Innovation System Evolution and Value Chain Positioning:

Lessons from Malaysia’s Semiconductor Sector for Latecomer Economies

Management of Technology - Msc Thesis

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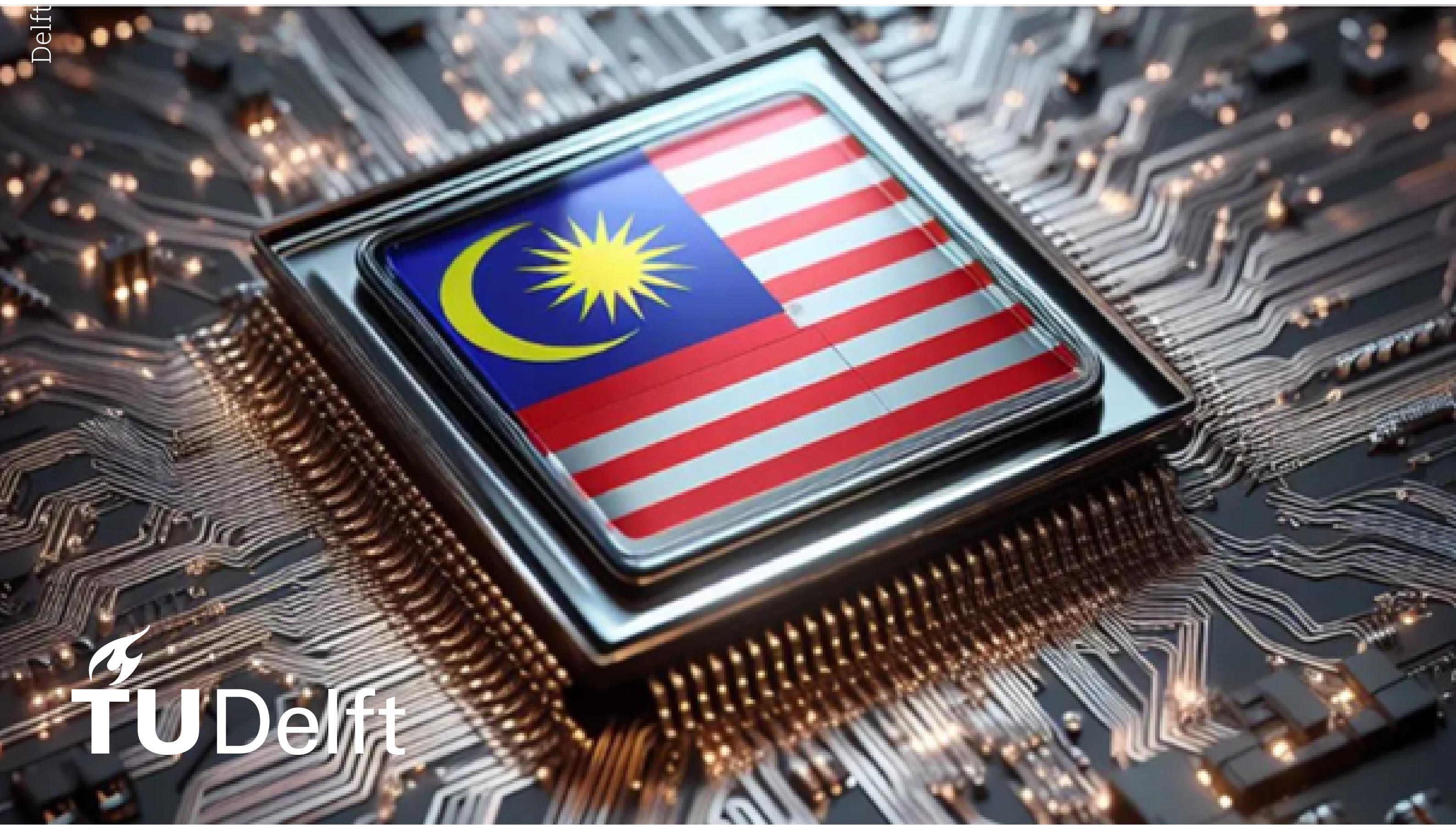

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by

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Preface

"Everyone wants to build their own semiconductor factories, but is that realistic? If it was that easy, there would be chipmaking plants everywhere in the world already"

CC Wei, CEO, TSMC
December 2022

Executive Summary

The semiconductor industry forms the foundation of today's technological advancements, underpinning innovation across nearly all modern-day electronics and digital structures. Their production is highly fragmented yet concentrated, locking latecomer economies into structurally disadvantaged segments. This thesis addresses an underexplored research gap: how technological innovation systems interact with global value chain dynamics to shape upgrading trajectories in knowledge-intensive globalized industries, particularly the semiconductor industry.

Malaysia represents a distinct and insightful case in this context. Malaysia started participation in the semiconductor industry in the 1970s through assembly, testing, and packaging activities. While it's not a latecomer economy, it remains a latecomer in high-value segments of the semiconductor industry, such as IC design and wafer fabrication. This nuanced trajectory provides an illustrative case to understand context-specific constraints and possibilities, which extracts lessons for latecomer economies seeking to advance in similar globalized industries.

The central aim of this thesis is to analyze how the functional performance of Malaysia's innovation system influenced its positioning within the global semiconductor value chain over time, and what lessons this case yields for latecomer economies. The main research question guiding this is: *How did the performance of innovation system functions in Malaysia influence its positioning within the global semiconductor value chain, and what lessons does this hold for latecomer economies pursuing industrial upgrading?* Sub-questions building towards this central questions investigate: (1) the evolution of actors, networks, and institutions across the global value chain segments, (2) functional performance over time and by segment, (3) the structure of the the semiconductor value chain and Malaysia's position within, and (4) key enabling and constraining domestic and external functional dynamics.

Seeking answers, this thesis combines a functional Technological Innovation Systems framework (Bergek et al., 2008) with a semiconductor-specific global value chain analysis. The Technological Innovation systems approach enables a systematic assessment of how key innovation system functions have supported or constrained Malaysia's upgrading in the sector, while the global value chain perspective situates these dynamics within the broader structural and governance conditions of the global semiconductor industry. This dual-framework design allows the analysis to capture both the internal systemic capabilities, providing a foundation for extracting lessons relevant to economies facing the structural constraints typically encountered by latecomers in high-technology sectors.

Malaysia's semiconductor industry is used as a unit of analysis for the exploratory longitudinal case study design. The temporal scope spans 1970 to the present. The analysis is based on a functional TIS assessment, by mapping actors, networks, institutions, and seven key systemic functions(knowledge development, entrepreneurial experimentation, market formation, legitimation, resource mobilization, influence on direction of search, and development of positive externalities), contextualized by global value chain characteristics.

The findings on Malaysia's innovation system display a dual character. While Malaysia successfully established a notable presence in assembly, testing, and packaging, facilitated by strong resource mobilization and a foreign-led market formation, it faced systemic barriers to upgrading into more knowledge-intensive and value-intensive segments (wafer fabrication and integrated circuit design). Key constraints identified include limited domestic knowledge development, legitimation, and entrepreneurial experimentation. Together, these dynamics enforced Malaysia's position in low-value segments while leaving it structurally dependent on foreign multinationals for higher-value activities.

