identifying and mobilising external resources (Aldrich, 2008). Building on this foundation, this section also reviews the innovation type orientations of the two clusters (product innovation or process innovation), aiming to reveal the structural characteristics of knowledge networks within the clusters. Additionally, this section discusses networks and collaborative relationships, with an analysis of how loose networks and tight networks influence cluster development pathways.

The second section of the chapter explores whether these two clusters exhibit or have overcome cognitive lock-in from the perspective of agency and cognition of key actors within the clusters. This part first focuses on the crucial role of entrepreneurial agency in shaping cluster development pathways, including an examination of industrial atmospheres and entrepreneurial ecosystems. The research emphasises the influence of socio-cultural environments and the varying degrees of support for entrepreneurial activities across different clusters on industrial agglomeration. Next, this section discusses the impact of collective cognition on how clusters respond to change. Group thinking and worldviews are important factors in explaining the common orientations and choices of clusters, which affect both the perception of innovative opportunities and the selection of future pathways. Finally, this section addresses workers' methods of learning and technology acquisition, analysing the characteristics and effectiveness of different learning models—whether based on 'learning by doing' and observing others through practical learning, or through more formal educational participation and knowledge spillover mechanisms. Through these analyses, this section reveals how clusters achieve self-renewal and path creation through effective learning.The final section examines the impact of policies on the development paths of the two industrial clusters. Policies serve as a double-edged sword, as they can provide support for cluster development, such as infrastructure development and financial assistance, but they can also foster symbiotic relationships between industries, leading to political lock-in (Friedman, 1977).

This section explores the relationship between local government resources and decision quality, as well as targeted interventions by the national government in the development of clusters.

7.1 Functional and Structural Assets and Relationships

A cluster refers to the geographical concentration of various interconnected enterprises and institutions operating in specific domains (Porter, 1998a). This means that factors such as the specialisation level of enterprises, inter-firm network connections and stable relationships are crucial for clusters to overcome negative lock-ins and to adjust industrial strategies in a timely manner to cope with external shocks. The e-waste industry clusters in Guiyu and Huaqiangbei appeared similar during their early growth in the 1980s, but Guiyu has since fallen into functional lock-in, while Shenzhen has shown little or no sign of such a trend. This section will examine the reasons for this.

7.1.1 Specialisation and Diversity

The discussion on whether specialisation or diversification is more conducive to long-term regional development has long existed in regional development research (Duranton and Puga, 2004; Bathelt and Storper, 2022), and numerous scholars have explored the impact of diversity on regional development. Frenken, Van Oort and Verburg (2007) argue that regional economies with high related variety experience more economic growth, providing a crucial foundation for regional economic development and a decisive factor in determining current and future development paths (Martin and Sunley, 2006; Henning, 2019). However, related variety differs from wider diversification, as it represents a specific form of internal diversified specialisation or related diversification (Frenken, Van Oort and Verburg, 2007). Bathelt and Storper (2022), however, contend that regression analysis and other models cannot clearly explain whether relatedness leads to the emergence of relationships between firms, within labour markets or among regional innovation systems and cannot clarify the nature of these relationships in terms of whether they are direct or indirect, transactional or non-transactional. Empirical research is needed to determine specific mechanisms and validate them.

The e-waste clusters in Guiyu and Huaqiangbei have diverged, with the former developing into a single dominant industry cluster (the e-waste dismantling cluster) and the latter exhibiting a pattern of multi-industry-related clustering. The e-waste industry in Huaqiangbei is closely associated with the local electronics industry, with the closest ties in technology and associated products. Responding to Bathelt and Storper’s (2022) call for case studies on related variety in industries, this research offers a comparative analysis of Guiyu and Huaqiangbei’s distinctly different development paths as e-waste industrial clusters to examine the impact of related variety and specialisation on the development trajectories of industrial clusters.

The e-waste cluster in Guiyu was always highly specialised and dominated by a single industry. According to official statistics, during its prosperous period, the e-waste industry accounted for over 90% of the town's total industrial output value (Shantou Chaoyang District People's Government, 2010). Guiyu was historically impoverished, and the e-waste industry was initially perceived by the local population as the only option to generate profits with minimal basic technical or educational skills. Compared to other industries, the e-waste industry offered substantial profits from low levels of investment, and this soon deterred locals from transitioning to other industries. Focusing on a singular industry enabled the local population to rapidly accumulate skills, despite their relatively low education levels, and a complete e-waste dismantling industrial chain was formed. Close collaboration within the industry improved efficiency and enhanced flexibility while reducing production and transaction costs, strengthening competitiveness in the global e-waste market (Martin and Sunley, 2011a). Guiyu became one of the world's largest e-waste dismantling clusters, and locals amassed considerable wealth from the industry, earning the town a reputation for prosperity.

These single-industry relationships facilitated the acquisition of technology and resources in Guiyu's hitherto underdeveloped region, as the advantages brought about by economies of scale be attained could only be achieved through agglomeration. Before any external policy shocks, Guiyu's e-waste industry cluster maintained a relatively favourable development status. However, the dominance of a single industry exposed the local area to the risks of lock-in and a lack of alternatives, resulting in low cluster resilience and an inability to withstand external shocks (Bathelt and Storper, 2022). However, this study concurs with Chinitz's (1961) view that the focus should not solely be on the degree of regional specialisation but rather on the form of the specialisation itself. This study argues that it was not the single industry *per se* that caused Guiyu's e-waste cluster lock-in; instead, it was factors such as its lack of outward orientation, its close network relationships, low-end and rudimentary levels of technology and low levels of labour education that mostly prevented the industry from breaking through the lock-in and achieving technological upgrading and transformation. In contrast, the nearby Huaqiangbei updated its technology and products continuously, moving towards the e-waste reassembly industry. The following sections explore these cultural, economic and political factors.

Shenzhen and Guiyu offer a striking contrast in their industrial structures. Guiyu is characterised by a single dominant industrial cluster, while Shenzhen boasts a more diversified industrial cluster structure that includes electronics and information, e-waste, biopharmaceuticals and modern logistics to form a complex, interrelated and mutually supportive industrial network. Within this diversified industrial structure, there is a particularly close connection between the electronics and the e-waste industries, which serves as the core focus of this study. The multi-industry model provided Huaqiangbei's e-waste processing sector with a much broader range of information resources, as well as advanced technologies and diverse processing options. The diversity and complexity within Shenzhen's industrial ecosystem created favourable conditions for the upgrading and transformation of its e-waste industry, enabling it to make a qualitative leap from simple e-waste disassembly to reassembly. The technological revolution in the electronics industry generated new standards and common technologies, forming a pool of knowledge that could be shared among different industrial enterprises and providing a unique and codifiable communication language among industry players (Grabher, 1993). The e-waste industry benefited from this knowledge spillover, which facilitated the expansion and strengthening of the industry. Furthermore, when launching new products, companies in the electronics industry often disclose relevant technical standards and system interfaces to suppliers for joint research and development. These open collaborative practices lower the barriers of entry into the electronics and technology sectors, promoting the upgrade and transformation of the e-waste industry.

In contrast to the Guiyu cluster, which accepted all types of e-waste, the e-waste reassembling industry in Shenzhen focused on specific types of products. The changes in its product types closely followed trends in the electronics industry, exhibiting distinct stage characteristics, such as pagers in the 1990s, mobile phones in the 2000s, and iPhones during the 2010s. The emergence of the electronic company MTK's 'one-stop solution' provided technical support for e-waste entrepreneurs with relatively high capital accumulation who wanted to transition to producing low-end electronic products. To summarise, the development of Huaqiangbei's e-waste industry has always been closely related to technological progress and product updates in the local electronics industry, which exhibited prominent dynamic characteristics of change. The result was the gradual formation of a relatively complete industrial chain from recycling, dismantling, component refurbishment, and professional reprogramming to packaging and sales, making Shenzhen a renowned collection point for the reuse of obsolete iPhones domestically and globally.

7.1.2 Networks and Collaborations

As Chapter 5 discussed, Guiyu's close internal network has resulted in all of its businesses being locked into specific transactional relationships. Throughout the development of Guiyu's e-waste industry, strong personal connections have replaced suppliers' marketing activities, with many transactions confined to clans or local areas, rendering companies in the network as 'tightly coupled'. Due to the convenience of transactions, those involved rarely need to understand other aspects, which means that they rely heavily on upstream and downstream suppliers, resulting in a 'dependent supplier syndrome'. As discussed in Chapter 5, Guiyu's e-waste industry functions like a large-scale assembly line with a distinct regional division of labour. Each village or family workshop specialises in a particular stage of e-waste dismantling. Because of the maturity of the industrial chain, workshops rarely understand or participate in operations beyond their specific stages, but this means that any disruption or control exerted on upstream or downstream suppliers could severely jeopardise the entire industry's production. This aligns with Grabher's (1993) assertion that the survival of such partners is imperilled once cooperative relationships are severed.

Consequently, when Guiyu found itself facing environmental issues, and the government imposed strict controls on the sources of e-waste, the entire industry suffered, leading to a rapid decline. Only a small number of individuals who knew about acquiring and smuggling e-waste were able to shift their businesses to remote areas in Vietnam, Cambodia or other regions in China with more flexible environmental policies. Meanwhile, most workers were forced to remain idle at home. Many interviewees indicated that they only understood their own responsibilities and knew little about other aspects, making it difficult for them to leave Guiyu's e-waste industry chain and conduct business elsewhere, producing a severe functional lock-in.

In contrast to Guiyu, enterprises in Shenzhen showed the characteristics of loose coupling within the network, maintaining relative independence while remaining interconnected. Firstly, Shenzhen boasted a diversified industrial structure. Benefiting from an open and inclusive business environment and favourable economic policies, many domestic and foreign enterprises and investors came to Shenzhen, creating a diversified industrial system. This diversity and richness provided a wider range of choices for enterprises in Huaqiangbei's e-waste industry, eliminating the need for them to be bound to specific relationships and collaborations. The connections and collaborations between enterprises were more flexible, and if certain cooperative relationships were disrupted for some reason, multiple alternatives were still available. According to my interviewees, practitioners in the Huaqiangbei e-waste industry had considerable autonomy in selecting business partners. Although they typically prioritised familiar supply chains, profit maximisation remained their highest principle, so they avoided excessive reliance on any single partner and adjusted their collaborations dynamically based on tangible factors such as product quality and pricing. In other words, their partnership decisions were driven entirely by economic interests, and they collaborated with whoever offered the most favourable conditions. This flexible and pragmatic business strategy reduced their dependence on specific partners, enabling them to maximise profits while maintaining resilience.

According to Weick (1976), loosely coupled systems can retain a form of ‘cultural insurance’ to be utilised during significant changes. This meant that when facing external shocks, the e-waste industry in Shenzhen demonstrated greater resilience, while the cluster in Guiyu, due to its tightly coupled network, became locked and remained in a state of lock-in when confronted with regulatory shocks.

7.1.3 Types of Innovation

Innovation patterns serve as a crucial perspective for understanding the connections between clusters and the external world. In the development process of industrial clusters, the choice of innovation type reflects the depth and breadth of interaction between clusters and their external environment. Product innovation typically requires more extensive and profound external connections. It demands that cluster enterprises actively acquire external market information, engage with diverse knowledge sources, and interact with different institutional environments. This type of innovation often relies on the diversified ‘global pipelines’ established between clusters and the outside world. Through these channels, clusters can access key information such as cutting-edge technological trends, changes in consumer preferences, and emerging market opportunities. Product innovation-oriented clusters tend to develop more open network structures, enabling them to rapidly absorb external knowledge and transform it into innovative outcomes. In contrast, process innovation exhibits more inward-looking and conservative characteristics. It primarily focuses on optimising existing production methods, improving efficiency, and reducing costs, typically based on specialized knowledge and experience accumulated within the cluster. Process innovation relies more heavily on ‘local buzz’ within the cluster—that is, incremental improvements achieved through localised knowledge exchange and learning networks. While this type of innovation can enhance cluster competitiveness in the short term, excessive dependence on internal knowledge cycles while neglecting external connections may lead to cognitive lock-in and path dependency in the long run.

Although both dealt with e-waste, the clusters in Shenzhen and Guiyu took completely different industrial directions; one was limited to disassembly, while the other focused on reassembly. The e-waste industry in Guiyu is labour-intensive, with relatively low technological requirements and limited innovation, primarily concentrating on improving operational processes such as upgrading coal-fired furnaces to electric furnaces. In contrast, the e-waste reassembly industry in Shenzhen puts greater emphasis on the research and development of the products themselves. As Bianhi (1990) points out, improving production processes without product development potentially threatens a region’s adaptability, and because of the stable profitability of Guiyu’s e-waste industry, its development continued to rely on the global generation of e-waste and the market in metals. It was, therefore, considered unnecessary to possess a great deal of self-awareness, and this resulted in minimal technological innovation and improvement. Guiyu boasts an abundant labour force with relatively low wage levels, but the advantage of inexpensive labour has, to some extent, impeded the mechanisation process of the local e-waste dismantling industry, meaning that this industry in Guiyu has remained mired in a labour-intensive traditional production mode, and has failed to achieve upgrading. The pyramid model (Figure 7.4) shows the relative importance of each part of the e-waste sector.

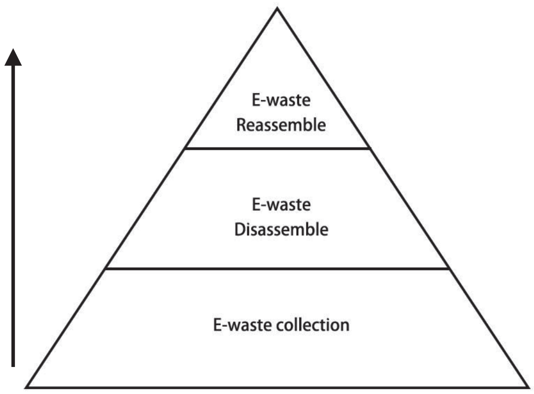

Figure 7.1 E-waste recycling pyramid model (Author)

In Guiyu, the local population generally had a low level of education and weak awareness of technology and innovation, and they simply imitated operational processes in e-waste collection and dismantling. More importantly, because of the rapid development and comparative stability of the industry, Guiyu residents fell into a mentality of 'easy money' and 'unrivalled superiority'. Almost every interviewee mentioned that Guiyu's e-waste dismantling process was world-leading. However, in reality, Guiyu relied on loopholes in policies and the rapid growth of global e-waste, sacrificing the environment to create immense wealth using primitive dismantling techniques. This was a dividend of the times rather than a testament to Guiyu's technological prowess. The cluster formed a tightly integrated production model supported by a closely-knit clan system, reflecting a perfect adaptation to the specific local economic environment. However, this adaptation weakened the region's adaptability, ultimately resulting in the internal system reaching 'pathological stability' and losing the ability to restructure internally to cope with unpredictable changes (Grabher, 1993). Faced with the long-term and significant inducement of wealth, the cluster was reluctant to break the existing balance and accept new ideas and new technologies, ultimately falling into a cognitive lock-in. A more detailed account of this will be provided in the second section.

Compared to Guiyu, innovation in Shenzhen primarily manifested in product and technological advances. Huaqiangbei's e-waste industry was mainly involved in refurbishing and reassembling e-waste, which necessitated a keen awareness of market demands and the latest products, technologies and related software systems and standards. This kind of user-producer interaction stimulates innovation (Lundvall, Dosi and Freeman, 1988). As described in Chapter 6, Huaqiangbei's e-waste industry adjusts itself based on the updating of electronic products such as pagers, mobile phones and iPhones, and incorporates advances in technology. This necessitates a flexible network to capture information effectively, and as products continued to evolve, Huaqiangbei's e-waste industry was forced to stay abreast of technological advances so that it could adapt to new products. The development of Huaqiangbei's e-waste industry depends largely on information differentials such as time and information gaps between products and technologies entering Shenzhen from abroad before disseminating to the mainland. Consequently, Shenzhen was compelled to update its technology at the fastest possible rate in order to maintain a competitive edge. The development of Shenzhen's electronic industry was closely intertwined with technological advances in the e-waste industry, resulting in a significant overlap between the two sectors and frequent exchanges. Shenzhen's electronic industry provided substantial technical support for the e-waste industry, while the development of the e-waste industry propelled advances in the electronics sector. The nature of the industry necessitated continuous innovation in Huaqiangbei's e-waste industry to avoid falling into lock-in.