Malaysia's experience reveals systemic barriers, relatable to latecomer economies, by emphasizing challenges related to technology accumulation, foreign dependency, and integration within hierarchically governed global value chains. These findings both reinforce and challenge established latecomer theories by highlighting how incremental upgrading alone might not suffice to overcome structural technological barriers in knowledge and capital-intensive industries.

The thesis concludes that latecomer economies aiming to enter and upgrade the semiconductor sector need to develop a strong symmetrical performance of systemic functions. The lessons derived emphasize the need for strategic policy interventions, robust institutional frameworks, focused R&D and human capital investments, combined with deliberate positioning in the global value chain. All together, this thesis provides strategic insights for evolving technological innovation systems that interact with global value chain networks in a high-technology sector. It offers lessons for policymakers and stakeholders in economies encountering similar constraints, underscoring the importance of addressing both systemic innovation challenges and global structural barriers when formulating upgrading strategies. Nevertheless, some limitations of this research should be acknowledged. The single case study design risks context-specific findings that may not be generalizable to other countries or industries. Next to that, the reliance on secondary data and the limited number of expert interviews may have constrained empirical robustness. Lastly, the applied functional TIS approach focuses on systemic dynamics and leaves political, economic, and physical infrastructural factors underexplored.

Contents

List of Figures

List of Tables

1

Introduction

1.1. Background and Motivation

Semiconductors form the foundation of contemporary technological innovation, serving as critical components in the advancement of artificial intelligence (AI), the Internet of Things (IoT), and the global implementation of 5G-networks. This technological ubiquity has significantly elevated the importance of semiconductors, with the worldwide semiconductor market projected to exceed 1 trillion USD by 2030 (Paris, Martine, 2024). Hence, nations around the world actively seek to secure and enhance their competitive positions within this strategically vital sector.

To establish a competitive semiconductor industry, a cohesive interplay is required of several fundamental factors, enabled by, among others, policy decision making, institutional positioning, and a resilient public infrastructure (H. Wang & Lim, 2023). Nations aiming to excel in this sector must also prioritize workforce development, strengthen research institutions, and establish strategic international collaborations to sustain innovation and enable scalable production (Damanpak Rizi et al., 2023). However, policy interventions alone are insufficient to guarantee success (Naumann & Schnitzer, 2024). The complex interplay of technological capabilities, availability of skilled labor, robust financial ecosystems, and a developed industrial infrastructure presents significant challenges, particularly for emerging economies lacking the foundational resources needed to compete at the frontier (Brugmans et al., 2024; Rasiah & Wong, 2021; C.-T. Wang & Chiu, 2014).

The experience of economies participating in the semiconductor industry shows that entering and upgrading within such a technologically demanding sector is far from straightforward. While some have navigated these barriers successfully, others have remained locked in lower-value segments of the value chain.

1.2. Problem Statement and Research Motivation

How do countries break into high-tech sectors? This question lies at the heart of a long-standing body of literature on latecomer industrialization and technological upgrading. Scholars in this tradition argue that firms and countries can gradually upgrade technological capabilities, moving from production and process engineering into design and innovation (Hobday, 1995b; Lall, 1996). Various models propose to explain these upgrading trajectories: from path-following and stage-skipping to more novel path-creating strategies. Each path is based on a differing combination of capability accumulations, access to external knowledge, and strategic linkage formation (K. Lee & Lim, 2001b; J. Mathews, 2002).

These perspectives show that upgrading is possible through different trajectories, yet they also assume global contexts where knowledge is moderately accessible and innovation proceeds incrementally. Whether such assumptions hold in highly complex, capital-intensive sectors like semiconductors is less certain.

Lessons falling short

High-tech industries exhibit a set of characteristics that raise the bar significantly for latecomers First of all, the capital intensity is peculiarly high, as a state-of-the-art chip fab costs between $10-20 billion and becomes increasingly expensive (OECD, 2023a). This means new entrants cannot start small or scale gradually. Next to that, proprietary and tacit knowledge are deeply entrenched, with a few companies dominating essential intellectual property (IP) and know-how, creating high barriers for imitation (Kleinhans & Hess, 2021; Naughton, 2023). Market concentration and vertical specialization further limit opportunities for latecomers to develop end-to-end industries, forcing them to compete for niches already controlled by incumbents.

In short, these factors produce what can be termed a technological exclusion effect. The OECD (2023a) notes that supply-chain concentration is intensifying, and knowledge flow is becoming increasingly inelastic. Under such conditions, conventional latecomer catch-up models offer little explanatory or prescriptive power for semiconductor upgrading. A sector-specific framework is therefore needed.

National paths in the semiconductor industry

Several economies have managed to upgrade their semiconductor industries by adopting distinct strategies.

Taiwan's semiconductor rise is widely attributed to a developmental state approach with a focus on strategic specialization. In the 1970s, the Taiwanese government invested heavily in acquiring foreign technology and nurturing domestic capabilities through institutions like the Industrial Technology Research Institute. This led to the creation of TSMC, which pioneered the first foundry that manufactured chips without owning IC designs. This allowed Taiwan to insert itself as a key supplier to foreign firms. Government policies promoting R&D and workforce training further fostered domestic semiconductor clusters. Over time, a vibrant ecosystem of fabless design companies, like Mediatek (see figure: 5.2), emerged alongside foundries. The Taiwanese path shows the importance of early institution-building and finding a niche (foundries, in this case) that matched the global market requirements and needs, while building domestic strengths.

South Korea followed a model, centered on chaebols, the Korean word for large family-owned companies, and an initial focus on memory chips. In the 1980s, the Korean government supported firms like Samsung and Hyundai (see figure: 5.2) through joint ventures, recruitment of foreign experts, and targeted industrial policy. By 1990, Samsung had caught up in memory chips, making them one of the few successful cases of rapid catch-up. This trajectory was characterized by concentrated talent and capital in a small number of national champions, combined with close state-industry coordination. While successful, it came at the cost of weaker small, medium-sized enterprises (SME) ecosystems.

China's approach started much later, in the 2000s, with little domestic capacity. Witnessing Taiwan's and Korea's success, the government adopted a state-guided, investment-driven strategy, channeling tens of billions into fabless design firms, research institutions, and foundries. These top-down measures, together with China's large electronic industry, led to a thriving mid-tier design sector by the 2010s. While China continues to create a large semiconductor industry, in volume terms, it faces a gap at the frontier. Unlike Taiwan and Korea, it lacked early Western alignment benefits. Instead, its model relies on large-scale public subsidies, forced technology transfer for foreign multinationals, and the use of government procurement to boost local firms. The case of China highlights that sufficient state backing and market scale can create momentum as a newcomer. However, it also shows that because of the complexity of the semiconductor industry, financial capital alone cannot guarantee frontier capabilities.

Compared with these paths, **Malaysia's** trajectory was initiated by foreign multinational corporations in the 1970s. Malaysia's entry point into this industry was concentrated in downstream activities, specifically assembly, testing, and packing (ATP) operations. Over time, Malaysia sought to expand into higher-value segments such as wafer fabrication and integrated circuit (IC) design, which were facilitated by strategies for foreign direct investments (FDI), targeted governmental incentives, and industrial cluster forming (Malaysian Reserve, 2024; Rasiah, 2017a). Efforts to upgrade into higher-value segments, such as wafer fabrication, chip design, and R&D, have been met with mixed results. While it strategically attracted FDI and developed flourishing industrial clusters, its semiconductor advancements remain uneven and constrained by reliance on multinational corporations and limited domestic capabilities (Malaysian Reserve, 2024; Rasiah, 2017b). Despite these limitations, Malaysia plays a critical role in the global semiconductor industry, currently ranking sixth worldwide in terms of total semiconductor export value, mainly through its strong ATP footprint. Yet, its continued reliance on foreign firms and technologies for the higher-value stages of the semiconductor value chain underscores a challenge.

Despite Malaysia's strong downstream foundation and decades of upgrading efforts, it has only achieved partial success in advancing higher-value activities. This raises questions about the extent to which Malaysia's semiconductor innovation system has effectively supported its advancements within the global value chain (GVC). Specifically, it remains unclear how key systemic functions shaped Malaysia's partial success and struggles within the global semiconductor industry. Understanding these functional dynamics can provide valuable lessons for other latecomer economies seeking to navigate similar constraints in high-technology industries.

1.3. Research Objective

This thesis seeks to explore the question of how the functional dynamics of a technological innovation system (TIS) shape a country's upgrading trajectory for positioning within a globally embedded value chain, and what lessons these dynamics hold for latecomer economies aiming to advance in high-technology industries. Existing literature on GVCs has exposed the hierarchical nature and constraints of semiconductor production networks, and latecomer industrialization theories have provided insights into catch-up strategies. However, these strands of research have yet to explore the functional performance of innovation systems as instrumental mechanisms. At the same time, research that assesses TIS tends to overlook the interactions of technological innovation processes within globally governed value chains.

This thesis aims to bridge this gap by examining how Malaysia's semiconductor innovation system has functioned over time. More specifically, how key innovation system functions-such as knowledge development and diffusion, entrepreneurial experimentation, market formation, resource mobilization, legitimation, and the generation of positive externalities, have enabled or constrained Malaysia's position within the global semiconductor value chain.

By combining a methodology for assessing functions of a TIS framework (Bergek et al., 2008) with perspectives from a semiconductor GVC analysis, this thesis seeks to extract lessons on systemic innovation dynamics within globalized production structures. This objective aligns with the broader ambition for a more advanced understanding of innovation system evolution integrated in a globally embedded context, to provide insights that can inform strategic upgrading strategies for economies facing structural constraints in high-tech industries.

1.4. Research Questions

The main research question guiding this objective is formulated as follows:

- How did the performance of innovation system functions in Malaysia influence its positioning within the global semiconductor value chain from 1970 to the present, and what lessons does this hold for latecomer economies seeking upgrading?

To address this main research question, the thesis is guided by the following sub-research questions:

- How did key actors, networks, and institutions in Malaysia's semiconductor innovation system evolve, and what roles did they play in ATP, wafer-fab, and design?
- How did the underlying functions of the innovation system perform over time, and how did this performance vary across the ATP, wafer fabrication, and design segments?
- How is the global semiconductor value chain structured across functional geographic segments, and where is Malaysia positioned within this structure?
- Which functional enablers and barriers, both domestic and value chain-related, characterized Malaysia's semiconductor innovation system, and how did they influence its upgrading trajectory?

1.5. Scientific Contribution

This thesis contributes to the literature on innovation systems, GVCs, and latecomer industrialization in three ways. It applies the TIS framework in a longitudinal analysis of Malaysia's semiconductor sector from 1980 to the current day, offering insights into functional dynamics and feedback mechanisms in a globally embedded industry. Second, the thesis bridges TIS and GVC approaches by integrating the internal system functions with external structural and governance factors of the value chain. This dual framework approach demonstrates their mutual interdependency and extends existing literature that typically treats GVC positioning and innovation system performance in a more isolated manner.

The findings contribute to latecomer industrialization theory by providing empirically grounded lessons for economies seeking to upgrade within technological complex and globally embedded industries. The Malaysian case reveals that long-term functional strengthening requires, next to target domestic capability building, also strategic engagement with global lead firms and evolving governance regimes. The resulting insights inform both academic debates on industrial upgrading and policy strategies for other latecomer economies, seeking to advance a globally embedded value chain in a high-technology industry.

1.6. Thesis Outline

This thesis is organized into six chapters that collectively address the main research question. The opening chapter starts by introducing the research context, outlining the motivation and relevance, and formulating the main and sub-research questions. Chapter 2 reviews the literature on GVCs, governance structures, upgrading pathways, latecomer industrialization, and the TIS framework. Hereby highlighting the limited interplay between GVC dynamics and innovation systems functions in high-technology industries. Chapter 3 develops the theoretical framework, presenting GVC and TIS as complementary analytical lenses and explaining the way they are applied to examine Malaysia's external positioning in the semiconductor value chain alongside the internal evolution of its innovation system. Chapter 4 further details the methodology, including the research design, temporal and spatial scope, operationalization of research questions, data sources, and analytical steps. Chapter 5 presents the results, starting with the mapping of the global semiconductor value chain and Malaysia's role within it, followed by a longitudinal functional analysis of Malaysia's innovation system across different value chain segments. The final chapter synthesizes the findings to discuss systemic barriers, dependency patterns, governance constraints, and the implications for upgrading. Thereby situating Malaysia's experience within broader debates on latecomer industrialization and concluding with the study's contributions, policy implications, and directions for future research.

2

literature Review

Three main bodies of literature underlie the functional foundation of this thesis: latecomer industrialization, the TIS framework, and GVC analysis. Each offers a complementary perspective for the internal and external dynamics of high-tech sectors and the way latecomer industries seek to enter and upgrade within.

The literature review is organized thematically. It begins with literature on latecomer industrialization, examining how countries accumulate technological capabilities and navigate catch-up trajectories. The second theme outlines the TIS framework and its application to understand systemic systems that shape technological development over time. The final theme reviews how GVC concepts have been applied to the semiconductor industry, with a focus on governance structures, upgrading pathways, and structural asymmetries. Together, these perspectives frame the conceptual ground for analyzing Malaysia's semiconductor trajectory through both innovation system dynamics and its embeddedness in the global production network, to extract lessons for latecomer industries.

2.1. Latecomer Industrialization and Upgrading

The literature on latecomer industrialization centers on how firms and countries accumulate technological capabilities through learning, linkages, and institutional support. In a foundational work on East Asia's electronics sector, Hobday (1995a) illustrates how latecomer firms gained process and product skills by acting as original equipment manufacturers (OEMs) and subcontractors for lead firms. These firms used export market demands to incrementally innovate production processes. As a much later extension to this, Rasiah (2017b) documents how Malaysia's electronics clusters, especially in Penang, benefited from a coordinated blend of state agencies, multinational firms, and local actors, which collectively enabled the gradual upgrading of production capabilities.