7.2 Agency and Cognition

7.2.1 Industrial Atmospheres and Entrepreneurial Ecosystems

The concept of Industrial Atmospheres can be traced back to Alfred Marshall. In his 'Principles of Economics' published in 1890, Marshall described 'knowledge in the air' in industrial districts, emphasising the importance of intangible socio-cultural environments within specific geographical areas for industrial agglomeration (Marshall, 1890). This atmosphere encompasses shared values, behavioural norms, specialised knowledge, and skills that accumulate and persist in specific regions through interpersonal interactions and intergenerational transmission. Entrepreneurial Ecosystems refer to interconnected networks of elements supporting entrepreneurial activities within specific geographical areas, including entrepreneurs, investors, incubators, universities, government agencies, as well as supportive cultural and institutional environments (Isenberg, 2010).

Industrial atmospheres and entrepreneurial ecosystems play crucial roles in the lifecycle of industrial clusters. During the cluster formation stage, existing industrial atmospheres may attract related businesses, while the emergence of startups strengthens the entrepreneurial ecosystem. Boschma and Frenken (2011)'s theory of related variety suggests that cognitive proximity between existing industrial foundations and emerging industries facilitates knowledge spillovers and branching evolution, a process requiring both suitable industrial atmospheres and supportive entrepreneurial ecosystems. In the cluster growth stage, industrial atmospheres facilitate the dissemination of tacit knowledge and informal cooperation between enterprises, while entrepreneurial ecosystems provide new vitality and sources of innovation for clusters. Martin and Sunley (2006) point out that the path evolution of industrial clusters is profoundly influenced by local environments, with industrial atmospheres and entrepreneurial ecosystems constituting important components of this environment. In the mature and potential decline stages of clusters, industrial atmospheres may lead to path lock-in and cognitive rigidity, while active entrepreneurial ecosystems contribute to the renewal and transformation of industrial clusters. Hassink (2010) indicates that regional industrial resilience largely depends on the ability to respond to external shocks, a capability closely related to regional industrial atmospheres and entrepreneurial ecosystems.

During their long-term development, the e-waste industries in both Guiyu and Huaqiangbei established close and stable inter-firm connections, the stability and mutual adaptability of which effectively reduced transaction costs, leading to the formation of complete industrial chains within both clusters. Through information and technology exchanges between firms, as well as understanding the technologies and products of relevant enterprises within the clusters, the need for autonomous long-term research and development to develop new products was significantly reduced and, in some cases, even relinquished. This situation was similar to findings from studies on the coal industry in the Ruhr area of Germany (Grabher, 1993). However, during the development process, Guiyu's exclusive culture fostered close regional relationships, locking its e-waste industry into transactions within clans and specific networks of personal relationships. This led to significant shortcomings in boundary-spanning functions, ultimately resulting in path lock-in and cognitive lock-in. In contrast, Shenzhen's culture of openness and inclusivity prevented such lock-ins.

Guiyu has always been an isolated town, receiving little attention in the political and economic realms and historically remaining severely impoverished. The e-waste industry became one of the few industrial choices for the people of Guiyu, resulting in a protectionist stance towards industries that could generate local wealth. Influenced by local clan culture (see Appendix G), Guiyu developed close regional relationships and fostered an intense atmosphere of commercial exclusivity. Guiyu's e-waste industry model reflected a 'courtyard economy', in which all components of the industrial chain are gathered in an enclosed space, and all processes are completed within this space, making it difficult for outsiders to enter. Tight networks facilitated rapid entry into the industry and erected a barrier that prevented outsiders from accessing information and engaging in the e-waste industry, thereby protecting Guiyu against external competition. Due to this mentality of exclusion, external capital investments were rare, resulting in Guiyu's e-waste industry becoming stuck in a development trap, lacking the ability and funds for industrial upgrades or technological research and development.

In contrast to Guiyu's e-waste industry, the business environment in Shenzhen is extremely open and inclusive. As one of Asia's largest electronic product distribution centres, Shenzhen attracts suppliers and customers from all over the world. Its electronic manufacturers frequently participate in international exhibitions, actively expanding their overseas markets, and local entrepreneurs often get together to exchange information. Interviewees told me that they like to have tea together and discuss the latest information, technology and development prospects, as well as cooperation and integration of resources. All interviewees noted that business professionals in Shenzhen are generally willing to share, especially those from overseas customers or entrepreneurial groups:

> *'They are willing to share their technologies and ideas and provide suggestions for products. They will introduce you to the situations in other countries to make the products more in line with international demands (S25D).'*

Shenzhen has a broad and liberal trading network, which enables it to avoid issues related to cognitive lock-in. Many interviewees said they chose Shenzhen because of its superior business environment. In 2023, Shenzhen was recognised as the 'Best Business Environment City in China', marking the fourth consecutive year in which the city received this award (China Centre for the Promotion of Small and Medium Enterprises, 2023). Shenzhen vigorously promotes its entrepreneurial spirit by providing policy and capital support and by pioneering the 'One-metre Counter' business model. This model refers to the subdivision of small stalls into one-metre counters within markets, allowing the independent processing of property rights, enabling small businesses to serve as basic operational units for registering companies, qualifying as small-scale taxpayers and even issuing VAT invoices.

Figure 7.2 ‘One-metre Counter’, also referred to as ‘The shop of future billionaires’ [32] (Author)

For example, in 1998, Huaqiangbei Electronics World, with a floor area of 43,000 square meters, was divided into more than 2,800 counters (HQBMuseum, 2020). Each counter and sales area, with an average size of only 10 square meters, was allowed to obtain independent property rights, effectively lowering the barrier to entrepreneurship and giving everyone the opportunity to become business owners. This is where Huaqiangbei’s e-waste reassembly industry originated. Many interviewees stated that their dreams about Shenzhen initially began in these areas of only 10 or so square meters. People left their hometowns to work at these counters, learning electronic product repair and reassembly skills. With the accumulation of technology, capital, supply sources and customer bases, they began to rent their own counters to start their businesses and gradually expanded from that point. Some transitioned to related electronic industries, while others developed their businesses in e-waste reassembly, establishing branch companies or expanding their operations to other cities. Many well-known enterprises have emerged from these small counters, including listed companies such as Da Zuchun Laser, Shenzhou Computers, Meilong Electronics, and the process produced more than 50 multimillionaires (HQBMuseum, 2020). Under this model, Shenzhen has continually introduced shared office spaces to address the high office costs entrepreneurial enterprises face. These spaces also serve as an alternative location for many e-waste reassembling operations.

Shenzhen’s investment environment was always very active and highly diverse, providing convenience for entrepreneurship. As well as traditional public offerings, investment banking and government capital, Shenzhen possesses abundant private equity and capital. Compared

[32] Each one-meter counter is a separate company.

to public offerings and investment banking, private capital is often more efficient, has relatively lower thresholds, and is more willing to provide opportunities for emerging innovations. The investment coverage in Shenzhen was, therefore, extensive. Large-scale, high-tech innovations and technologies were able to obtain investments from readily available capital, such as public offerings, investment banking and government funds, while small-scale start-up ventures and small businesses received substantial support from private capital. According to interviewees, many excellent ideas remain undeveloped due to a lack of early-stage capital, but Shenzhen's investment environment provided entrepreneurs with opportunities to get started and grow their businesses.

Figure 7.3 Shared office spaces, each room is a company (Source: Red Book Social Media)

While the e-waste industry has limited opportunities for direct investment in innovation, a favourable investment environment facilitated the entry of new and innovative resources into related industries, particularly the electronics industry. These resources created by the electronics industry provided the potential for technological support in the e-waste reassembly industry in Huaqiangbei, and the emergence of new projects and products also presented opportunities for the transformation of e-waste reassembly. Around 2014, some e-waste reassembly companies began shifting their focus towards manufacturing and selling low-end electronic products, such as virtual reality (VR) devices, low-end drones, and Wireless headphones. Shenzhen's high-quality business environment, open industrial information network and cross-border multi-party cooperation endowed it with a higher degree of flexibility and adaptability, thereby avoiding the issue of cognitive lock-in.

Figure 7.4 Products from electronics factories that transformed from e-waste industries: VR, counterfeit Apple watch, computer with projection function and Bluetooth audio (Author)

7.2.2 Culture Context and Groupthink

Evolutionary economic geography emphasises the influence of history on pathways, which essentially includes cultural background, specific worldviews and groupthink during the development process (Boschma and Martin, 2007). A specific worldview can be shaped within a particular socio-economic and cultural environment, exhibiting uniqueness, with different regions having distinct worldviews. This worldview determines the phenomena that people perceive and choose to focus on, as well as the phenomena they overlook (Grabher, 1993). During the early stages of China's post-revolutionary development, Guiyu and Shenzhen were both impoverished agricultural towns in the southern region of the country. However, as development progressed, their social, cultural and economic backgrounds diverged significantly, resulting in vastly different environments of industrial development. Guiyu's conservative, stable and exclusionary 'smallholder mentality' [33] contrasted with Huaqiangbei's advanced, competitive and inclusive entrepreneurial mindset. This contrast led to Guiyu

[33] *Xiaonong yishi,* 小农意识 in Chinese.

becoming cognitively locked in the development of the e-waste industry while Shenzhen continued to maintain rapid growth.

Because of its strong clan relationships, Guiyu developed a unique worldview and form of groupthink, which determined its orientations in terms of industry and technology choices, as well as how it responded to structural changes resulting from external shocks after falling into cognitive lock-in. The smallholder mentality was a prominent characteristic of Guiyu and was characterised by a complex socio-psychological phenomenon based on a tendency towards self-satisfaction, self-equilibrium and self-preservation, coupled with an overall resistance to change, risk-taking and competition (Liu, 2007). In economic activities, this mentality is typically manifested in the form of individual household businesses, where operators lack organisational cohesion and have a relatively weak awareness of profit and responsibility (Yuan, 2000). This means that they tend to show vulnerability in the face of market risks and external shocks. The smallholder mentality is regarded as the common ideology of the lowest strata of the feudal society, stemming from information asymmetry and leading to a rejection of risk and change, manifesting as contentment with modest wealth, lack of self-discipline and reverence for clans and kinship. This was a prevalent condition among the commoners of the feudal society, which was not limited to peasants (Zhang, 2012).

The smallholder mentality was a joint assessment of the Guiyu region by interviewees in Shenzhen, who saw Guiyu's citizens and workforce as exhibiting exclusionary tendencies, conservatism, fear of change and self-interest, thus constraining industrial innovation and transformation. This was primarily reflected in the composition of the industry, which was dominated by family workshops and the high concentration of trade networks within personal and clan relationships. Theoretically, dense interpersonal networks in a familial society should allow family businesses to grow into large or even super-large enterprises, but in practice, Guiyu possessed few large-scale enterprises. In Guiyu, the e-waste industry was predominantly composed of household-based firms, with intense competition and low levels of integration. Friends or relatives who were initially cooperative sometimes parted ways due to conflicting interests, and some families separated when their children married or started their own businesses. If they were able to, residents tended to establish their own small companies, and while this fragmented development model benefited individual wealth, it also reduced opportunities for pooling information, resources and capital for expansion.

Meanwhile, due to the complacent attitude and exclusive smallholder mentality mentioned above, residents were reluctant to accept the entry of foreign technology and investment. They were unwilling to share resources with 'outsiders' and believed that the e-waste dismantling technology in Guiyu was already at the forefront globally, making other regions less competitive.

This attitude ultimately led to the stagnation of Guiyu's industry, as its firms lacked the capacity or funds for industrial upgrading and technological research and development, resulting in the loss of their ability to reorganise internal structures to adapt to unpredictable environmental changes, thereby failing to adjust the direction of industrial development in time (Morgan, 1986). Even when the government proposed to regulate the e-waste industry, Guiyu merchants persisted in believing that it was government rhetoric that would never be implemented. This unquestioned form of groupthink explained the lack of early restructuring in the Guiyu e-waste industry, even when the region still possessed ample resources and opportunities (Schlieper, 1986).

Shenzhen stood in strong contrast to this. The social network in Shenzhen was extremely open, fostering a fiercely competitive environment. As a city of immigrants, Shenzhen has always shown a high level of inclusivity and openness. A promotional slogan for Shenzhen said: 'Once you arrive, you're a Shenzhener'. According to the Shenzhen Municipal Bureau of Statistics (2021), the number of immigrants in 2020 reached 124,387,000, accounting for 70.84% of the total population. Meanwhile, the population aged between 15 and 59 accounted for 79.53% of Shenzhen's permanent population, while those aged 60 and over accounted for only 5.36%. The demographic structure and demographic dividend are extremely significant, and this means that due to the high proportion of migrants in Shenzhen, there are fewer 'local forces' obstacles than in other cities. The local dialect of Shenzhen, Cantonese, was even completely replaced by Mandarin, which is a rare phenomenon in the development of Chinese cities. Because of the large number of migrants from all over China, each with their own regional dialects, Mandarin became Shenzhen's primary communication language. This fact alone serves as ample evidence of Shenzhen's inclusivity and welcoming attitude towards immigrants.

The increase in immigration also led to the loosening of social networks in Shenzhen. China is a country that values interpersonal relationships, and in many cases, the smooth handling of affairs requires the bridging of social connections (Guanxi). Shenzhen, a city that was formed by immigrants from all parts of the country, has yet to establish a tightly-knit social network, so the ease of government affairs and the freedom of contact between enterprises were always relatively high. This meant that Shenzhen did not exhibit the same exclusionary tendencies as other places or rely on personal relationships to conduct business and that everything was based on merit. Many interviewees told me that much less time and effort were required in Shenzhen to accomplish the same tasks and that all affairs were conducted openly and transparently: 'In Shenzhen, success is attainable as long as one possesses the requisite skills and abilities, whereas in other cities, bribery may be necessary to get things done (S25D).'

Immigrants to Shenzhen often integrated family members or fellow villagers into related or upstream and downstream industries after accumulating sufficient capital, which contrasts with Guiyu, where entire kinship groups converged on a single industry. In Shenzhen, kinship relationships consolidated their influence, improved competitiveness and secured more resources. Immigrants typically formed regional groups based on their places of origin, such as the Hunan and Chaoshan Chambers of Commerce. This approach avoided competition within kinship groups and enabled them to fully leverage their resources and social networks, bringing entire related industrial chains under the control of their respective groups. Consequently, unlike Guiyu's industrial ecosystem, which was dominated by a single industry, Shenzhen allowed the coexistence of multiple interlinked industries.

The family of interviewee S9N exemplified this pattern. S9N's father was among the original immigrants from Puning who engaged in Huaqiangbei's e-waste industry. After graduating from university, S9N also left his hometown to seek employment in Shenzhen. Typically, immigrants initially worked at a relative's company to accumulate information, resources and technical skills before eventually selecting an industry within the related upstream or downstream supply chain in which to establish their own business. S9N ultimately transitioned from his family's e-waste business to low-end electronics production. At the same time, his brother entered the electronic components industry, and his brother-in-law was briefly involved in the counterfeit mobile phone industry. Most of their raw materials and product demands could be met within the ecosystem of their extended family's business, allowing them to capture an extensive market share. This model contributed to the formation of Shenzhen's multi-industry entrepreneurial ecosystem.