A central idea for this is capability accumulation, which suggests that firms and countries can gradually build up technological capabilities, from production and process engineering into design and innovation, to close the gap with incumbents. These processes involve learning efforts such as importing technology, reverse engineering, and investing in human capital development (Lall, 1996). However, often latecomers do not start from scratch, but act as fast followers. Meaning that they adapt and adopt existing technologies, and so they can catch up with new technologies quicker and cheaper (Hobday, 1995b).

Building on this K. Lee and Lim (2001a) identify three distinct catch-up trajectories:

- **Path-following**, where latecomers gradually replicate the steps taken by incumbents.
- **Stage-skipping**, where intermediate stages are bypassed through accelerated capacity building
- **Path-creating**, where latecomers develop novel trajectories or niche specializations.

J. Mathews (2002) further argues that latecomer firms' success depends on targeting resources "that are least rare and most imitable and transferable", while simultaneously forming international linkages and building absorptive capacity.

State versus market-led upgrading

The role of the state in shaping upgrading trajectories is a major point of debate. Classic scholars such as Gerschenkron (1962) and Amsden (1989) argue that active state guidance can alleviate latecomer disadvantages. This view is supported by H. Wang and Lim (2021), who compare China and Malaysia's semiconductor strategies: while both economies attracted FDI, China's pro-active industrial policies (including institutionalized R&D and technology transfer incentives) resulted in more advanced domestic capabilities. Malaysia's more passive, FDI-driven model yielded only limited technological spillovers.

In contrast, other scholars emphasize the role of markets and the learning potential rooted in global market participation. Humphrey and Schmitz (2002) and Kaplinsky and Morris (2001a) highlight that upgrading emerges from the discipline of meeting buyer requirements and interactive learning processes with lead firms.

More recent contributions aim to bridge these perspectives. For example, J. A. Mathews (2002) points to the effectiveness of hybrid approaches, where successful latecomer upgrading typically combines external engagement with selective domestic support.

Diversity of upgrading outcomes
Comparative experiences (see section:1.2) illustrate that there is no single uniform path to upgrading in latecomer industrialization. Comparative experiences illustrate this point: South Korea and Taiwan reached leadership positions in electronics through combining strong state-industry coordination, with integration into global markets, whereas Malaysia has remained in lower-value industry niches despite similar global connections. This uncertainty reveals a critical dilemma in traditional latecomer frameworks: whether countries should follow an incremental, path-dependent approach to capability building or attempt a more radical leapfrogging into higher-value activities (K. Lee & Lim, 2001a).

2.2. Technological Innovation Systems

The TIS framework offers a lens to understand how specific technologies evolve to understand how technologies evolve within the institutional and industrial aspects of innovation. The TIS originates from Carlsson and Stankiewicz (1991). Here, it was emphasized that innovation outcomes are not solely shaped by individual firms, but by an interplay of actors, networks, and institutions. This fundamental perspective set the stage for later studies that reoriented the TIS towards a system of functions. Jacobsson and Johnson (2000) made the shift to not only identifying who is involved in innovation, but also to what these actors do to advance technological knowledge.

M. Hekkert et al. (2007) categorized this into seven interrelated functions that innovative systems require: (knowledge development and diffusion, influence on the direction of search, entrepreneurial experimentation, market formation, resource mobilization legitimation, and development of positive externalities). These functions provide for an analysis of how innovative systems evolve and how they hinder or enable a country's innovative progression. Bergek et al. (2008) further conceptualized this into a stepwise procedure that uses the analysis of functions to identify system failures and formulate recommendations. Malerba (2002) set a sectoral innovation systems framework (SIS) that focused on the knowledge base and technological regimes. For this thesis, the choice was made to focus on TIS as it offers a more functional focus to understand the system's evolution over time.

Several more recent works have extended this way of analyzing a TIS. Markard and Truffer (2008) combines the TIS with a multi-level perspective to understand how multiple layers of actors and regimes shape the innovation system. Binz and Truffer (2017) propose the Global innovation systems framework, which analyzes an innovation goes further than domestic boundaries by acknowledging the cross-border knowledge flow.

These methodological advancements show the importance of conceptualizing an innovation system with regard to global influences. Complementing this Coenen et al. (2012) critiqued earlier TIS approaches for underestimating the role of geography in shaping the systems interactions, especially in globalized innovation systems, such as in this case, the semiconductor industry.

2.3. Global Value Chain

GVCs have increasingly shaped the industrialization trajectories of latecomer economies. While a detailed explanation of the GVC framework follows in section 3.1, this section reviews how GVC-related themes have been addressed in the literature.

Kaplinsky and Morris (2001b) defines a value chain as the full range of activities required to bring a product or service from conception to end use. This not only includes production but also design, marketing, logistics, and all other value-added activities. It is important to consider that value chains are not just linear or vertical structures, but rather consist of a network of interlinked processes in which upstream and downstream actors provide mutual influence. For instance, within the subject of semiconductors, a smartphone company might request that it needs a more powerful energy-efficient chip that supports the new product features. At the same time, the technical limits of chip design may constrain what capabilities the smartphones can have, and thereby what smartphone retailers can offer to their customers. This perspective opens up a more dynamic understanding of industrial systems, moving beyond sectoral or firm-level understanding of industries.

The dynamic concept of the value chain has become especially relevant in the context of globalization. Gereffi and Fernandez-Stark (2011a) presents the concept of GVC as a dispersed network of firms across different countries, where value-adding activities are carried out. GVC-analysis not only examines the sequence of value-adding activities, but also who performs them, where they occur, and how value is captured along the chain. Developing countries participating in a GVC might encounter opportunities, such as employment and access to technology. However, challenges also arise because, in practice, often powerful buyers capture most value through control of design and branding, while suppliers remain in low-value roles. Kaplinsky and Morris (2001b) emphasizes that sustained income growth from global trade “requires the capacity to learn and upgrade”. In GVC terms, this means moving up the chain, which is heavily dependent on the nature of governance and the distribution of powers within the chain.

Value chains can be divided between producer-driven and buyer-driven chains. Buyer-driven chains are common in consumer goods, like electronics and fashion, where brand owners often define product specifications and control market access. Whereas producer-driven chains, such as automobiles and semiconductors, manufacturers coordinate production and set technical standards (Gereffi & Fernandez-Stark, 2011a). This distinction has important implications for industrial upgrading. In buyer-driven chains, upgrading may require building capabilities in design, logistics, or branding. Whereas in producer-driven chains, suppliers follow lead firms in adopting advanced technologies. Kaplinsky and Morris (2001b) underscores that upgrading is crucial for translating participation in GVC into sustained growth. Without, countries risk being locked into low-value-added segments with limited developmental impact.

Building on the conceptual foundations outlined above, this section reviews empirical applications of the GVC in the semiconductor and related electronics industries. The studies reveal four categories that are relevant for understanding Malaysia's positioning within the global semiconductor chain.

The first one is GVC governance. Early GVC research by Gereffi (1999) positioned electronics value chains as hierarchically governed by a small number of firms, that set standards and design with significant constraints for other contributors of the value chain. However, later work by Sturgeon (2002) and Sturgeon and Kawakami (2011a) highlights the rise of modular product designers and contract manufacturing in the electronics industry. This enabled greater supplier specialization and entry, but also strengthened lead firm dominance through control of systems integration and proprietary knowledge. The semiconductor sector illustrates this paradox clearly: firms like TSMC open up the possibility for external modular outsourcing of fabrication. However, control over design tools and the use of equipment remains concentrated in these upstream firms.

Another relevant pattern of literature is about functional upgrading trajectories. Early GVC literature often limits its emphasis on process and product upgrading for the final-assembly context. Later studies cover more complex forms of upgrading. Ernst (2005a) shows that certain semiconductor clusters, including Malaysia and the Philippines, have been able to move into higher value activities, such as advanced ATP, and some design activities. This upgrading has typically occurred through incremental learning with the help of multinational subsidiaries. Lee and Gereffi (2015) builds on this by identifying 'switching' strategies, where firms in South Korea and Taiwan successfully transitioned from assembly to chip design and foundry service. These cases show that governance regimes are not static but evolve with the accumulation of technological and organizational capabilities of firms.

The third strand of literature is about geographic concentration and its systemic risks. Inomata and Hanaka (2021) preliminary underscores that advanced fabrication remains highly concentrated in Taiwan and South Korea, creating risks within global production networks. The less advanced production activities, however, are more dispersed, particularly in South East Asia (Sturgeon & Kawakami, 2011a). Next to the risks, it also shows that countries can perform in high-value segments, while in regions that are characterized as production economies of low value capture. Hence, highlighting the need for an understanding of the specific trajectories.

2.4. Synthesizing for Research Gap

Despite extensive research on GVC dynamics, latecomer trajectories, and innovation system functions, several important knowledge gaps remain. Most notably, literature tends to examine internal and external development mechanisms in isolation, thereby underestimating the complex interactions between innovation systems and global production structures.

While GVC research, particularly the work of Gereffi et al. (2005) and Humphrey and Schmitz (2002), provides insights into global production structures, but tends to focus less on how innovation capabilities evolve or how lessons can be derived from sectoral contexts. On the other side, while the TIS framework has been widely applied to assess performance in various innovation system contexts, proposed by Bergek et al. (2008) and M. Hekkert et al. (2007), it rarely incorporates the external structural constraints posed by novel, highly globalized industries.

Malaysia's semiconductor sector reflects this missing analytical integration. While various studies have examined its industrial developments, only a few studies directly examine the functional dynamics in Malaysia's semiconductor industry in the context of the GVC. Rasiah (2017b) identifies underinvestment in R&D and human capital as major constraints of the sector, which indicates a poorly performing knowledge development function. H. Wang and Lim (2021), compare Malaysia and China, and conclude that passive FDI-driven strategies failed to lead to institutional learning, which indicates weak legitimation and poor entrepreneurial experimentation. K. Lee and Lim (2001b) highlighted that even in the foreign-dominated electronics sector, micro-level strategic actions are important. One of the few direct TIS analyses on this topic is provided by H. K. Lim et al. (2025), who examines the development and diffusion as functions for gallium nitride technology in Malaysia. While the results are acknowledgeable, the study purposefully limits its functional scope and calls for broader analysis of TIS dynamics in the sector. Next to that, Lema et al. (2020) gives a similar context of Malaysia's semiconductor industry, by sketching its trajectory and shortly going into its value chain structure, within the context of green industrial policy, yet without analyzing its innovation system functions. In addition, while the GVC literature increasingly discusses upgrading trajectories in electronics and semiconductors (Ernst, 2005b; Sturgeon & Kawakami, 2011a), it tends to approach these from a firm-level or governance-centric lens. Less is known about how such upgrading interacts with functional system weaknesses or strengths. Likewise, classic latecomer development theory emphasizes the role of state support, absorptive capacity, and fast-follower strategies (Lall, 1996; K. Lee, 2024); however, it provides little guidance on how such capabilities unfold with evolving innovation system structures embedded in globalized production networks.

This thesis addresses these gaps by combining a longitudinal, function-based TIS analysis with a sectoral GVC perspective to analyze the evolution of Malaysia's semiconductor industry. By tracing the longitudinal dynamics of system functions and the structural positioning within the GVC, the thesis develops a dual-level explanatory approach that captures how internal and external forces interact in shaping upgrading outcomes. This integrated perspective makes it possible to identify not only structural constraints and enablers of upgrading, but also how systemic patterns in weaknesses or strengths emerge, persist, or are resolved. In doing so, the thesis attempts to gain a better understanding of latecomer economies that attempt to engage with globally embedded innovation systems in complex, high-tech sectors.

3

Theoretical Framework

This chapter introduces the conceptual frameworks applied in this thesis: GVC analysis and the TIS framework. While the previous chapter reviewed related literature, here the emphasis is on defining and operationalizing these frameworks to analyze Malaysia's semiconductor trajectory.

3.1. Global Value Chain Framework

The global value chain framework provides a lens to get an understanding of how industries are organized across borders, and how value is created and distributed among actors. This makes it useful for analyzing industries where production is fragmented across countries and where relations between firms and actors influence market outcomes and technological development.

In high-tech sectors like semiconductors, GVC governance structures and high-entry barriers determine both a country's position in the value chain and its scope for moving into higher-value segments. Participation in the GVC offers countries opportunities for industrial growth, but also poses challenges in overcoming structural constraints imposed by governance arrangements.

By applying the GVC framework to the semiconductor industry, this thesis examines the distribution of activities and power across segments and the structural conditions that shape Malaysia's position within the value chain.

3.1.1. Global value chain governance

Governance in the context of GVC refers to the coordination and control of the value chain activities and how the value is distributed across different firms. It is all about who has decision-making authority, how and what kind of information flows across firms, and what powers suppliers have. To understand how tasks are divided, how capabilities are developed, and how upgrading opportunities are shaped, it is crucial to identify the governance arrangement within the globalized value chain (Gereffi et al., 2005; Humphrey & Schmitz, 2002).

Based on different types of value chains (markets, modular, relational, captive, and hierarchical), J. Lee and Gereffi (2015) identified belonging types of governance that are to be expected for each type. These types are distinguished by different levels of control, codified knowledge, and supplier capabilities.

In a market-based governance, there is minimal coordination between firms, and transactions are mostly price-driven. Modular governance applies when suppliers mainly meet the lead firm's requirements through specifications and codified language. Within these types, suppliers often deliver assembled subsystems and have a high level of autonomy.

Relational governance is characterized by hard-to-codify tasks, with reliance on trust and reputation, which leads to mutual interdependence and a high amount of exchange through tacit knowledge. In situations where joint problem-solving is required, this creates opportunities for incremental upgrading and development. (Gereffi & Fernandez-Stark, 2011a; Kaplinsky & Morris, 2001c). In captive governance, lead firms have high control over suppliers. Suppliers in this type often have defined tasks with difficult characteristics for learning or upgrading. The fifth governance type is hierarchical, which has the most integrated form of governance. Lead firms internalize production activities, control knowledge flows, and production processes. These systems involve minimal inter-firm exchanges (Cattaneo et al., 2013).