The high immigration rate and the high proportion of young people show that Shenzhen is a city characterised by high mobility, intense competition, youthfulness and vibrancy. Young people are constantly coming and going to and from Shenzhen. In contrast to the pursuit of stability by Guiyu's residents, key terms frequently mentioned by interviewees when describing life in Shenzhen included 'fast-paced', 'intense competition', 'rapid turnover' and 'enormous pressure', as individuals can only thrive and remain in Shenzhen through continuous learning, progress and innovation. Set apart from other cities as China's first Special Economic Zone, Shenzhen was always synonymous with economic dynamism and efficiency. Making money is the foremost goal for those who come to Shenzhen, and migrants from other regions were often referred to as going to Shenzhen to 'pan for gold'. Due to high local housing prices, many young people find it difficult to stay, preferring to earn money while young before returning to their hometowns in their later years to spend it.

Almost all interviewees expressed disinterest in matters outside of Shenzhen, focusing solely on earning money, and everything was geared towards this objective. Any profitable endeavour was pursued immediately, and any useful information was promptly utilised. Undoubtedly, Shenzhen's loose social network preserved more 'cultural insurance', fostered greater sharing and exchange of information and technology, reduced interdependence among enterprises, improved the adaptability of its industries and prevented the occurrence of cognitive lock-ins (Weick, 1976).

In addition to loosening internal social networks, Shenzhen also actively engaged in external connections. Foreign trade was an essential aspect of Shenzhen's enterprises, with significant trading partnerships becoming established with Hong Kong, the United States and the European Union. Shenzhen served as China's first window of openness to the outside world and shouldered the responsibility for scientific, technological, informational and talent exchanges with the outside world. Openness and inclusivity have always been Shenzhen's characteristics, and according to Shenzhen Customs (2024), Shenzhen's total import and export volume ranked first among mainland Chinese cities for 31 consecutive years. Its openness to foreign markets and international cooperation not only created broader market opportunities for enterprises but also injected fresh technological and informational vitality, which helped prevent industrial development from becoming stagnant and locked in.

For the e-waste industry, which heavily depended on product innovation and iteration, cross-border information exchange and technological collaboration were particularly crucial, and these interactions ensured timely access to the latest product information and technological resources, thereby maintaining the industry's vitality and competitiveness. The e-waste industry in Shenzhen was able to integrate actively into the global value chain, using international cooperation and the division of labour to achieve optimal resource allocation and industrial upgrading, thereby injecting sustained momentum into its development.

7.2.3 Learning and Skills Acquisition

The channels through which workers acquire learning and technical knowledge serve as an essential dimension in terms of assessing the vitality and adaptability of an industrial cluster. As mentioned above, the e-waste industry in Guiyu primarily adopted a manual labour-intensive mode of operation that involved simple technologies. Because of the relative simplicity of processes and low entry barriers that required only minimal educational or professional levels of development, knowledge transfer relied mainly on master-apprentice mentoring and on-the-job training, with no systematic learning or educational channels. This was a form of 'learning by observation', a craft-based skill acquisition process that limits the advancement of workers' technical proficiency and may hinder the industry's overall capacity for innovation and its future development potential.

Figure 7.5 Using hand tools to dismantle e-waste in Guiyu (a & b); using machines for reassembly in Huaqiangbei (c & d) (Author and interviewees)

In Guiyu, the e-waste industry primarily consisted of family workshops, where households served as the ‘factories’ for dismantling, and family members acted as the primary workforce. Many women, children and elderly individuals were involved. Interviewees told me that when they were young, they would go home to help with disassembly after finishing school. Many foreign media outlets documented these scenes of disassembly, demonstrating the simplicity of the technology used in Guiyu’s e-waste industry.

Figure 7.6 Women and children in the e-waste industry in Guiyu (Source: https://wasteinternational.weebly.com/)

Excessive reliance on low-skilled and labour-intensive work, coupled with the depreciation of education and skill acquisition, limited the cluster's ability to adapt to technological advances, environmental regulations, and continuously changing market demands. Guiyu's long-standing tradition of prioritising commerce over education cultivated a prevailing mindset within the local community that favoured business pursuits over academic achievement and placed more value on basic technical or practical knowledge than on innovation. While this mindset facilitated the development of the industry and provided employment opportunities, it also restricted further development. According to the Shantou City Chaoyang District Statistics Bureau (2021), for every 100,000 people in Guiyu, only 2,552 individuals possessed a bachelor's degree or higher in 2020. Meanwhile, the average years of education for individuals aged 15 and over was only 8.61 years, significantly lower than the mandatory 9 years of schooling[34] stipulated by Chinese law. Locals generally saw studying as a waste of time, believing that investing time in education was less profitable than focusing on earning money. Knowledge reserves and learning aspirations remained weak in such a society. Most individuals, including the younger generation, typically completed only primary or junior high school education before engaging in commercial activities with the rest of their families. A common saying in the area was: 'Even with your high education, you will still end up working for us elementary school graduates (G13G).'

In this overarching context, there is no doubt that Guiyu lacked research institutions, technology centres or universities to provide education, information and technological innovation services. The low level of education constrained locals' ability to learn and acquire technology, making low-threshold manual disassembly their only choice. Meanwhile, lower educational attainment limited receptiveness to and learning capacity for new technologies and innovations, as well as any desire for technological innovation, industrial upgrading and factory expansion. Locals stubbornly resisted the introduction of mechanised disassembly and environmental protection technologies, considering the purchase of machinery and the installation of environmental facilities as wasteful costs, while manual disassembly was seen as the optimal, most efficient and most suitable method for e-waste treatment.

Guiyu can be seen as a single-loop learning system, with its learning capacity limited because the system could only maintain processes of action that were determined by operational norms and standards. When these standards-defined behaviours encounter changes, they can often promote inappropriate behaviour patterns (Grabher, 1993). According to Morgan (1986), highly

[34] China's compulsory education system consists of 6 years of primary school and 3 years of junior high school. High school (3 years) and university (4 years) are optional.

complex single-loop learning systems prevent organisations from adjusting their learning directions promptly, leading the system to persistently follow the wrong path, ultimately losing its ability to respond to potential challenges and falling into decline. When the local government proposed installing exhaust hoods in disassembly workshops to collect waste gases in 2013, for example, it faced resistance from locals and was ultimately forced to abandon the policy.

In contrast, highly mechanised and automated production modes often require a more skilled workforce, placing higher demands on human resource development and skill enhancement. The acquisition of technology in Huaqiangbei's e-waste industry is closely related to formal education, as the industry primarily involves reassembling electronic components, a process that requires a higher level of electronic knowledge and skills to operate. This means that there are certain entry barriers. According to the Shenzhen Municipal Bureau of Statistics (2021), Shenzhen had 28,849 individuals with university degrees per 100,000 population in 2020, with a higher proportion in Futian District, an e-waste industry cluster area which contained 40,507 individuals with university degrees per 100,000 population. In Nanshan District, another electronic industry cluster area, 46,175 individuals with university degrees per 100,000 population, making Nanshan and Futian the two areas with the highest educational levels in Shenzhen. The average years of education for individuals aged 15 and above in Shenzhen was 11.86 years, but in the Futian and Nanshan Districts, the average years of education were 12.88 and 13.26, respectively, reaching a level of high school education or above on average. The concentration of these highly educated talents is largely attributed to Shenzhen's abundant employment opportunities and the attractiveness of its inclusive socioeconomic environment.

Table 7.1 Education Statistics in Guiyu and Shenzhen

Region	Number of people with university-level educational attainment per 100,000 population	Average years of schooling of the population aged 15 and over (years)
Guiyu	2552	8.61
Shenzhen	28849	11.86

(Source: Statistics Bureau, 2021)

Shenzhen established a platform to cultivate and attract high-level talents by conducting scientific research, disseminating high-tech information and facilitating high-level international exchanges. Shenzhen is home to several universities and higher education institutions. By the end of March 2022, Shenzhen had established 6 key national laboratories, 4 Guangdong provincial laboratories, 12 basic research institutions and 11 Nobel Prize laboratories, with a total of over 3100 innovative carriers (Wang, 2022). The technological innovations of these highly educated talents have steered Huaqiangbei's e-waste industry towards a reassembly development direction that contrasts strongly with the disassembly process in Guiyu. Higher education facilitates greater adaptability, rapid learning and the ability to apply new technologies more effectively. A notable example of this industry evolution is Fuqing Fan, whose career trajectory illustrates the transformation of the e-waste sector in Shenzhen. Fan, upon completing his university degree, initially entered the e-waste dismantling industry. During his career in this field, he developed an innovative ‘character library localisation’ technology, which advanced the processes of e-waste disassembly and reassembly. After accumulating sufficient capital, Fan’s transition from e-waste to founding an electronics company, BEASUN, epitomised the sector’s shift towards value-added production. The establishment of these scientific research and educational platforms has not only effectively attracted a substantial influx of outstanding talent but also provided a solid foundation for the cultivation and development of local talent, creating a virtuous interactive mechanism between talent recruitment and indigenous talent development.

Meanwhile, Shenzhen’s research and development (R&D) expenditure has increased yearly, reaching 168.2 billion yuan in 2022, accounting for 5.49% of GDP, with enterprise R&D expenditure accounting for 94% (Guo, 2023). The rapid improvement in the scale and quality of intellectual property rights is a significant indicator of Shenzhen’s transition to innovative growth. In 2022, the city’s effective invention patent ownership reached 243,829, accounting for approximately 7.28% of the national total of patents. The number of PCT international patent applications was 15,892,[35] accounting for 22.99% of the national total, ranking Shenzhen first among China’s large and medium-sized cities for 19 consecutive years (Shenzhen Market Supervision Bureau, 2023).

These patents are primarily concentrated in the field of electronics or electronics-related industries. As mentioned previously, Huaqiangbei’s e-waste and electronics industries share a close connection, making it difficult to separate them. The electronics industry provides the e-waste industry with the latest technological and product information, and due to the latter’s demand for technology, Shenzhen has even formed a front-end technology research and development industry as well as a design industry based on the reassembly of e-waste products. Simultaneously, the flourishing of the e-waste industry has facilitated the emergence and technological innovation of small and medium-sized electronic enterprises and solution design companies. The intimate interaction and synergistic development relationship between the two major industries have formed a beneficial cycle of mutual promotion and reciprocal benefits, which underscores Audretsch and Feldman’s (1996b) theory that knowledge spillovers from public institutions and private laboratories have significant influences on the region.

[35] Note: Excluding applications from foreign companies and individuals in China.

Research and development investments, technological advances, and patent developments within the electronics industry also contribute to the e-waste industry. The close proximity and interplay between these two related yet distinct industries facilitate knowledge and technological transfers, fostering an environment that is conducive to innovation and growth within the broader regional industrial ecosystem. As one interviewee said:

> *'In Shenzhen, there are many electronics companies that are focused on the research and development of reassembly technologies. Companies like us in small-scale reassembly only need to learn and buy techniques without further exploration (S6L).'*

This happens because knowledge typically exhibits the characteristics of a public good, including non-rivalry and non-exclusivity. Knowledge created by one actor or research institution may benefit many other actors, although it may not necessarily be compensated for (Arrow, 1972). Acs, Audretsch and Feldman (1992) noted that the innovation output of enterprises increases with an increase in R&D investment by enterprises and universities. Meanwhile, the microeconomic externalities caused by knowledge spillovers promote economies of scale in clusters, enhancing their vitality (Potter and Watts, 2011; Lan and Zhangliu, 2012). Taking the Shenzhen Tsinghua University Research Institute as an example, as of 2022, it had incubated 3,264 enterprises and cultivated over 30 listed companies (Wang, 2023). However, not all new knowledge generated by laboratories and research institutions can be translated into commercial benefits, leading to a degree of knowledge redundancy (Audretsch and Lehmann, 2005). This redundancy not only allows social systems to adapt to specific environmental changes but also questions the appropriateness of adaptation. Positive redundancy can improve a system's ability to respond to uncertain shocks, improve adaptability and prevent clusters from falling into development stagnation.

7.3 Political and Institutional Context

Policy administration can effectively help to guide industries towards optimal development trajectories in various ways, including infrastructure construction, capital support and project assistance. However, it is crucial to note that when industry development encounters impasses, policy directions that do not match local development strategies may impede the healthy evolution of industrial clusters (Grabher, 1993). North (1981) emphasises that institutional changes, rather than technological advances, often serve as the primary determinants of economic growth. In this context, the government's role should be that of an effective and impartial enforcer of contracts to ensure the validity of property rights and the legal execution of contractual obligations. However, it is important to recognise that government power is exercised by individuals, and failure to effectively prevent opportunistic behaviour during the exercise of this power may lead to paradoxical outcomes that compromise the interests of society. Effective governmental execution is therefore paramount, and government responsibilities extend to constructing and continuously refining market institutions, as well as guiding and regulating the behaviour of market entities in accordance with legal frameworks. This role should not supplant the market's determinative function in resource allocation, but strict adherence to the rule of law by government bodies will foster a fair, transparent, and efficient market economic system, thus cultivating a stable, equitable and predictable international business environment of the highest calibre. A proactive government can promote and safeguard the development of industrial clusters, adjusting directives promptly when necessary, and this happened in Shenzhen. However, a passive governmental approach can engender political lock-in at the local level, as happened in Guiyu.

The policy administration system is a multidimensional framework, and the administrative hierarchy of China's political system can be divided into national (central), provincial, municipal, district and township levels. During the early establishment of the People's Republic of China, a planned economic system was implemented that concentrated power at the central level through a hierarchical structure of administrative and economic units. Despite subsequent policy reforms that decentralised some of this power, the hierarchical nature of the Chinese political system from top to bottom still persists, serving not only the needs of the command economy but also the requirements of political and social governance. Higher-level government continues to control the appointment of key personnel in subordinate units, with power and decisions emanating from higher-level organisations. Higher-level government embodies political and administrative power and influences the allocation of financial resources within the national budgetary system and the development of local economies. Having too many administrative levels can lead to confusion, and local governments are the primary policy implementers who interact directly with the people, while higher-level governments serve as policy supervisors. This chapter collectively refers to non-local governments – such as the central and provincial governments, which have less direct contact with the local population – as higher-level governments. However, due to differences in administrative levels between Shenzhen and Guiyu, Shenzhen is at the municipal level with its higher-level government made up of central and provincial governments, while Guiyu is at the township level with its higher-level government made up of district, municipal, provincial, and central governments. All levels of government are considered in this research.

7.3.1 National Government Interventions

China's reform and opening-up policy, initiated in 1978, marked the beginning of its transition from a planned economy to a market economy. As an emerging market economy, China faced challenges that are common to developing countries. According to Stiglitz (1997), market failures are more prevalent in developing economies, as the market has relatively weak self-coordinating and self-regulating capabilities (Von Mises and Greaves, 2011). Influenced by traditional habits and a dominant government presence, China's market-oriented measures still retain some shadows of a planned economy based on government intervention. However, government intervention is no longer comprehensive and appears more selectively in specific regions or sectors. The methods of intervention also exhibit a form of duality and may be proactive, with the government providing positive support and assistance to create an environment conducive to economic development. However, they may also be negative. When market failures lead to unsustainable development, the government can sometimes resort to restrictive or shutdown measures, resulting in short-term adverse effects on localities or related industries, such as the closure of specific polluting industries.

In Guiyu, the state at first paid little attention to its development and did not intervene extensively. As discussed in Chapter 5, Guiyu historically existed in a governance vacuum with minimal oversight from higher-level government authorities. This absence of effective administration resulted in clan powers temporarily superseding governmental authority, consequently triggering regional governance disorder and transforming the area into a hub for various illegal activities. It was precisely within this distinctive institutional environment that Guiyu's e-waste industry was incubated and developed. National attention to and regulation of Guiyu's e-waste industry cluster began after the environmental problems caused by this industry received widespread global discussion, at which point the central government was compelled to intervene, which includes closing all existing dismantling workshops and designating a specialised circular industry park, stipulating that only enterprises within the park could engage in e-waste-related activities. Simultaneously, local governments were required to implement comprehensive controls on the e-waste dismantling industry, including strict limitations on dismantling zone designation, total volume control, and process standards.

To enhance the technological level of the park, with support from higher-level government, the park introduced an e-waste dismantling enterprise under the listed company TCL. On the surface, TCL's company and Guiyu's traditional e-waste dismantling industry belonged to the same industrial sector, but in reality, there was a significant disconnect between them. Whether in terms of technological approaches, personnel composition, waste sources, or operational models, TCL's company exhibited marked differences from the local traditional industry. These differences prevented TCL from bringing the expected technological spillover effects to the local dismantling industry and instead created a state of internal industrial separation.

Although TCL's entry brought considerable tax revenue to the locality, somewhat alleviating the economic pressure caused by the decline of the traditional dismantling industry, this was entirely the result of external institutional (government) promotion, creating an ‘adaptive isolation’ phenomenon between TCL and the local traditional dismantling industry. Apart from making certain positive contributions to local finances, the effects in terms of employment absorption were extremely limited. This was primarily because the local traditional dismantling practitioners were not TCL’s target employee group, and there were obvious differences in the e-waste sourcing channels between the two parties.

Over time, this separation between adaptation and adaptive capacity gradually transformed into a competitive relationship (Hu and Hassink, 2017). Guiyu’s e-waste dismantling cluster developed a severely uncoordinated industrial environment: the traditional dismantling industry comprised of local family workshops continued to decline, while TCL’s dismantling company's market share grew increasingly, gradually establishing its dominant position. Under this negative conflict where adaptive measures became disconnected from adaptive capacity, the entire industrial cluster fell into a state of negative lock-in, seriously constraining the transformation and upgrading path of the entire industrial cluster.

Therefore, the intervention by higher-level governments in Guiyu had an overall negative impact. To protect the environment, higher-level governments intervened assertively in Guiyu’s e-waste industry, ordering the closure of non-compliant workshops and strictly controlling the entry and exit of e-waste. These stringent policies forced Guiyu to consider industrial transformation or upgrading, but due to its cognitive, functional and political triple lock-in, Guiyu failed to adapt proactively or adjust to changes in technology and industry, ultimately becoming locked into its existing situation.

Historically, Shenzhen and Guiyu were extremely impoverished. However, due to Shenzhen’s proximity to Hong Kong and various political and economic considerations, the government designated Shenzhen as a Special Economic Zone, making it a window for China’s reform and opening-up and a pioneering demonstration area for socialism with Chinese characteristics. Shenzhen’s unique development acquired distinctive production and political missions. To better promote its development, the state adopted various policy support measures, with Shenzhen even being described as a ‘city built on policies’, indicating the crucial importance of policies in Shenzhen’s economic and industrial development. In terms of administrative status, Shenzhen was gradually elevated from a county (Bao’an County) in 1971, eventually becoming a sub-provincial city in 1981, with its own economic management authority and administrative rank that was equivalent to that of a province. Shenzhen was designated as a city with separate economic and social development planning from the province, meaning that the central government issued key planning targets directly, covering industrial and agricultural production, major commodity distribution, foreign trade and scientific and technological development.

Shenzhen's key leaders were also directly appointed by the central government. In this sense, Shenzhen's development trajectory reflected China's national strategy and was a result of concentrated state support.

This meant that the development direction and path selection of Shenzhen's industries were determined by national-level think tank research and policy formulation. As Chiping Yuan, Director of the Hong Kong and Macau Economic Research Centre at Sun Yat-sen University, pointed out, Shenzhen adopted an active transformation rather than a passive one in the process of industrial upgrading, which meant that it initiated upgrading and transformation while the industrial sector was still thriving, deploying new and alternative industries. In the early stages of Shenzhen's development, the state established the electronic industry as the city's key direction for industrial development and introduced a large number of related enterprises and talents, which promoted the development of Shenzhen's electronic industry and facilitated the flourishing development of the e-waste industry.

However, as the e-waste industry grew rapidly, several issues emerged, including rampant smuggling, widespread intellectual property infringement and an excessively low-end industrial chain. These challenges caused the development of Shenzhen's industries to be perceived negatively and criticised. For a long time, whenever Shenzhen was mentioned, it was often associated with issues of plagiarism and counterfeiting, which were highly detrimental to the city's image and its industrial development. Such unfavourable images and development trends were not going to be tolerated as a demonstration area of China's political and economic development, so central and local governments formulated a series of targeted planning measures to help Shenzhen overcome these challenges and achieve rapid industrial transformation and upgrading. These measures mainly included establishing and developing Shenzhen as an independent innovation-oriented city, cracking down on smuggling, counterfeiting, pollution and other low-end industries and transferring them to surrounding cities, thereby promoting the upgrading of Shenzhen's industrial structure.

To promote the development and upgrading of industries in Shenzhen, the state granted Shenzhen considerable autonomy. As described above, Shenzhen is a sub-provincial city. Generally, the fiscal revenue policy for Chinese cities requires a certain proportion of their funds to be submitted to the state and provincial finances, but Shenzhen only needs to submit a portion to the state and can use the remaining funds at its own discretion. Compared to other cities, Shenzhen is able to allocate more independent funds towards urban construction, improving people's livelihood safeguards, talent subsidies and other aspects of economic and social development. Unlike Guiyu, which is forced to rely passively on allocations from higher-level governments to support industrial upgrading and transformation, Shenzhen had substantial funds of its own to promote industrial restructuring and directional adjustments. For instance, in 2017 the Futian District Government of Shenzhen invested 1 billion yuan in special funds over three years to create over 200,000 square meters of innovative industrial space, establish over 20 maker spaces, incubators and accelerators and cultivate more than 2,000 innovative entrepreneurial teams. This well-designed top-level deployment was conducive to the path of innovation and sustainable development for Shenzhen's emerging industries, and as a result of these measures, reassembly technology has been upgraded, and some e-waste merchants have transitioned into the electronics industry.

Shenzhen has also been granted various privileges, with certain practices previously prohibited as capitalists that were forbidden in China gradually being introduced on a trial basis. This included independent legislative power so that as long as it complied with the principles of the constitution and administrative regulations and laws, the city could directly file with the provincial and national people's congresses. This provided a guarantee for Shenzhen to establish and improve a legal system centred on intellectual property rights protection and to cultivate a fair, equitable and open environment of market competition. Regarding intellectual property issues, the Standing Committee of the Shenzhen Municipal People's Congress promulgated the 'Regulations on the Protection of Technical Secrets in the Shenzhen Special Economic Zone' and the 'Regulations on the Protection of Computer Software Copyrights in the Shenzhen Special Economic Zone'. To stimulate the enthusiasm of scientific and technological personnel for technological development, the municipal government also issued the 'Interim Measures for the Extraction and Use of Enterprise Technology Development Funds in Shenzhen' and the 'Interim Measures for Internal Employee Stock Ownership in Enterprises in Shenzhen'. Shenzhen gradually established equity-based technology incentives, equity ownership for technological backbone personnel and technology development reward mechanisms in accordance with the law, forming a distribution mechanism and operational management system that was centred on intellectual property protection. This provided intrinsic motivation for the transformation of high-tech achievements into productive forces. Meanwhile, the local enterprises' vibrant technological innovation system provided real market demand for venture capital.

The substantial support provided by the national government to Shenzhen conferred a higher degree of autonomy and decision-making authority, enabling the city to rapidly accumulate human resources, physical infrastructure, and capital elements during its early development phase. These accumulations established a solid foundation for Shenzhen's subsequent industrial relocation, transformation, and upgrading, while simultaneously creating favourable conditions for the diversified development pathways of its e-waste industry.

7.3.2 Local Governments and the Quality of Decision Making

Local governments are usually the primary implementers of policies at the cluster scale, and their execution, decision-making capabilities and autonomy significantly influence local development. The local government of Guiyu always found itself in an awkward position. Influenced by clan forces, the local administration had long remained covert, showing passivity and inaction. Guiyu existed in a state of 'village autonomy' for a considerable time, with the government's role limited to providing support for basic infrastructures. As described in Chapter 5, Guiyu is one of the few areas in contemporary China where clan culture remains well-preserved, and despite the gradual introduction of modern administrative management methods, clans remained a significant force in the local context.

For a long time, clan power in Guiyu surpassed government administrative power, placing it in a situation of local autonomy. The government's role was limited to providing basic infrastructure support such as land and electricity. Consequently, Guiyu's e-waste industry developed freely without any regulatory oversight. Additionally, as the e-waste industry generated substantial economic benefits for the locality, local government and industry formed close formal and informal relationships, which some scholars characterize as '*Filz*' or capture-referring to the mutually beneficial yet potentially opaque relationship structures formed between government and commercial interests (Friedman, 1977; Grabher, 1993; Phelps, 2000). Specifically, the fiscal revenue of the Guiyu local government was heavily dependent on the e-waste industry and its derivative economic activities. This industry attracted a large influx of migrants, thereby stimulating the development of local consumer markets and the real estate sector. Moreover, the e-waste industry generated substantial economic benefits for the area, significantly elevating regional consumption levels. According to interview data, prior to the strict regulation of the e-waste industry, Guiyu was characterised by a high density of consumption establishments such as hotels, KTVs, and restaurants. Furthermore, due to the enormous economic interests associated with the industry, many local government officials and their family members became directly involved in this sector. This phenomenon led to the formation of tightly interlinked interest mechanisms between the government and the industry, resulting in evident role conflicts for the government in terms of industrial regulation.Therefore, when higher-level governments began to require regulatory intervention in Guiyu's e-waste industry, local authorities failed to effectively implement these directives and instead formed collusive relationships with industry entities to circumvent superior oversight. This collusion manifested in various forms, including: advance notification to villagers about upcoming inspections from higher authorities; fabrication of compliance conditions during inspections; and verbal commitments to implement requirements from higher levels of government without actual follow-through (specific actions of local government are detailed in Chapter 5). This regulatory failure not only provided favourable conditions for the disorderly development of the e-waste industry, but also resulted in a lack of timely and effective intervention and adjustment mechanisms when the industry evolved toward unsustainable directions (such as economic growth at the expense of environmental degradation). Ultimately, the internal contradictions of this development model accumulated to a critical threshold, leading to the functional lock-in of the industrial system.

Unlike Guiyu, the local government of Shenzhen demonstrated more proactive characteristics. Shenzhen has consistently adhered to the principle of planning ahead and a forward-looking layout. Since the adoption of the 'Shenzhen Urban Construction Master Plan' in 1980, the city has developed a range of strategic plans covering comprehensive urban and economic development, along with specialised plans for the growth of the electronics industry, high-tech development and other sectors, demonstrating its forward-looking and proactive characteristics (Guangdong Provincial Party Committee, 2022).

According to Audretsch and Lehmann (2005), not all new knowledge generated by labouratories and research institutions can necessarily be commercialised. In many cases, a disconnection exists between research institutions and enterprises and between research and the market. To address this issue, Shenzhen established a technology development system that is market-oriented, enterprise-driven and based on collaboration between national higher education institutions and research institutions. Research topics originated from market demand and were guided by market needs, prompting enterprises to develop products accordingly, and the objectives of technological development were always clear and precise. Shenzhen has achieved a situation in which 90% of its research personnel are concentrated in private enterprises, 90% of the city's research funding comes from these enterprises, more than 90% of research institutions are established within enterprises, and more than 90% of utility model patents originate from private enterprises. The conversion rate of research results is around 90% (Wu, 2010).

Meanwhile, Shenzhen has implemented numerous policies to attract talent, focusing on a balanced approach between the independent cultivation of expertise and external recruitment. The city has established a comprehensive talent development system to support the growth of high-tech industries. Due to historical reasons, Shenzhen had not established any higher education institutions at the beginning of the Reform and Opening-up period in 1978. Given the objective difficulties in establishing multiple universities and research institutions within a short timeframe, the Shenzhen municipal government adopted a pragmatic 'importation strategy' in its talent policy to meet the human capital and technological support needed for economic restructuring, industrial upgrading, and high-tech industry development.

In December 1996, the Shenzhen municipal government established the Shenzhen Research Institute of Tsinghua University through a collaboration in which the government provided funding and land while Tsinghua University contributed its academic brand and faculty resources. Subsequently, the Shenzhen government partnered with Peking University and the Hong Kong University of Science and Technology to establish the Shenzhen-Hong Kong Industry-University-Research Base, and collaborated with Harbin Institute of Technology to establish the Shenzhen International Institute of Technological Innovation. Once established, Shenzhen provides these key universities with free office space and equipment as well as free access to intermediate testing equipment. This collaborative model has continued to the present day, with Shenzhen hosting a total of 17 higher education institutions by 2025. At the same time, the Shenzhen Human Resources and Social Security Bureau (2022) has established a Talent Market to attract high-level experts to work in Shenzhen. In addition, policies such as the settlement of high-level talent, talent subsidies and the allocation of affordable housing units have also been implemented.

The development of high-tech industries requires substantial financial support. Without addressing funding issues, enterprises cannot sustain their development, and some potential high-tech companies may face closure due to a lack of funding. To address this issue, Shenzhen has explored the establishment of a multi-channel technology investment system, with government technology investment as a guide and enterprise technology development investment as the mainstay, supplemented by strong support from bank loans, corporate listings, venture capital funds and other sources. Specifically, at the end of 1994, the Shenzhen municipal government invested 100 million yuan to establish the Shenzhen High-Tech Industry Investment Service Company, utilising fiscal funds in a market-oriented manner to support high-tech enterprise development. By 2000, the company’s capital had increased to 400 million yuan. These funds were primarily used to provide interest subsidies for working capital loans to high-tech enterprises. All types of high-tech enterprises registered in Shenzhen with independent legal status could apply for this support and receive funding after approval by an expert committee. In September 1997, the Shenzhen municipal government established a Science and Technology Venture Capital Leadership Group headed by the mayor, initiating the construction of a venture capital market system that integrated technology and finance. The municipal government established high-tech entrepreneurship funds both domestically and in Hong Kong: the mainland fund primarily adopted a private placement approach with a scale of 2 billion yuan, while the Hong Kong-registered fund amounted to 50 million US dollars, serving as an ‘export’ channel for the mainland fund. Simultaneously, the Shenzhen municipal government actively explored mechanisms for high-tech venture capital. In August 1999, the government funded the establishment of the nation's first venture capital fund company—Shenzhen

Innovation Technology Investment Company. Subsequently, the Shenzhen High-Tech Investment Guarantee Company and the Shenzhen Small and Medium Enterprise Guarantee Company were successively established, while actively introducing numerous international venture capital institutions to invest in Shenzhen. Regarding enterprise technological investment, the Shenzhen municipal government permitted businesses to reasonably increase the inclusion of technology-related expenses in their costs and supported high-tech enterprises in financing through capital markets. By May 1999, 67 high-tech enterprises in Shenzhen had entered the capital market through methods such as issuing stocks or reverse mergers, with total issuance and rights offering financing reaching 23 billion yuan. In 1996, the Shenzhen branch of China Construction Bank initiated export buyer's credit business for high-tech enterprises, supporting the product exports of companies such as Huawei and ZTE, which have now become internationally renowned electronic information companies (HQBMuseum, 2020).

While government support for high-tech industries may not directly impact the e-waste industry in Shenzhen, the development of related industries has provided technological and informational support to the industry, influencing its upgrading and transformation. Moreover, as argued above, the government's support for innovation has created a favourable environment in Shenzhen, and the municipal government has implemented many supportive policies for all entrepreneurial activities, particularly small private enterprises. For instance, starting in 2015, startup companies, sole proprietors and corporate entities are eligible for a one-time subsidy of 10,000 yuan, a rental subsidy of up to 50,000 yuan and interest subsidies for startup loans of up to 600,000 yuan per person and 3 million yuan per enterprise (Shenzhen Entrepreneurial Dynamics, 2024). This policy support framework was extended to start-ups and individual proprietors, effectively facilitating the transformation of the e-waste workshops towards related sectors, such as expansion into the electronic components sales business or the diversification into the e-commerce domain.