The characteristics of the governance types become especially relevant in sector with high-technology sectors. The global semiconductor value chain is overall characterized by highly coordinated governance structures with high levels of control. The type of governance differs across segments. Segments like advanced design, photolithography, and equipment manufacturing often operate in hierarchical or captive arrangements due to the complexity and strategic value. However, back-end operations, such as ATP, tend to be governed in captive or modular forms, where process knowledge is standardized, and suppliers operate under close supervision (Ernst, 2005b; Sturgeon & Kawakami, 2011a). Malaysia, as a participant in the semiconductor GVC, has mainly operated with characteristics belonging to captive or hierarchical structures. Foreign MNCs capture dominance in design and process development while Malaysian firms operate in ATP activities. Advancements by suppliers have primarily occurred within the boundaries set by the MNCs. Some firms, however, have managed to expand into higher-value activities. These patterns shape the functional patterns of innovation and upgrading across the semiconductor value chain, and are thus a central concept to describe industrial development trajectories.

3.1.2. Value chain upgrading

Firms and players often aim to improve their position within GVCs to attain higher-value activities or more strategic power; this is referred to as value chain upgrading (Humphrey & Schmitz, 2002). Define the purpose of this term for firms as to: ”increase the skill content of their activities and/or move into market niches which have entry barriers and are therefore insulated to some extent from these pressures”. This upgrading is not just a matter of improving efficiency, but more a structural change towards more complex, high margins and often highly innovative tasks (Gereffi et al., 2005; Kaplinsky & Morris, 2001c).

Next to a structural change, it also alters the position that firms have, by increasing the autonomy, dependency, and influence within the chain (Gereffi & Fernandez-Stark, 2011b). Upgrading remains a versatile and complicated riddle that latecomer economies seek a solution for to escape low-age assembly roles.

The GVC literature distinguishes four types of upgrading, each contains different ways of advancement in capabilities.

- **Process upgrading** improves production efficiency en enables cost reduction, without changing the product or function.
- **Product upgrading** involves producing more complex or higher quality goods. This is often done in response to changing buyer or market demands, and requires more knowledge, better materials, or tighter tolerances
- **Functional upgrading** is established when firms require a new role in the value chain. This means a vertical shift in strategic control and often demands a different set of skills and institutional support.
- **Inter-sectoral/chain upgrading** occurs when the existing capabilities are applied to a new sector or value chain.

The ability to upgrade depends on multiple factors. The GVC governance structure shapes which and what type of upgrading is possible. When firms controlled by lead firms over design, branding, and market access, thus in hierarchical or captive chains, they often face limited scope for functional upgrading (Gereffi et al., 2005; J. Lee & Gereffi, 2015). In these situations, the process upgrading is usual, as it benefits the lead firms for quality improvements and cost reductions.

Next to governance dynamics, also institutional conditions play a role in the ability to upgrade. Upgrading trajectories are purely dependent on the value chain, but are further shaped by the technological system of innovation. For example, the quality of education systems, the role of supporting organizations, and the IP regime all influence the factors for upgrading.

3.1.3. Global value chain of semiconductors

The industry for producing semiconductors is structured as a globally distributed system. Different countries specialize in specific segments of the value chain, such as raw material extraction, equipment manufacturing, chip design, wafer fabrication and assembly, and testing. This fragmentation aligns with the conceptual logic of GVC. Literature on GVC describes the way that value creation and capture are distributed across borders. Upstream and knowledge-intensive segments are dominated by a few countries and firms, while downstream, more labor-intensive processes are more widely dispersed (Gereffi & Fernandez-Stark, 2011a). The semiconductor GVC is concentrated in several dominant countries. The United States leads in IC design and software tools, Japan and the Netherlands are specialized in manufacturing equipment, while Taiwan and South Korea dominate wafer fabrication, and Malaysia and China capture large chunks of assembly, testing, and packaging operations. The distribution of activities across the value chain reflects the characteristics of each segment. Low-value segments, such as assembly and testing, are more accessible due to lower capital and knowledge requirements. Whereas segments like IC design and wafer fabrication are characterized by significant knowledge and capital-intensive barriers. Furthermore, upgrading into higher value segments is constrained by substantial barriers such as tacit knowledge accumulation and IP restrictions (J. Lee & Gereffi, 2015; Rasiah, 2017a).

Understanding the structure of the semiconductor GVC provides the foundation for explaining which conditions countries participate in and upgrade within the chain. It also forms the theoretical grounding for assessing how Malaysia has positioned itself in the global semiconductor industry. The semiconductor production process follows a fragmented and interdependent sequence of stages. It begins with research and development (R&D) and the design of integrated circuits (ICs), enabled by electronic design automation (EDA) software. This is followed by wafer fabrication, which depends on highly refined materials and specialized equipment supplied by advanced equipment manufacturers. The process concludes with ATP, which prepares chips for integration into end products (see figure 3.1)

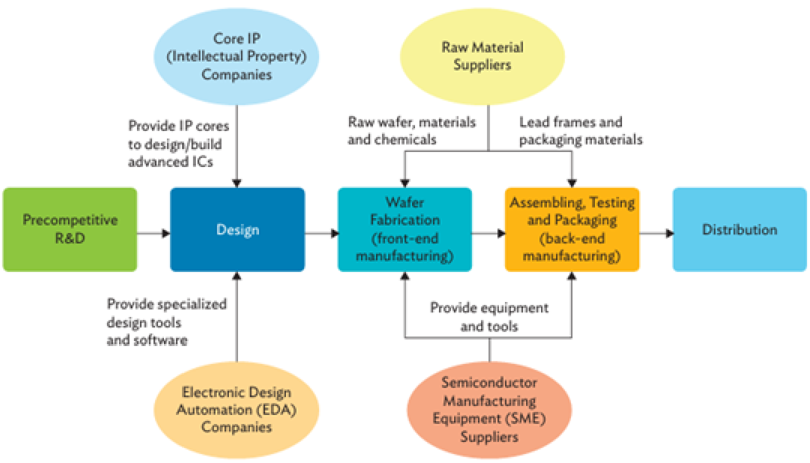

Figure 3.1: "The semiconductor production process"
retrieved from: (Munday et al., 2024)

3.2. Technological Innovation Systems Framework

As an analytical instrument, a framework is applied that combines a structural and functional TIS perspective to assess how actors, networks, and institutions interacted over time to enable or constrain its trajectory within the semiconductor GVC.

3.2.1. Technological innovation system fundamentals

The TIS framework provides a structured lens to understand the specific technology developments and innovations within the broader socio-economic context. Originating from the innovations systems literature of the late 1980s, the TIS approach was formerly introduced as a variation of innovation systems focusing on a particular technology rather than a country or sector. B. Carlsson and R. Stankiewicz, 1991 defined a TIS as ”a network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology”. National or Regional Innovation Systems assess innovation capacity at the country or regional level. A TIS, on the other hand, focuses on a specific technology or knowledge, while still operating within a defined geographical context, to examine the factors that influence its innovation and diffusion. This provides an analytical tool that, in practice, is used to study the dynamics of emerging technologies and to identify system strengths or weaknesses that can inform policy intervention. Over the past decade, it has become an approach for analyzing innovation in complex and evolving industries. For example, it is considered a key framework in sustainability transitions research and has been applied to novel technologies, such as solar photovoltaics, wind energy, and hydrogen fuel vehicles(M. Hekkert et al., 2007) (Markard et al., 2015).