Shenzhen's successful implementation of industrial transformation and upgrading was closely associated with government efforts and the development of innovation networks. In the early stages of new technologies, knowledge tends to be highly tacit, and enterprises and individuals can benefit from geographical proximity (Audretsch and Lehmann, 2005). The geographical proximity and ease of communication between enterprises facilitate the dissemination of tacit knowledge, thereby fostering innovation. Meanwhile, public spending on research and development, as well as appropriate intellectual property policies, increases the stock of public knowledge and fosters innovation and transformation. Effective government measures to promote the flow of knowledge and to create and expand the commons of shared knowledge are thus crucial policy actions for accelerating innovation-driven growth (Stiglitz, 1997). In this context, the effectiveness of Shenzhen's transformation policies was closely related to the establishment of public R&D institutions and the promotion of shared knowledge. Shenzhen's municipal government has established numerous platforms for knowledge exchange, including roadshows and maker spaces. The city also hosts the China International High-Tech Achievement Fair annually, and has done so for twenty-five consecutive years, attracting huge amounts of attendees and facilitating numerous cooperations.

The Shenzhen municipal government is both active and proactive, and although its policies are not explicitly targeted at any particular industry, the e-waste industry, as a small part of Shenzhen's current industrial system, benefits from the overall environmental impact. Notably, the gathering of high-quality talent, the rapid development of related industries and the establishment of information exchange platforms have played a significant role in transforming and upgrading the e-waste industry in Shenzhen, thus avoiding political lock-in.

7.4 Conclusion

This chapter has contrasted the different evolutionary paths of the e-waste industry clusters of Guiyu and Huaqiangbei, explaining why one became locked-in while the other was able to upgrade. The chapter compares factors that influenced the industry in each location, such as the industrial atmosphere, inter-company connections, learning capabilities and political support from regional institutions. It concludes that these socio-economic conditions can develop these regions and potentially hinder their innovation, ultimately leading to the 'rigid specialisation' trap. The long-term stability and profitability of e-waste supply attracted a large number of people to invest in the industry, forming specialised industrial chains, and by comparing the two locations, it was found that clusters lacked resilience when facing external shocks, which may be due to functional, cognitive and political lock-ins.

Table 7.2 Threefold Lock-in During the Development of Guiyu and Huaqiangbei

		Guiyu	Huaqiangbei
Similarities		Small workshops	
Differences	Functional lock-in	Single dominant industry cluster Specialisation; Close Interfirm Linkages; Innovation focus on processes	Multi-industry Related variety; Loosely Coupled Networks; Innovationocus on products

Cognitive Lock-in	Closed, conservative and exclusive business environment; Dualist community (with migrants) smallholder mentality; Learning by doing Low education, no research institutions	Openness and inclusiveness; Welcomed migrants modern mindset; Learning by education High education, lots of research institutions, high R&D invest
Policy Lock-in	Negative local government and decision-making, Lack of foresight and planning; Ignored by higher levels of government	Positive Local government and decision-making, Positive foresight and planning; Model of socialist region, Autonomy granted by the central government

As emphasised by EEG, regional backgrounds have an essential influence on the development paths of industrial clusters (Martin and Sunley, 2006). Due to their distinct cultural and historical backgrounds, Guiyu and Shenzhen developed entirely different industrial ecosystems, network relations and cognitive patterns. Influenced by its conservative and exclusive 'smallholder mentality,' Guiyu remained satisfied with the current development of the e-waste industry and was averse to external capital, technology and personnel, ultimately forming a single e-waste industrial cluster based on a 'courtyard economy' development model. Although this low-end, single-industry cluster was able to rapidly achieve capital accumulation and generate cluster effects in its initial stage of development, its lack of technological innovation capabilities and weak resilience to risks made it vulnerable to external shocks, leading to the decline of the cluster.

This study verifies Bathelt and Storper's (2022) theory regarding the potential risks of lock-in and the lack of alternative pathways in single-dominant industry clusters. Through empirical research on Guiyu's e-waste industry, this research further argues that single industry clusters dominated by low-tech industries are more prone to lock-in and are unable to achieve upgrading or transformation because they are highly substitutable and unable to reach the technological thresholds required for transformation. Furthermore, the type of industrial chain is also a crucial factor influencing the development of single-industry clusters. Guiyu's e-waste industry was concentrated at the dismantling stage, forming a horizontal rather than a vertical industrial chain with a high degree of homogeneity among enterprises, making it easier to fall into lock-in. In contrast, vertical industrial chains ensure that each part maintains relative independence while remaining interconnected and cooperative, resulting in greater flexibility and adaptability.

In comparison, Shenzhen possessed an ‘entrepreneurial mindset’ based on competition and inclusivity, constantly innovating and embracing new technologies and ideas. Intense market competition drove Shenzhen to form a highly related multi-industry ecosystem, which, to a certain extent, promoted economic growth within the cluster and provided diverse options for industrial transformation, thus avoiding cluster lock-in. This verifies the general perspective of EEG that compared to regions with low related variety, economies in regions with high related variety experience more growth in productivity, innovation and patenting, making them more conducive to economic development (Boschma and Frenken, 2006; Frenken, Van Oort and Verburg, 2007).

This study also argues that although close interdependence within the region facilitated cooperation between companies and reduced transaction costs, low transaction costs may also lead to overinvestment by companies in specific transactions, resulting in a vicious circle that locks companies into specific exchange relationships, known as functional lock-in. This severely limits the ability of companies to acquire external information and perception, thus reducing the possibility of innovation. Innovation and information acquisition by companies need to come from a broader network of partners, including related industries, universities and research institutions (Lehner, Nordhause-Janz and Schubert, 1989).

Meanwhile, the tightly coupled network structure led to the formation of a common language, such as specific abbreviations and terms, which improves group awareness and culture, further solidifying the network relationships of the cluster and making it an ‘island’ which difficult for external groups to penetrate (Morgan, 1986). This severely restricts the perception of innovative opportunities and leaves no space for ‘bridging relationships’, resulting in the loss of any ability to gather diverse information from beyond the narrow scope of the cluster itself (Wegener, 1997). This ‘island’ development pattern also narrows the cluster’s perspective, making it difficult to make long-term plans and leading to self-sealing behaviour, causing the system to fall into a ‘pathological stability’. This has the effect of keeping organisations on the wrong track, as people are not prepared for unpredictable environments (Morgan, 1986), resulting in short-term defensive opportunism, depriving actors of future long-term aggressive opportunism (Streeck, 1991), ultimately leading to ‘cognitive lock-in’.

The impact of policy on industry development is particularly significant, especially in the Chinese context. Policy interventions can have positive and negative impacts on industry development which are largely contingent upon the quality of decision-making and implementation capabilities of local governments. Inadequate regulation and government guidance may lead to unrestrained market expansion and short-term economic growth, but poses long-term negative implications for sustainable industrial development and social welfare. The passive political-administrative system's alignment with industry interests impedes timely industry restructuring and innovation (Kunzmann, 1986). In contrast, more loosely-coupled networks, adaptive learning and proactive political-administrative capabilities can facilitate the restructuring, transformation, or upgrading of industries by enabling information exchange, generating new solutions and supporting self-reflective capabilities. By building upon this, supportive government measures can compensate for inadequate investment capacity driven by individual interests, stimulating the generation and use of surplus capacity while striking a balance to avoid the kind of excessive intervention that leads to political lock-in (Grabher, 1993).

In general, Shenzhen has exhibited greater adaptability and economic resilience than Guiyu. Both regions have responded to external shocks by making certain adjustments. However, due to differences in their approaches to adaption, the resulting impacts on adaptability varied, ultimately leading to divergent evolutionary paths. Adaptation in Guiyu unfolded primarily in a top-down way, in which concerns about environmental pollution prompted government control over the e-waste dismantling industry, including restrictions on dismantling areas, volumes and methods. However, these top-down policy interventions lacked sufficient consideration of an organic connection to the actual conditions of local industrial development, failing to establish effective interaction mechanisms with local industrial actors. This ultimately resulted in the e-waste industry cluster becoming trapped in a state of developmental lock-in.

In contrast, Shenzhen's approach to new industries and the vitality of its e-waste reassembly industry was a result of coordination between top-down and bottom-up efforts, offering a scenario of long-term balanced adaptation from internal and external forces. While providing Shenzhen with strong policy support, the central government granted it substantial autonomy, avoiding the 'short-sighted' interventions that might arise from its limited understanding of local conditions (Hu and Hassink, 2017). Based on expert research, the central government charted a long-term development path for Shenzhen and supported funding, talent and taxation benefits. It also offered privileges to Shenzhen. The appropriate macro-control and substantial autonomy endowed Shenzhen with robust adaption and adaptability, facilitating the interactive integration of the local e-waste industry with the electronics industry, thus reshaping local adaptive forms and achieving regional industrial upgrading.

Building upon Hu and Hassink's (2017) classification of the relationship between adaptation and adaptability, this study proposes that top-down policy interventions can expedite industrial recovery or economic remediation through external assistance or industrial transplantation, something that is difficult to achieve through bottom-up approaches alone. However, the 'universal' nature of top-level policies may sometimes overlook local realities, necessitating a degree of autonomy for local reorganisation. The success of local restructuring, however, depends largely on the leadership capabilities of the local government, and scholars emphasise that far-sighted and charismatic local leaders who are capable of transcending narrow individual interests and short-termism and seizing short-, medium- and long-term development opportunities are crucial for local development (Grillitsch and Sotarauta, 2020; Martin et al., 2021). While acknowledging Hu and Hassink's (2017) assertion of the importance of national institutions in shaping regional resilience processes and capacities, this study argues that a region's resilience and adaptability are more dependent on locally based leadership. As the implementers of top-level policies, local leaders play a pivotal role, and efforts to improve local resilience should not focus solely on policies but should also prioritise cultivating local leadership capabilities.

In essence, this study advocates for an integrated approach that balances top-down policies with local leadership, as this form of holistic strategising will enhance a region's adaptability, resilience and sustainable development. Top-down policy interventions provide external support for industrial transformation, while bottom-up local leadership undertakes dynamic reorganisation that is tailored to local realities. These two forces complement each other, creating a synergistic effect.

Chapter 8 Conclusion

Grounded in the theoretical framework of EEG, this thesis develops a multidimensional analytical approach to examine how external shocks disrupt cluster development and how different clusters adapt to such changes.Through the analysis of two case studies, one involving successful upgrades and transformations in response to shocks and the other experiencing lock-in, this research examines the roles of agencies, institutions, related variety, and policies in industrial evolution.

The findings suggest that industrial clusters function as complex adaptive systems, with their evolutionary paths exhibiting diverse characteristics. The distinct contexts and institutional frameworks influence regional development in specific ways, potentially leading to growth, decline, or lock-in (Storper et al., 2015; Buchholz, 2019). Particularly in the reorganisation and restructuring phases following a shock, the adaptation strategies employed by different stakeholders to the new context may result in the emergence of multiple evolutionary paths simultaneously. Industrial clusters do not exist in isolation; their evolutionary processes are influenced not only by other clusters within the same industry and the external competitive environment but also by the activities of internal firms, regional culture, social networks, and local politics (de Haan, 2006). In response to shocks, different clusters exhibit varying degrees of resilience, which essentially reflects a process of multi-agent interaction. Some clusters may become functional, cognitive, or political lock-in, while others manage to overcome these constraints, ultimately achieving upgrading and transformation.

This study posits that the synergistic effects of various policies, including spatially targeted and place-based approaches, along with active government intervention, loose network structures, open and related multi-industry ecosystems, and competitive market environments, are crucial factors in enhancing cluster adaptability and resilience. Empirical findings suggest that the e-waste industry can be broadly categorised into disassembly and reassembly types. The initial industrial choices made by agents in a cluster significantly influence subsequent decisions regarding technology, information, and talent, thereby impacting the cluster’s overall resilience and adaptability.

This chapter aims to achieve several objectives: firstly, to review the extent to which this research has achieved its initial goals; secondly, to elucidate the main findings and contributions of this study and provide recommendations for the development of e-waste clusters; and finally, to reflect on the limitations of the research and propose directions for further research.

8.1 Evaluation of Research Aims and Questions

This research aims to investigate the evolution of e-waste industrial clusters in China, with a focus on two representative clusters. By comparing and analysing their divergent development trajectories in response to shocks, the study examines how one cluster became lock-in while the other successfully achieved transformation and upgrading. The core objective of this research is to dissect the different strategies employed by these two clusters in coping with shocks and to explore the fundamental reasons leading to the divergence in their development directions. Concurrently, the study thoroughly examines the key factors influencing the resilience and adaptability of industrial clusters. Through comparative analysis of cases, this study seeks to identify critical influencing factors and potential points for policy intervention, providing valuable insights for promoting the sustainable development of e-waste clusters.

This study successfully achieved its research objectives and addressed core questions through in-depth fieldwork, including interviews and participant observation. During the research design phase, a thorough literature review was conducted to establish the theoretical framework for the study. Methodologically, previous studies on cluster evolution paths have often favoured quantitative methods due to their ability to more directly describe the spatiotemporal changes in cluster evolution. However, with the increasing importance of concepts such as shocks and resilience in research, relying solely on quantitative methods fails to fully capture the actual state of clusters, especially in terms of network relationships, political environment, and cultural-economic context. As Chlebna and Simmie (2018) advocated, qualitative methods can play a key role in EEG research. Grounded in this methodological consideration, this study conducted extensive fieldwork over eight months at two case sites, completing 85 interviews. Interviewees included local practitioners, local government officials, and higher-level government leaders to ensure comprehensive and representative data. This multi-perspective research approach enables us to transcend the limitations of traditional quantitative research and gain a deeper understanding of the complexity of e-waste cluster evolution, this sensitive grey industry in China, which enabled the aims and objectives to be achieved. In the following sections, the main findings of this study are discussed in detail.

8.2 Main Findings

8.2.1 Empirical Findings

E-waste stands as one of the fastest-growing waste streams globally, yet its conceptual definition remains somewhat ambiguous. Nevertheless, there is a consensus that e-waste possesses dual values: material recovery value and equipment refurbishment and reuse value.

Through field research, this study proposes a novel classification method for the e-waste industry, dividing it into two main categories: the dismantling-oriented industry, focusing on material recycling and the reassembly-oriented industry, emphasising equipment repair, refurbishment, and reuse. These two processing approaches not only exhibit significant differences in their technological and innovation paths but also demonstrate marked divergence in their industrial development trajectories. Consequently, these two types of e-waste industrial clusters require differentiated approaches in terms of management strategies and policy orientations. The Guiyu and Shenzhen cases selected for this study exemplify two distinct e-waste processing clusters, providing a lens to explore the central role of path dependence theory in cluster research. Specifically, the initial choice of industrial development direction within a cluster not only directly shapes the selection of technological pathways and talent cultivation but also significantly influences the cluster’s subsequent developmental trajectory, its evolution, and its capacity to respond to external shocks.

This study reveals that these two clusters exhibit characteristics consistent with the adaptive model (Martin and Sunley, 2011a). However, the research findings indicate that following external shocks, the clusters’ evolutionary paths demonstrate features of multiple coexisting trajectories. Taking the Guiyu case as an example, after experiencing a policy shock, several concurrent paths emerged: path disappearance, where approximately 90% of workers were forced to cease e-waste dismantling activities; path renewal, evidenced by the establishment of a government-led and primarily government-invested e-waste disassembly park; and path replacement, where some areas bordering other towns achieved path substitution by learning from neighbouring industries, textile. The Shenzhen case presents an even more complex, diversified evolutionary path influenced by multiple factors, including policies, related industries, and culture. It exhibits various evolutionary pathswith some paths overlapping temporally. Notably, this stage of coexisting multiple pathways can be viewed as a transitional period for the emergence of new paths, which is often overlooked by researchers. However, this study emphasises that in actual practice, this may represent a prolonged process of exploration and reconstruction, involving complex interactions and negotiations among multiple forces and stakeholders.

This empirical study reveals that the formation of industrial clusters may stem from two primary mechanisms: path dependence based on the original accumulation of resources and sudden external shocks, particularly policy changes. The Guiyu e-waste cluster exemplifies typical path dependence characteristics, evolving from traditional waste processing to e-waste handling, demonstrating industrial evolution continuity. In contrast, Huaqiangbei’s e-waste industry emerged primarily due to external environmental changes, coinciding with China’s ‘Reform and Opening-up’ policy and the global shift of electronic industries to developing countries, which can be viewed as a product of sudden changes in the external policy environment. These two cases represent cluster formation driven by endogenous evolution and external shocks, providing crucial empirical support for theories on industrial cluster origins.

As agglomeration effects become apparent, industrial clusters gradually mature, with an increasingly evident specialised division of labour within clusters and more intricate and complex differentiation structures. While this phenomenon aligns with traditional industrial cluster theories, the study emphasises that relying solely on the economic 'agglomeration effect' theory is insufficient to explain industrial agglomeration (Krugman, 1980). The research stresses the importance of fully considering regional culture, social structure, and political factors in industrial agglomeration. For instance, the geographical distribution of Guiyu's e-waste cluster highly correlates with the spatial distribution of local clans, highlighting the role of culture and social structure in shaping industrial spatial patterns. The formation of Huaqiangbei's e-waste industry is closely related to government decisions, underscoring the significance of political factors. These cases strongly demonstrate the crucial role of non-economic factors in industrial agglomeration.

This study reveals through case analysis that policy intervention's impact on industrial cluster evolution is multifaceted and complex, potentially generating both negative stimuli that lead to constrained cluster development or path lock-in, as well as positive effects that promote cluster transformation, upgrading, or path creation. China's unique political-economic system exhibits distinctly different characteristics from Western countries in terms of policy-driven industrial development. Unlike Western countries' general emphasis on neoliberal market ideology, the Chinese government possesses stronger intervention capabilities and more direct guiding roles in the industrial development process (Peck and Zhang, 2013). This 'Chinese characteristics' government-market relationship provides an important perspective for understanding the differentiated evolutionary trajectories of industrial clusters across regions.

The successful transformation and upgrading of Shenzhen's e-waste industry benefited significantly from active government participation and systematic intervention. As China's first Special Economic Zone, Shenzhen's development carries distinct political strategic significance, thereby receiving sustained support and policy preferences from central to local governments (Chen and de'Medici, 2010). When facing environmental challenges in e-waste management, Shenzhen was able to leverage this political advantage to mobilise diverse resources, driving industrial transformation toward higher value-added and more environmentally friendly directions, achieving a leap from simple dismantling to high-end circular economy (Wang *et al.*, 2013).

In contrast, Guiyu was long trapped in a 'political vacuum'. Due to its lack of strategic significance and political attention, Guiyu was overlooked by policy perspectives during its early economic development, thereby providing survival space for ‘grey’ industries such as e-waste (Tong and Wang, 2004). This political marginality resulted in a lack of effective guidance and regulation during Guiyu’s industrial development process, causing it to develop along environmentally unsustainable paths. More critically, when industrial development deviated from the correct trajectory, due to its prolonged existence in a policy blind spot, Guiyu failed to receive timely external intervention for correction and adjustment.

This study further reveals that the timing and mode of policy intervention are crucial to industrial cluster evolution. Shenzhen’s e-waste industry was incorporated into a regulatory management framework early in its development, with policy intervention characterised by foresight and gradualism. The government promoted industry development toward environmentalisation and higher value-addition through multiple tools such as industrial guidance funds, technological upgrade subsidies, and environmental standards, while respecting market principles (Yu *et al.*, 2014). In contrast, Guiyu’s policy intervention exhibited significant delay and abruptness. During the early stages of industrial development, government regulation was absent; when environmental pollution issues attracted widespread domestic and international attention, the government implemented drastic restrictive policies, including large-scale closure of traditional dismantling workshops and mandatory implementation of regulated industrial park models. While this ‘one-size-fits-all’ intervention approach temporarily curbed environmental pollution, it failed to promote the indigenous transformation of the industry due to a lack of organic connection with local industrial realities, instead leading to developmental path disruption and lock-in (Tong *et al.*, 2015). Notably, these differences in intervention modes reflect variations in participation mechanisms and power structures in the policy-making processes across regions. Shenzhen’s policy intervention demonstrated a combination of top-down and bottom-up characteristics, allowing enterprises and industry associations to play certain roles in policy formation; whereas Guiyu’s policy intervention was primarily top-down command implementation, lacking effective integration of local knowledge and practices.

In the specific process of e-waste cluster remediation, this study reveals it manifests as a complex, long-term process of multi-stakeholder conflict and negotiation.This process reflects the complex interactions across multiple dimensions, including the collision between traditional social structures and modern governance models, the contradiction between economic development and environmental protection, and the coordination between central policies and local practices. The study points out that divergent interests among different stakeholders lead to multiple resistances in the formulation and implementation of regulatory policies. As the industry develops, the relationships among these stakeholders continue to evolve. For instance, the power structure in Guiyu shifted from an initial ‘strong clan, strong market, weak government' to a new pattern of 'strong government, weak clan, weak market'. This finding emphasises that cluster research should not only view cluster development as a dynamic process but also recognise the continuous changes in agents, relationships, networks, and politics.

The research particularly emphasises that the effectiveness of policy implementation largely depends on the execution capacity of local governments, as well as their vision and 'imaginary' for the future of the cluster. The contrast between the passive local government in Guiyu and the proactive government in Shenzhen ultimately resulted in different industrial transformation and upgrading outcomes. In the Guiyu case, the negative political-administrative system formed a binding relationship of interests with the industry, jointly responding to higher-level government supervision and rectification actions. This powerful symbiotic relationship hindered timely industrial restructuring, causing innovation and reform to stagnate. Furthermore, Guiyu's xenophobic ideology exacerbated cognitive lock-in and functional lock-in (Grabher, 1993).

This study reveals the significant impact of industrial structure on cluster resilience and empirically verifies the positive effects of related diversity on cluster development. In the modern industrial era, the global and local division of labour has become increasingly specialised and complex, with regional industrial clusters often forming specialised segments within large-scale mechanised production chains. While this unified and specialised production model has improved supply chain efficiency and output, it has also made single industry chains vulnerable to external threats, which is particularly true for low-end technology industries, where unforeseen risks can directly lead to industry decline or disappearance (Parmentola, Ferretti and Panetti, 2021). The Guiyu e-waste cluster represents a typical specialised industry, with its single industrial structure exposing it to higher external risks. In contrast, Huaqiangbei's e-waste cluster has formed a mutually influential and co-developmental relationship with the electronics industry, constructing a specialised and related-diversified industrial cluster. In the Shenzhen case, the electronics industry provides timely products, information, and technological resources to the e-waste industry, enabling it to flexibly adjust its development path according to market demands, effectively avoiding lock-in.

Overall, through an in-depth examination of the dynamic processes of industrial cluster evolution, this study reveals the crucial roles of structural factors, policy choices, and industrial interactions in shaping regional adaptability and development trajectories. This dynamic perspective provides important insights for both industrial cluster theory and practice. Firstly, the research finds that structural factors, such as local culture and social structures, profoundly impact the formation and development of industrial clusters. These inherent factors not only shape the initial conditions of clusters but also continuously influence their evolutionary paths. For instance, the study observes the significant influence of clan culture on industrial spatial layout and network formation in certain regions, challenging the limitations of traditional industrial cluster theories that pay insufficient attention to cultural factors. Secondly, policy choices are proven to be critical variables affecting cluster evolution. The study demonstrates that policies can directly intervene in industrial development or indirectly influence cluster dynamics by shaping the institutional environment. However, the realisation of policy effects highly depends on local governments' implementation capacity and socio-economic conditions, emphasising the importance of tailoring policies to local circumstances. Furthermore, this research mainly focuses on the impact of inter-industry interactions on cluster evolution. Through comparative analysis, it finds that related variety plays a crucial role in enhancing cluster resilience and innovation capacity. This synergistic effect between industries not only helps to diversify risks but also promotes knowledge spillovers and technological innovation, thereby enhancing the overall competitiveness of clusters.

8.2.2 Theoretical Findings

This study transcends the limitations of single theoretical perspectives by constructing a multidimensional analytical framework that provides a systematic tool for comprehensively understanding the dynamic processes of industrial cluster evolution. Currently, the field of industrial cluster evolution research has witnessed the emergence of various theoretical perspectives, including path dependence, path creation, and life cycle theories within EEG. However, these singular perspectives often struggle to adequately capture the intrinsic complexity and diversity of cluster evolution. In light of this, this study draws theoretical inspiration from Grabher's (1993) three types of lock-in theory while grounded in the theoretical foundations of EEG. Drawing upon multiple theoretical perspectives including actor theory and related variety theory, this research constructs an integrated process analytical framework. This framework employs a multidimensional perspective to systematically examine the combinations of processes that generate diverse evolutionary outcomes, encompassing three key dimensions: first, functional and structural assets and relationships, including industrial structure, network characteristics, and innovation patterns; second, agency and cognition, including entrepreneurial behaviour, collective cognition, and learning capabilities; and third, political and institutional backgrounds, including policy intervention, institutional environment, and governance structures. This multidimensional analytical framework not only explains the characteristics of clusters under static conditions but also reveals their evolutionary mechanisms within dynamic processes.

EEG provides a dynamic perspective for examining the spatiotemporal evolution of industrial cluster development paths. This approach particularly emphasises the importance of history, especially past choices, in shaping the subsequent development of clusters, forming the core of path dependence theory as articulated by Walker (2000). This study thoroughly validates this theory, arguing that the development of clusters is a dynamic process shaped by the interaction between existing innovations and historical legacies. However, the research also reveals that, particularly in the pre-formation phase of clusters, the contingent influence of external shocks can play a crucial role in cluster formation and development. These external shocks include disruptive technologies, policy adjustments, or major catastrophic events. It is important to note that in today's world, polycrises are increasingly intertwined. Sudden and extreme events such as geopolitical conflicts, global pandemics, and localised wars are no longer rare occurrences but are realities that significantly influence our daily lives. These events profoundly impact local economies, landscapes, social habits, and cultures, which cannot be overlooked. In light of these findings, this study suggests that evolutionary economic geographers should incorporate these complex external factors into research frameworks. This approach not only contributes to a more comprehensive understanding of cluster formation and development processes but also better explains the adaptability and resilience of clusters when faced with external shocks in complex and changing environments. By considering these factors, we can construct a more complete and more dynamic theoretical model to better explain and predict the evolutionary trajectories of industrial clusters.

The findings provide a valuable supplement and enhancement of the adaptive model proposed by Martin and Sunley (2011a), suggesting that the adaptive processes of clusters may be more complex and diverse than the original model describes. This study argues that the modified adaptive model builds upon traditional lifecycle theory by further considering the inherent complexity of clusters, the unpredictability of their evolutionary trajectories, and their resilience in responding to external shocks and changes (Martin and Sunley, 2011a), which constructs different models to depict the evolution of clusters, provides a more comprehensive and dynamic perspective for understanding cluster development paths. The study emphasises clusters' path exploration phase after experiencing external shocks. It reveals that when faced with such shocks, clusters may not follow a single predetermined path but might simultaneously explore multiple potential development paths. This diversification in path selection reflects the adaptive strategies of clusters in dealing with uncertainty. Contrary to traditional views, the study finds that this coexistence of multiple paths may persist for an extended period rather than merely a temporary transitional phase. This finding challenges the conventional assumption that cluster development inevitably converges toward a single stable state. By observing the responses of clusters to external shocks, the study highlights the dynamic nature of cluster resilience. Resilience is not only manifested in the ability to recover to the previous state but is more prominently reflected in exploring and adapting to new environments.

Additionally, this study explores the dual impact of socio-economic conditions such as industrial atmosphere, social-culture context, tight network relationships, learning capabilities, and strong political support on the development of industrial clusters. The findings indicate that while these factors can enable certain regions to stand out in competitive environments, they can also hinder innovation by causing clusters to fall into the 'rigid specialisation' trap, characterised by functional, cognitive, and political lock-in (Grabher, 1993). The study validates Bathelt's (2005) theory, which posits that clusters dominated by a single industry face potential risks of lock-in and limited alternative development paths. In contrast, multi-industry clusters, especially those with interactions between related industries, are more likely to facilitate rapid industrial transformation and upgrading. Cross-industry knowledge spillovers and technological integration enhance the adaptive resilience of clusters, providing diversified development pathways and effectively avoiding the risk of path lock-in.

Furthermore, the results suggest that clusters dominated by low-end technology industries are more prone to becoming lock-in and struggling to achieve upgrading or transformation. This is primarily due to the high substitutability of low-end technology industries and their difficulty in reaching the technological thresholds required for transformation. Additionally, the study finds that the type of value chain significantly influences the development of single-industry clusters. Compared to vertical value chains, firms within horizontal value chains are more homogeneous, making them more susceptible to lock-in. In contrast, a vertical value chain structure can enhance the cluster's resilience and adaptability by ensuring inter-enterprise connectivity and cooperation while preserving relatively independent development spaces for each enterprise.

The agency and decision-making behaviours of various actors profoundly impact the developmental trajectory of these clusters. However, it is important to note that agency does not always manifest positively. According to recent research, agencies can be categorised into change, reproductive, and maintenance agencies (Bækkelund, 2021; Baumgartinger-Seiringer, 2022). Among them, reproductive agency, in particular, is often viewed as a source of lock-in effects or a barrier to innovation. In the Shenzhen case, the change agency dominates, driving continuous upgrading and transformation of the cluster. In contrast, the Guiyu case is predominantly characterised by reproductive and maintenance agencies, which has led to the cluster lock-in. In reality, different types of agency may exist in complex mixtures and undergo transitions (Bækkelund, 2021). However, empirical research on this remains insufficient.

This study validates the positive role of loosely coupled networks and adaptive learning in preventing industrial clusters from falling into a state of lock-in. The close interdependence among firms within a region can foster cooperation and reduce transaction costs. However, this reduction in transaction costs can, in turn, encourage investment in specific transactional relationships, creating a self-reinforcing cycle (Vicente, 2018). This cycle may lead to firms becoming locked into particular exchange relationships, resulting in what is known as functional lock-in (Grabher, 1993). Such a lock-in can limit a firm's capacity for innovation and adaptability, making it difficult for the cluster to respond to changes in the external environment. In contrast, loosely coupled networks and adaptive learning offer mechanisms that can help clusters break free from lock-in and achieve restructuring, transformation, or upgrading. A key feature of loosely connected networks is their ability to generate redundancy. As Bateson (2000) pointed out, redundancy enables a system to adapt to specific environmental changes and, more importantly, prompts the system to question its adaptability. This capacity for self-reflection is crucial for supporting systems capable of learning and self-organisation. It allows a cluster to proactively reorganise its internal structure to respond to shocks. In other words, loosely coupled networks and adaptive learning provide a dynamic adaptation mechanism that enables clusters to maintain stability while possessing sufficient flexibility to address changes in the external environment.

Policy factors play a critical role in the evolution of industrial clusters. Support measures provided by political and administrative systems, such as infrastructure development, the optimisation of the business environment, and talent recruitment, can effectively compensate for the lack of redundancy investment capacity that individual firms may have due to profit-driven motives. These interventions stimulate the generation and effective utilisation of excess capacity, thereby providing the necessary external support to enhance the overall competitiveness of clusters. However, government policy interventions require a careful balance between state and market relations to avoid political lock-in resulting from excessive intervention. Based on Hu and Hassink's (2017) classification of the relationship between adaptation and adaptability, this study proposes a significant point: top-down policy interventions can rapidly achieve industrial recovery or economic remediation through external assistance or industrial transplantation, which is challenging to accomplish through bottom-up approaches. This finding underscores the important role of central or higher-level governments in cluster development.