A standard TIS analysis maps out the core structural components, including actors, networks, and institutions that shape innovations. The actors include the organizations and individuals-such as, firms, universities, research institutes, government agencies, intermediaries, and end-users, that contribute to the development of the technology. These actors are intertwined through networks of relationships that can be formal collaborations, informal connections, industry alliances, and knowledge exchange networks. Guiding these interactions is the set of institutions, including the formal regulations, policies, standards, and the informal cultural norms and values that shape the way actors behave, and with it, how the technology evolves.

Overall, a TIS can be seen as a configuration of different kinds of actors linked by networks, while operating under a specific institutional framework to create and diffuse new knowledge, products, and processes. By examining these elements, this framework helps diagnose the state of an innovation system by, for example, identifying if crucial actors are missing, if networks are weak or fragmented, or if institutional barriers are hindering progress. This perspective offers an insight into the innovation capacity of technological fields and provides a foundation for understanding how well the system can support the technology’s maturation.

Nevertheless, it is important to acknowledge that the TIS approach has certain limitations. Scholars have critiqued the standard TIS for sometimes being too inward-focused – potentially neglecting external or contextual factors – and for the analytical challenge of delineating system boundaries (deciding what is inside or outside a given TIS) (Bergek et al., 2015; Markard & Truffer, 2008; Markard et al., 2015) Other critiques point to insufficient consideration of geographical scale and political power in early TIS studies (Coenen et al., 2012; Markard et al., 2015; Smith & Raven, 2012). Despite these criticisms, the TIS framework remains a robust conceptual tool in innovation studies.

Structural mapping of a TIS involves identifying and characterizing its building blocks. In the context of Malaysia's semiconductor industry, this means mapping the actors, networks, and institutions that shaped the semiconductor innovation system. Within this context, these three structural elements are defined as follows:

- **Actors:** organizations and individuals that influence the semiconductor innovation in Malaysia. This includes industrial actors such as firms, government agencies and ministries, research and educational institutions, and industry associations. Identifying the most important actors provides a foundation for understanding who contributed resources, knowledge, or policy support across the industry.
- **Networks:** the relationships among these actors, taking the form of formal collaborations and linkages (joint R&D programs, industry clusters, and policy networks). Next to that, it includes informal networks, such as personal ties between industry actors. Mapping these networks sheds light on how knowledge flows among actors, facilitating or hindering the innovation process.
- **Institutions:** the overarching structures that affect behavior in Malaysia's semiconductor TIS. This includes formal institutions (laws, regulations, and policies) that set strategic directions for the industry, as well as informal institutions, like cultural norms, expectations, and unwritten practices. Mapping institutions clarifies the incentives, constraints, and enabling conditions that shaped innovation development.

3.2.2. Functional TIS

Beyond mapping structure, an extension of the TIS framework also highlights how these components interact to drive innovation. To explore how semiconductor industries emerge in different contexts, this thesis applies the TIS framework through the functional lens proposed by (Bergek et al., 2008). While the standard TIS approach focuses on actors, networks, and institutions,(B. Carlsson and R. Stankiewicz, 1991), the functional perspective shifts the emphasis toward understanding how well an innovation system performs. It complements the structural analysis by examining dynamic system behavior, while still building on the actors–networks–institutions foundation. Rather than asking *who is involved*, the functional TIS framework investigates *what is happening* within the system. This distinction enables the analysis to move beyond static structural mapping and toward assessing whether the necessary processes for innovation are in place.

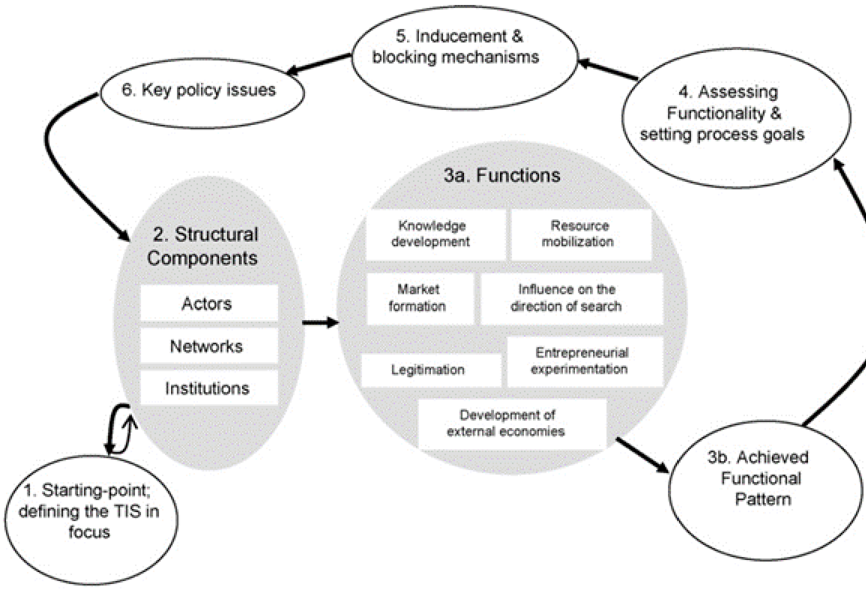

Figure 3.2: Functional TIS methodology framework
- extracted from: (Bergek et al., 2008)

In line with (Bergek et al., 2008), the following seven functions will be examined in the Malaysian semiconductor innovation system.

- **Knowledge development:** captures the creation and diffusion of knowledge among actors. It reflects the strength of the sector's knowledge base and learning mechanisms. In operational terms, the indicators include the establishment of R&D centers and laboratories (both public and private), the introduction of technology-related programs in universities or training institutes, technology transfer instances, patenting or publication activity, and forums for knowledge exchange. In addition, the analysis considers GVC-related mechanisms such as the establishment of foreign-led R&D units, and knowledge within international standards. A strong fulfillment of this function is indicated by the evolution from basic ATP capabilities, starting in the 1970s, towards the present, more sophisticated embedded knowledge in ATP, design, and wafer fabrication.

- **Influence on the direction of search:** concerns the incentives and pressures that shape the priority for innovation activities. It covers factors of the role of government policies and plans (such as the Industrial Master Plans and specific technology programs that identified electronics and semiconductors as a growth sector). Next to that, it includes fiscal and regulatory incentives as well as market signals from global semiconductor trends. From a GVC perspective, evolving requirements from the lead firm and international standards influenced the technological direction. Visions and expectations set by leaders and experts, to climb the value chain, are also considered. Together, these elements indicate how internal and external factors directed actor attention across different technological and value chain segments over time.
- **Entrepreneurial Experimentation:** This function reflects the trial-and-error activity in which new ventures emerge and existing ones diversify. For Malaysia, this includes emerging local firms, spin-offs from established firms, and pilot projects or innovative experiments that took place. Government programs aimed at fostering tech entrepreneurs, such as tech parks or incubator schemes, are also relevant. From a GVC lens, the degree of flexibility allowed by lead firms and the formation of joint ventures shape the entrepreneurial activity. A strong experimentation function would be reflected in multiple firms attempting new initiatives in the sector across multiple stages of the value chain, rather than depending on a few foreign MNC branches alone.
- **Market formation:** involves the development of markets for semiconductor products and related industries. In Malaysia's export-oriented context, this involves integration into global product markets. Indicators include consistent export demands and the creation of domestic market and regional niches. Policy efforts to create or secure markets, such as export promotion or trade agreements, as well as protective measures or domestic procurement, are considered. From the GVC perspective, the degree of autonomous and market access for domestic actors is important. Sustained market access, integration of end-use applications would suggest a more mature market formation.
- **Legitimation:** is about the degree of social and political support of the semiconductor industry. This includes government rhetoric and vision, the formation and role of industry associations in lobbying, and the extent to which the industry aligned with the country's development goals and social values (for instance, job creation for Malaysians, and industrial and technological upgrading) Evidence that the semiconductor industry gained high-level political support and that it attracted positive attention in media and academia would indicate a strong legitimation function. Challenges to legitimation may arise from critiques of foreign dominance or the lack of domestic benefits.