Simultaneously, the study also highlights the potential limitations of top-down policy interventions. The 'universal' nature of higher-level policies may overlook local specificities, making it necessary to grant localities a certain degree of autonomy in restructuring. This perspective emphasises the importance of flexibility and context-specificity in the policy formulation. Furthermore, the study stresses that the success of local restructuring largely depends on local governments' strategic and delivery capabilities. Therefore, when considering local resilience, attention should not be limited to the policy level but should also prioritise cultivating local leadership. This finding highlights the critical role of local governments in the policy implementation process and the importance of enhancing local government capabilities for cluster development. In the Chinese context, policy plays a particularly significant role in industry development. Policies can not only promote the rise and growth of a particular industry but also lead to its rapid decline or disappearance. Administrative directives can, to some extent, override market mechanisms and directly shape the evolutionary trajectory of industries. This phenomenon is relatively rare in Western countries, highlighting the special characteristics of China's industrial governance model.

This study proposes the theoretical concept of 'metropolitan cluster resilience', revealing the significant influence of metropolitan environments on industrial clusters' life cycles, adaptive capabilities, and transformation pathways. The research demonstrates that large cities not only serve as 'incubators' providing initial growth environments for industrial clusters, but more importantly, when clusters face external shocks and transformation pressures, metropolitan environments can provide diversified resources and adaptive mechanisms, thereby significantly enhancing the resilience and restructuring capabilities of clusters. This theoretical finding expands the research scope of traditional industrial cluster theory. Unlike traditional research that primarily focuses on internal network structures, specialization levels, and innovation mechanisms within clusters (Maskell, 2017), this study emphasises the crucial role of broader urban environments in shaping cluster evolutionary processes.

Methodologically, this study employs qualitative research approaches to conduct an in-depth analysis of the evolution of e-waste industrial clusters, offering significant methodological contributions to EEG. This methodologicssal choice not only transcends the limitations of traditional research approaches but also offers new perspectives and tools for understanding complex industrial evolution processes. EEG has long relied on quantitative research methods to delineate the evolutionary trajectories of industrial clusters, typically based on large-scale statistical data and econometric models to examine cluster growth, decline, and transformation (Boschma and Frenken, 2011). However, quantitative research has inherent limitations in capturing the sociocultural dimensions and micro-mechanisms of industrial evolution. Particularly, e-waste as a 'grey' economic sector presents unique challenges to traditional research methods. Such industries typically operate outside formal statistical systems, making their economic activities difficult to capture through conventional data collection methods (Tong and Wang, 2004). Many core production data, income information, and environmental impact indicators do not appear in official statistical yearbooks, and practitioners often, for various reasons, are unwilling to disclose accurate data. Qualitative methods can effectively overcome these data collection difficulties.

Secondly, qualitative methods can systematically explore the ‘soft’ factors influencing cluster evolution, including latent elements such as social relationship networks, trust mechanisms, cultural norms, and informal institutions. The evolutionary process of industrial clusters is deeply embedded within specific socio-cultural contexts, influenced by multiple social, cultural, and institutional factors (Gertler, 2004). While quantitative research can reveal statistical correlations between macro-level data, it often fails to provide in-depth understanding of the socio-cultural mechanisms underlying these data.

Another significant methodological contribution of this study lies in its fine-grained depiction of cluster evolutionary processes. Unlike quantitative research which focuses on macro-variable trends, qualitative research can delve into the micro-level of evolutionary processes, revealing the specific decision-making logic, coping strategies, and interaction patterns of key actors (Boschma and Frenken, 2011). Through case analysis of critical events and in-depth interviews with major actors, this approach can provide detailed descriptions of how clusters respond to external shocks.

Moreover, traditional quantitative research in the temporal dimension is often constrained by data availability and continuity, making it difficult to track long-term evolutionary processes completely. However, qualitative methods such as historical document analysis, oral history, and retrospective interviews can construct complete temporal sequences from cluster formation to development. This methodological innovation enables researchers to capture critical turning points and gradual changes, deeply understanding the specific mechanisms of path dependence and path creation (Sydow, Schreyögg and Koch, 2009). Particularly through in-depth analysis of critical events and turning points, it reveals how external shocks trigger internal cluster adjustments and how these adjustments manifest differently under various socio-cultural contexts. This temporal analytical approach provides important tools for understanding the historicity and contingency of industrial evolution, expanding the methodological boundaries of evolutionary economic geography.

Specifically, this study initially employed narrative interview methods, guiding participants to describe their career development processes in a natural and fluid manner. This strategy not only helped alleviate interviewees’ tension but also enabled the collection of historical information about local industrial development in chronological order. Changes in individual career trajectories are often closely related to local policy adjustments, economic transformation, and industrial development; in some cases, individual career development paths can even serve as microscopic reflections of local industrial evolution. In the deeper stages of interviews, researchers focused on whether interviewees mentioned policy changes, transformations in government management models, or their interactions with government and other organisations. Researchers combined previously accumulated background information with interviewees' descriptions to pose targeted questions or stimulate interviewees' memories. To obtain more detailed attitudes and perspectives, researchers encouraged interviewees to elaborate through specific cases, which not only facilitated researchers' overall understanding of events but also helped interviewees with limited education or weaker expression abilities to articulate their views more appropriately. This method is particularly suitable for obtaining relatively sensitive information such as policy attitudes and social relationship networks, as people typically have deeper concerns and memories about personal experiences.

Simultaneously, with permission from practitioners across multiple local industries, researchers conducted in-depth participant observation to thoroughly understand specific operational processes, interaction mechanisms between different procedures, and communication and learning patterns among different groups. During observation, researchers maintained continuous communication with participants, especially when new discoveries or information emerged. Through these methods, researchers obtained multidimensional information regarding local cultural environments, social network structures, learning characteristics, sources of innovative knowledge, interaction patterns between different actors, and attitudes and response strategies toward policies.

These qualitative data not only filled gaps in statistical information but also revealed the operational logic and social relationship networks behind quantitative data. This methodological approach provides a valuable reference for research in other industries where formal data is difficult to obtain, such as informal economies and early stages of emerging industries (Williams and Windebank, 2002).

In summary, this study posits that industrial clusters are complex dynamic systems that do not exist in isolation. The evolutionary paths of clusters are influenced not only by other clusters within the same industry and the external competitive environment but also by the activities of firms within the cluster, which in turn affect the competitive landscape of the entire industry (de Haan, 2006). Therefore, to gain a deep understanding of cluster evolution, it is essential to consider multiple factors comprehensively, including culture, politics, entrepreneurial environment, technology, and various agencies. This research extends the determinants of regional resilience proposed by Martin and Sunley (2015a), which include industrial and business structure, labour market conditions, decision-making capacity, financial arrangements, and governance mechanisms. This study further emphasises the importance of cultural and habitual contexts, arguing that these factors can influence other factors' selection and mode of action. As the global environment continues to evolve, with new factors such as global pandemics and geopolitical conflicts emerging, it becomes imperative to continuously update research frameworks and perspectives according to the changing characteristics of clusters and their external environments. This study advocates for a multi-dimensional, multiscale, and multi-theoretical perspective to more fully grasp the complex dynamics of cluster development. This approach helps us understand the interactions between clusters at local and global levels, although our knowledge of global-scale processes in e-waste management remains limited. It also sheds light on how these interactions affect cluster development, providing a more comprehensive explanation of cluster development trajectories and performance in different environments.

8.3 Policy Implications

The sustainable development of industrial clusters is a critical issue in contemporary economic research and practice. Based on an in-depth analysis of e-waste cluster evolutionary dynamics, this study provides recommendations to enhance cluster adaptability and innovation capacity. The findings suggest that industrial clusters should prioritise fostering entrepreneurial behaviour by providing support and opportunities for education and learning. Secondly, agencies in clusters should seek to build a diversified and resilient development environment. This entails maintaining the advantages of specialisation while actively promoting related variety within the cluster. Firms and institutions should explore areas related to, but distinct from, the dominant industry to enhance overall adaptability and innovation potential. (Frenken, Van Oort and Verburg, 2007).

Additionally, the study emphasises the importance of developing network relationships within the cluster while cautioning against overly tight dependencies. The formation of loosely coupled networks can be encouraged by promoting cross-industry collaboration and establishing knowledge-sharing platforms. This approach helps maintain the cluster’s openness and flexibility, fosters an open, inclusive, and innovation-encouraging cultural atmosphere, and facilitates the flow and collision of innovative ideas (Uzzi, 1999). The self-renewal capacity of clusters is also crucial to sustainable development. This includes not only technological innovation but also organisational and institutional innovation. Each entity within the cluster should maintain sensitivity to external environmental changes and possess the ability to rapidly adjust and adapt (Maskell and Malmberg, 2007).

In addition, establishing effective governance mechanisms is equally crucial. With regard to government policies, this study underscores the significance of local government implementation capacity. Central policy formulation should fully consider the heterogeneous characteristics of local economic and social development, avoiding the adoption of standardised policy templates. Given the differences in development foundations and resource endowments across regions, policymakers should be wary of simple policy transplantation while drawing on successful experiences from other regions, and should instead focus on localising policy adaptation. To this end, central governments should strengthen training and capacity building for local governments to enhance their understanding and implementation of policies. Meanwhile, policy design should incorporate appropriate flexibility and establish dynamic adjustment mechanisms to adapt to different stages of cluster development and changes in external environments. This requires establishing a comprehensive policy evaluation system to regularly track and assess policy effectiveness, making necessary adjustments and optimizations based on evaluation results. Moreover, during policy implementation, attention should be paid to balancing market mechanisms and government intervention, playing the government's guiding role while respecting market principles and avoiding excessive intervention that could harm market vitality.

Preventing lock-in effects is another critical policy consideration. Policymaking should be vigilant against risks that may lead to functional, cognitive, or political lock-ins. These can be prevented through encouraging external connections, supporting the introduction of new technologies, and promoting industry-academia-research cooperation. While emphasising top-down policy interventions, space should also be reserved for bottom-up innovation, such as through the establishment of innovation funds and support for entrepreneurial activities. When environmental and economic development conflicts during industrial growth, the government can intervene and make timely adjustments.

By adopting these multi-dimensional and dynamic development strategies, industrial clusters can enhance their adaptability and innovation capabilities while maintaining their distinctive characteristics and advantages. This approach enables clusters to achieve sustainable development in the rapidly changing global economic environment, maintaining long-term competitiveness and vitality. These recommendations are not only applicable to low-end industrial clusters but also provide valuable insights for other types of industrial clusters.

8.4 Limitations and Further Research

Due to the sensitivity of the research subject, this study primarily employed qualitative research methods for data collection. While these methods facilitate a deep exploration of complex social phenomena, they also have certain limitations. Firstly, the data collection process relies heavily on the interviewees' memories and descriptions, which introduces a degree of subjectivity and depends significantly on the interviewees' experience, recollection, and ability to express themselves clearly. Moreover, the lack of large-scale quantitative data limits the study's capacity to map the evolutionary trajectories and spatial distribution patterns of the e-waste industry entirely. Consequently, future research could consider incorporating more quantitative data collection and analysis to provide a more comprehensive and objective industry overview.

Secondly, the study's sample is limited to two e-waste clusters in Guangdong Province, resulting in a relatively small sample size that may affect the generalisability of the findings. Subsequent research could broaden the scope by including e-waste clusters from different cultural and policy environments to explore a broader range of cluster operation models, both in China and elsewhere. For instance, further investigation is required into global patterns of e-waste—where are new clusters emerging, and where are existing ones declining? Additionally, how has China's regulation of e-waste influenced the growth of this industry in other regions? Moreover, this study primarily focuses on clusters of relatively low-end e-waste processing technologies. However, with technological advances, an increasing number of high-tech enterprises are entering the field, including emerging niches such as battery recycling. Future research could investigate how these technological innovations impact the evolution and upgrading of industrial clusters. For example, is the rise of the battery recycling industry in Shenzhen related to the e-waste reassembly industry? In the process of avoiding the homogenisation of e-waste clusters, are there other effective strategies besides integrating the e-waste industry into the electronics cluster, as seen in Shenzhen, to enhance its resilience against risks? Lastly, the e-waste industry is associated with certain illegal activities and grey areas, which could yield unexpected insights. Although research in these areas presents ethical and practical challenges, it may provide a valuable understanding of the industry's complete ecosystem.

Overall, these limitations highlight directions for future research. By expanding the research scope, incorporating quantitative analysis, examining technological innovations, exploring the grey areas of the industry, and addressing the balance between environmental concerns and economic interests in the e-waste sector, we can achieve a more in-depth understanding of e-waste industrial clusters, which not only helps to refine relevant theories but also provides stronger support for policymaking and industry development.

Appendix A List of interviewees

Table A- 1Number of interviews in Guiyu and Huaqiangbei

Field sites	Government officials	People engaged in the industry	
		Experienced regulation transition (Guiyu)/ Year before 2017 (Huaqiangbei)	Have not experienced regulation transition (Guiyu)/ Year after 2017(Huaqiangbei)
Guiyu	16	35	2
Shenzhen	8	25	7

Note: As some people may have multiple identities simultaneously, the final total will be greater than the total number of interviewees.

Table A- 2 Basic information of the government officials

Field sites	**Name**	**Occupation level**	**Features**
Guiyu	G2L	County-level	The official of the National Circular Economy Pilot Industry Park. Outsider.
	G3G	Town-level	Former e-waste worker.
	G4L	County-level	The former official of the National Circular Economy Pilot Industry Park and has been involved in the construction of the Park. Outsider.
	G9G	Village-level	Former government official and former e-waste worker. Now has transferred to the textile industry.
	G10G	Village-level	Government official and former e-waste worker. Now has transferred to the textile industry.
	G12L	Town-level	Former e-waste worker and now become an official worker.
	G14L	Village-level	Still work in the e-waste industry.
	G15W	Province-level	Guangdong Institute of Social Studies. Outsider.
	G17L	County-level	The official of the National Circular Economy Pilot Industry Park. Outsider.
	G18F	County-level	The official of the National Circular Economy Pilot Industry Park. Manager of many companies in the

			Park. Outsider.
	G19Z	Village-level	Former e-waste worker.
	G24W	Town-level	Former official and former e-waster worker. Outsider.
	G34L	Town-level	Guiyu resident.
	G35Z	Town-level	Former official. Outsider.
	G37L	Town-level	Former e-waste worker and now become an official worker.
	G42Z	Town-level	Former official. Outsider.
Huaqiangbei	S16H	Municipal-level	Outsider.
	S17G	Municipal-level	Outsider.
	S18D	Municipal-level	Outsider.
	S19J	Municipal-level	Outsider.
	S20C	Municipal-level	Outsider.
	S24G	Municipal-level	Outsider.
	S25D	Municipal-level	Outsider.
	S34Y	Municipal-level	Outsider.

Table A- 3 Basic information of interviewees in Guiyu

Name	Gender	Experienced regulation transition or not	Current employment situation in e-waste	Working pattern	Features
G1C	Male	Yes	Still engaged.	Small company	Moved into the Park. Past family workshop.
G3G	Male	Yes	No longer engaged.	Family workshop	Now work in the government.

G5Z	Male	Yes	Still engaged.	Small company	Moved into the Park. Past family workshop.
G6G	Male	Yes	Still engaged.	Small company	Moved into the Park. Past family workshop.
G7G	Male	Yes	Still engaged.	Small company	Moved into the Park. Past family workshop.
G8G	Male	Yes	Still engaged.	Small company	Moved into the Park. Past family workshop.
G9G	Male	Yes	No longer engaged.	Family workshop	Used to be a government official.
G10G	Male	Yes	No longer engaged.	Family workshop	Now work in the government.
G11Z	Male	Yes	No longer engaged.	Family workshop	Transferred to new electronic device sales.
G12L	Male	Yes	No longer engaged.	Family workshop	Now work in the government.
G13G	Male	Yes	No longer engaged.	Family workshop	Transferred to textile.
G14L	Male	Yes	Still engaged.	Family workshop	Government official.
G16G	Male	Yes	No longer engaged.	Family workshop	Transferred to textile.
G19Z	Male	Yes	No longer engaged.	Family workshop	Now work in the government.
G20L	Male	Yes	Still engaged.	Family workshop	Moved into the Park.

G21L	Male	Yes	Still engaged.	Small company	Moved into the Park. Past family workshop.
G22C	Male	No	Still engaged.	Big company	TCL Deqing Environmental Development Co., Ltd
G23B	Male	No	Still engaged.	Big company	TCL Deqing Environmental Development Co., Ltd
G24W	Male	Yes	No longer engaged.	Family workshop	Transferred to other jobs.
G25P	Male	Yes	No longer engaged.	Family workshop	Transferred to electronic sales.
G26R	Male	Yes	No longer engaged.	Family workshop	Transferred to other jobs.
G27G	Male	Yes	No longer engaged.	Family workshop	Transferred to other jobs.
G28Z	Male	Yes	No longer engaged.	Family workshop	Still finding a job.
G29C	Male	Yes	No longer engaged.	Family workshop	Still finding a job.
G30J	Couple	Yes	Still engaged.	Small company	Moved into the Park. Past family workshop.
G31L	Male	Yes	Still engaged.	Small company	Moved into the Park. Past family workshop. Unemployment for a long time.
G32F	Male	Yes	No longer	Family	Transferred to other

			engaged.	workshop	jobs.
G33J	Male	Yes	Still engaged.	Small company	Moved into the Park. Past family workshop.
G36Z	Male	Yes	No longer engaged.	Family workshop	Still finding a job.
G37L	Male	Yes	No longer engaged.	Family workshop	Still finding a job.
G38Z	Male	Yes	No longer engaged.	Family workshop	Still finding a job.
G39Z	Male	Yes	No longer engaged.	Family workshop	Still finding a job.
G40Z	Female	Yes	No longer engaged.	Family workshop	Still finding a job.
G41P	Male	Yes	No longer engaged.	Family workshop	Find a job in Shenzhen Huaqiang Bei.
G43C	Female	Yes	No longer engaged.	Family workshop	Still finding a job.
G44C	Male	Yes	No longer engaged.	Family workshop	Still finding a job.
G45Z	Male	Yes	No longer engaged.	Family workshop	Still finding a job.

Table A- 4 Basic information of interviewees in Huaqiangbei

Name	**Gender**	**Year before 2017 or not**	**Ever been involved in e-waste**	**Working pattern**	**Current work**
S1G	Male	Yes	Yes	Small company	Working in electronics in another province.
S2A	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei.
S3Q	Male	Yes	Yes	Self-employe	Working in electronics in Huaqiangbei and selling

				d	second-hand mobile phones.
S4H	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei.
S5J	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei.
S6L	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei.
S7G	Male	Yes	Yes	Small company	Working in electronics in another province.
S8C	Female	Yes	Yes	Small company	Working in electronics in Huaqiangbei.
S9N	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei and extended to other provinces.
S10Y	Male	No	Yes	Small company	Working in electronics in Huaqiangbei.
S11Z	Male	Yes	Yes	Small company	Transferred to other jobs.
S12N	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei and extended to other provinces.
S13Y	Male	No	Yes	Self-employed	Working in electronics in Huaqiangbei and selling second-hand mobile phones.
S14J	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei and extended to other provinces.
S15D	Male	Yes	Yes	Family workshop	Working in electronics in Huaqiangbei.
S21M	Female	No	No	Big company	Huawei in Shenzhen.
S22X	Male	Yes	Yes	Small company	Transferred to other jobs.

S23W	Male	Yes	No	Big company	Working in electronics in Huaqiangbei.
S26P	Female	No	Yes	Self-employed	Working in electronics in Huaqiangbei.
S27K	Male	No	Yes	Self-employed	Working in electronics in Huaqiangbei and selling second-hand mobile phones.
S28H	Male	No	Yes	Self-employed	Working in electronics in Huaqiangbei and selling second-hand mobile phones.
S29Y	Male	No	Yes	Family workshop	Working in electronics in Huaqiangbei and selling second-hand mobile phones.
S30X	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei and extended to other provinces.
S31Z	Male	Yes	Yes	Small company	Transferred to other jobs.
S32V	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei and extended to other provinces.
S33X	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei.
S35N	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei and extended to other provinces.
S36Y	Male	Yes	Yes	Small company	Moving company to other cities.
S37S	Male	Yes	Yes	Small company	Transferred to other jobs.
S38L	Male	Yes	Yes	Small company	Working in electronics in Huaqiangbei.

S39G	Female	Yes	Yes	Small company	Still looking for a job.
S40L	Male	Yes	Yes	Small company	Transferred to other jobs.

Appendix B Interview Guide (Government Officials)

1. Could you please tell me what the local e-waste industry is like and how it has developed over the last ten years? Are there any changes?
2. What are the attitudes and policies of the e-waste industry? Are there any changes from the old days?
3. What is the current attitude and policy of the central government towards the e-waste industry?
4. How do local governments implement the policies of the central government?
5. Is there any tension between central and local governance?
6. What do the local people think about managing the e-waste industry?
7. How do you balance the different requirements of local people and the central government?
8. Are there any policies and plans to guide the transformation of the industry?
9. What are the future plans for the development of the e-waste industry?

Appendix C Interview Guide (Workers with Long Experience)

Entrepreneurs

1. What is your workshop's main business (disassembly or reassembly)?
2. Could you please introduce the history of your workshop? And how long have you been involved in this and why?
3. Why did your workshop grow up in this location?
4. Under the history of your workshop, has the amount of e-waste processing you do go up or down?
5. Are you involved in the local supply chain? Who do you work for, the local big electronic company or something else?
6. What is the relationship with other workshops and industries? Do you exchange knowledge with other industries or local suppliers?
7. What is your main market? Has it changed?
8. What do you think has had the most significant impact on the workshop's development? Do policies affect the development of the workshop? Can you give some examples?
9. What are the plans for your workshop?
10. Would you like to move into another type of activity, and what are the key obstacles to this? Why?
11. Are there some policies that are not conducive to the development of the workshop? How do you deal with them?
12. How did you get your workshop's license?
13. What skills does your workshop need when dealing with e-waste? Did they change or not?
14. Do you want to move the circuit park set by the government? Why?

Staff

1. How long have you been working in the e-waste industry, and why?
2. Could you please describe your work experience in the e-waste industry?
3. Have you felt something changed in this industry, like wages, the number of employees, etc.?
4. What factors have tended to influence this over the years?
5. What skills do you need in the e-waste industry? Did they change or not?
6. What do you think of the policy changes?
7. (If they were no longer working in the e-waste industry) What skills do you need in your current job? Are they relevant to what you need in the e-waste industry?

8. What are your future career plans? Will you change your job? Why?
9. What are the main elements you considered if you want to change your job?
10. Can you comment on the local government's effort to balance central policy with local needs? Do you know some good examples of other cities?

Appendix D Interview Guide (Workers Recently Joined)

1. How long have you been involved in the e-waste industry, and why?
2. Could you please describe your work experience in the e-waste industry?
3. Why have you changed your job and chosen to work in the e-waste industry?
4. What skills did you need in the e-waste industry? Did they change or not?
5. What skills do you need in your previous job? Are they relevant to what you need in the e-waste industry?
6. Have you felt something changed in this industry, like wages, the number of employees, etc.?
7. What factors have tended to influence this over the years?
8. What do you think of the policy changes?
9. Can you comment on the local government's effort to balance central policy with local needs? Do you know some good examples of other cities?

Appendix E Ethics Approval

Approved by Faculty Ethics Committee - ERGO II 67331

University of Southampton

ERGO II – Ethics and Research Governance Online https://www.ergo2.soton.ac.uk

Submission ID: 67331
Submission Title: Industrial evolution in developing countries: A study of e-waste industrial growth paths in China
Submitter Name: Junwanguo Guo

Your submission has now been approved by the Faculty Ethics Committee. You can begin your research unless you are still awaiting any other reviews or conditions of your approval.

Comments:

- please add the ethics numbers where appropriate, for you this is 67331 and was allocated when you first created the submission form.

Click here to view the submission

TId: 23011_Email_to_submitter___Approval_from_Faculty_Ethics_committee__cat_B___C_ Id: 454870

J.Guo@soton.ac.uk coordinator

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Appendix F Disassembly Process of E-waste in Guiyu

Based on fieldwork, the e-waste dismantling in Guiyu can be broadly categorised into the following types: whole electronic household appliances dismantling, small electronic household appliances and digital products dismantling, wires and cables dismantling, larger circuit boards dismantling, dismantling of small circuit boards with heat air machines, processing of small electronic components, disposal of empty circuit boards devoid of electronic components, utilisation of waste copper wires, metal scraps, utilisation of waste plastic, incineration of plastic waste, and acid washing.

According to the dismantling process and the pollution caused, these activities can be roughly classified into four categories: the first category is pure manual dismantling, which is essentially pollution-free. Skilled workers use tools such as screwdrivers, blades and scissors to dismantle e-waste manually. The second category uses small-scale mechanical equipment, such as electric heat air machines, with relatively low pollution. The third category is the procession of small electronic components and empty circuit boards, involving the use of strong acids and high-temperature melting, resulting in significant water and air pollution. The last kind is the extraction of precious metals, like gold, which employs high-concentration sulfuric acid and causes considerable pollution.

Pure manual dismantling mainly involves the disassembly of integral e-waste appliances, electrical wires and cables, and large circuit boards. This part involves a rudimentary disassembly and classification of e-waste, such as wires and cables, which are disassembled into plastic, copper, or aluminium wires based on the different metal materials inside. Circuit boards involve removing larger, easily dismantled components and selling the remaining difficult-to-dismantle boards with small components to other workshops. Circuit boards have significant dismantling value due to various components like chips, capacitors, diodes, and metals such as gold, solder, and copper on the surface. Guiyu workers typically use an electric hot air machine to heat and soften the solder points on the circuit board, then use tweezers to separate and dismantle small electronic components from the circuit board. The dismantled electronic components are then sold after classification. Due to the presence of metals such as tin and gold on the circuit board, workers heat the boards over a coal stove with an iron plate or a flat pan. The molten tin stays on the iron plate, and some remaining electronic components are dismantled by tapping. This process generates a large amount of dust and exhaust, producing a pungent smell. Workers have minimal protective measures, and some workshops place one or several large industrial fans for cooling, though with little effect.

Figure F- 1 Pure manual dismantling (Source: Author 02/04/2022)

Figure F- 2 Use an electric hot air machine to heat the circuit board (Source: Author 21/03//2022)

Figure F- 3 Heat the boards over a coal stove with an iron plate or a flat pan (Source: By (Shantou Chaoyang District People's Government, 2010))

After dismantling, the empty circuit boards usually undergo two steps. First, they are placed in a crusher for crushing. The crushed material is pumped into a water-shaking machine after mixing evenly with a blender, allowing the metal particles to separate from the non-metal particles through gravity in water. The dried metal powder can be sold, while the non-metal, mainly resin, fibreglass, and flame retardant powder, is sold after being pressed and filtered into blocks in a waste pool. Another method is soaking the circuit boards and other electronic components in a strong acid solution and heating them appropriately. Stirring dissolves the oxide of precious metals in the acid solution. After soaking for some time, the insoluble material is removed, and the diluted acid is then mixed with a reducing agent such as ferrous sulphate to reduce the precious metals, which are then sold. This part, due to the extensive use of strong acids and other chemical reagents, results in severe pollution to the environment in terms of wastewater and waste residue.

Figure F- 4 Copper powder (Source: Author 30/03/2022)

Figure F- 5 Copper ingots (Source: Author 25/03/2022)

In addition to circuit boards, e-waste dismantling also generates a large amount of plastic, wires, and non-metals. Plastic recycling generally starts with sorting the plastics. Since different plastics have different compositions, workers use their experience to classify them based on different smells released during burning. Afterwards, the plastics are shredded in a crusher. After washing and drying, they are placed in a furnace, softened at high temperatures, and eventually form plastic liquid flowing out of the electric heating tube, becoming plastic cylinders. After cooling in a sink, they are then put into a granulator for further processing. Some factories also have the capability for injection moulding, where the plastic solution is placed in plastic moulds to produce plastic products.

Figure F- 6 Acid washing (Source: By (Shantou Chaoyang District People's Government, 2010))

Figure F- 7 Plastic granules (Source: Author 01/04/2022)

For the hardware waste generated during the dismantling process it is first smelted using a blast furnace or reverberatory furnace to produce crude copper. Then, through an anode furnace, it is turned into an anode plate. Subsequently, it enters an electrolytic cell, decomposes into copper plates and anode mud, and the anode mud is further processed to extract precious metals. Through the exploration of different processes for dismantling various types of e-waste, layer by layer, Guiyu has ultimately formed a relatively integral electronic waste dismantling industry chain. As one interviewee said:

> *'The dismantling industry chain in Guiyu is highly mature. In simple terms, less valuable plastic blocks are sold to nearby plastic factories, while valuable circuit boards are heated on an electric heater or stove to melt out components. Among these, reusable components such as chips, capacitors, and diodes are collected and sold to merchants engaged in reassembly. The remaining circuit boards are used for refining precious metals. The process of melting metals such as copper and tin using an electric soldering iron is called 'burning board', and the process of extracting gold using strong acid is known as 'gold washing' in Guiyu (G14L).'*

Appendix G Clan Culture in Guiyu

Guiyu is a traditional small town deeply influenced by Chaoshan clan culture. Historically, ancestors of the Chaoshan people migrated southward from the Central Plains and frequently clashed with local indigenous peoples due to spatial issues (Mo, 2017). To resist external pressures, they formed tightly-knit clan relationships, which played a crucial role in resource acquisition, security defence, and community governance through the reinforcement of clan ties. Meanwhile, aggression and warfare in coastal areas further strengthened clan organisations. Clans helped each other and protected one another by constructing ancestral halls, establishing clan rules, and enhancing community cohesion and strength. Consequently, whether in rural or urban areas, their houses were built together, with ancestral halls erected first, followed by surrounding dwellings, gradually forming a unique 'village within a village' or 'fortress-style building' structure. Surrounding moats, walls, and guard towers protected the clans, allowing only members of the same ethnicity to reside within the walls, significantly ensuring the homogeneity and purity of the resident population . In Guiyu, a village typically comprises individuals of the same surname (Wang, Qian and He, 2022). This enclosure not only prevented the intrusion from external forces but also hindered communication with the outside world, leading to a closed, conservative, and exclusionary business environment.

Figure G- 1 Traditional architecture in the Chaoshan Culture (Sources: From the Internet, Baidu Picture)

Guiyu is clustered based on clans. Influenced by the traditional Confucian filial piety culture, the Guiyu region greatly emphasises family culture, with common multigenerational households and a clan often constituting a natural village. Villages typically have ancestral halls, which serve as places for clan descendants to pay respects to their ancestors and conduct family affairs. Ancestral halls (Ci'tang 祠堂) also have 'clan rules' (Zugui 族规), which govern family conduct. Family affairs are managed by the clan leader (Zuzhang 族长), who is typically the most prestigious and influential person within the clan. The clan head's authority, known as clan power, includes presiding over ancestral rituals, formulating and amending family rules, managing clan affairs, regulating clan members' behaviour, and adjudicating clan disputes, ranging from minor family conflicts to major events such as ancestor worship and temple management. Historically, the clan head controlled the management and distribution of clan fields and other communal properties, as well as the clan's external relations. The clan head had the authority to decide various punishments, including the death penalty, for clan members who violated clan regulations (He *et al.*, 2014). The traditional Chinese opera *Su Liuniang* describes the widespread use of private punishment in the ChaoSha region, to which Guiyu belonged: 'Clan Leader: My Su clan of Lipu has been upright for generations. Due to your lax discipline and poor upbringing of your daughter, she would commit such acts that disgrace our ancestors. I am determined to enforce the clan rules and send your daughter away to be drowned in the river.'

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