- **Resource mobilization:** analyzes how well various resources were mobilized during its development, such as financial capital, human capital, and complementary assets. It includes FDI inflows, state support regulations, and infrastructural development, as well as indicators of talent through the expansion of education and training related to electronics. Strong resource mobilization would be reflected by capital intensity that supports upstream movement, a growing talent base, and access to specialized infrastructure and services.
- **Development of positive externalities:** represents the spillover benefits that emerge as the innovation system matures. In other words, it captures the self-reinforcing "free utilities" generated by a developing industry, such as pooled labor markets, knowledge spillovers, and the emergence of specialized suppliers or additional industries. In Malaysia's case, it assesses whether a semiconductor cluster effect emerged, creating a pool of skilled labor and expertise through tacit knowledge sharing. This supports the industry around ATP firms and enables experienced engineers from multinational firms to start local ventures, thus spreading know-how within the innovation system.

4

Methodology

4.1. Research Design

This thesis applies a dual-framework research design, combining the TIS framework with GVC analysis. The two frameworks are used in a complementary manner to examine both internal and external dimensions of industrial development.

The TIS framework is applied to enable tracing how the seven system functions of Bergek et al. (2008) have evolved over time and across different value chain segments. This allows the identification of the strengths, weaknesses, and shifts in Malaysia's semiconductor innovation system from the start to the current day.

The GVC analysis complements the TIS analysis by positioning Malaysia's semiconductor innovation system within the broader global production network. It focuses on mapping different semiconductor value chain segments, identifying governance structures, and thereby assessing upgrading constraints and opportunities.

Combining these perspectives, the research design enables an integrated analysis where the TIS framework reveals the functional system dynamics of the actors, networks, and institutions that shaped Malaysia's innovation system performance, while the GVC framework situates the dynamics concerning global production structures. The synthesis of both frameworks supports a better understanding of how internal systems function and external structural conditions jointly influence Malaysia's upgrading trajectory. This way, the thesis tries to unravel the mechanisms that enable or constrain industrial progression.

4.1.1. Case selection

Malaysia is chosen as a case because it represents a distinct trajectory within the semiconductor GVC. Unlike typical latecomer success stories such as Taiwan or South Korea, structurally locked-in cases such as Thailand, or strategically dominant semiconductor champions such as the United States and Japan, Malaysia occupies a dual position: it is simultaneously essential at the lower end of the value chain yet constrained in its attempt to move upward. This duality makes Malaysia particularly insightful to examine how the innovation system functions under the pressure of hierarchical codified GVC structures. Furthermore, the availability of longitudinal policy archive, industry-level data, and access to information-rich industry actors provide an empirical advantage. This offers a unique setting to investigate how systemic innovation functions within a globalized semiconductor industry structure.

4.1.2. Temporal and spatial scope

The analysis in this thesis resembles a longitudinal and qualitative research design. It covers the period from 1970 to the present to capture the Malaysian semiconductor industry as an evolving innovation system, instead of a static outcome. This enables tracing the functional dynamics of the system over multiple industrial development phases, while relating these to changing GVC characteristics over time.

The spatial scope of the analysis is primarily national, while the industrial trajectory is shaped by national policy frameworks, institutional arrangements, and regional clusters. However, because the technological innovation system is embedded in a globalized value chain, it incorporates Malaysia's global linkages as a contextual dimension. This combined perspective reflects the hybrid nature of the semiconductor industry,

The time frame of this thesis covers 1970 to the present to capture Malaysia's full historical trajectory. The spatial scope of the analysis is mainly national. Malaysia's development trajectory has largely been shaped by nationally coordinated strategies and regionally concentrated clusters. Nevertheless, the study also incorporates Malaysia's global linkages, particularly its integration into multinational production networks and GVCs. This combined spatial perspective reflects the hybrid nature of the semiconductor industry, which combines localized policy instruments and institutional dynamics with international interactions.

4.2. Operationalization of Sub-Research Questions

To ensure methodological transparency, each sub-research question(SRQ) is operationalized within the research design. The SRQs are linked to components of the TIS framework, data sources, and analytical strategies to support a traceable research logic.

SRQ1: How did key actors, networks, and institutions in Malaysia's semiconductor innovation system evolve, and what roles did they play in ATP, wafer-fab, and design?

This question is addressed through the structural mapping of Malaysia's semiconductor innovation system, following the TIS framework's core elements: actors, networks, and institutions(B. Carlsson and R. Stankiewicz, 1991). The mapping is conducted longitudinally to capture shifts over time and across value chain segments. The evidence for the answers is derived from archival policy documents, scientific literature, and interviews with industry experts.

SRQ2: How did the underlying functions of the innovation system perform over time, and how did this performance vary across the ATP, wafer fabrication, and design segments?

The second question is operationalized through a functional analysis (Bergek et al., 2008). This examines how well the seven system functions performed over time. The analysis is both temporal and segmental, while it identifies functional strengths and weaknesses over time in specific segments of the value chain. The performance of each function is assessed by triangulating indicators in Table 4.1 with evidence from policy archives, industry reports, trade and FDI patterns, and interview data. The judgments are made relative to the performance of other functions in Malaysia during the same period and to the ability to support upgrading within the relevant segments.

SRQ3: How is the global semiconductor value chain structured across functional geographic segments, and where is Malaysia positioned within this structure?

This question is addressed through a segmental mapping of the semiconductor value chain, by disaggregating up-, mid, and downstream activities and their geographic concentration. The mapping is based on established GVC segmentation approaches and integrates sector-specific insights from semiconductor industry studies and reports. Sources include global market reports, trade statistics, and segment-specific intelligence reports. Malaysia's position is then located within this structure while acknowledging the barriers that separate or characterize different segments.

SRQ4: Which functional enablers and barriers, both domestic and value chain-related, characterized Malaysia's semiconductor innovation system, and how did they influence its upgrading trajectory?

The fourth question synthesizes insights from the previous SRQs to identify key enabling mechanisms and bottlenecks that have shaped Malaysia's trajectory. The findings are contextualized within the nature of the semiconductor GVC. This perspective forms the basis for deriving broader lessons for latecomer economies.

4.3. Sources of Data

The material used for this thesis was gathered through a combination of desk research and semi-structured interviews, complementing each other to ensure breadth and depth of the insights. The data collection uses triangulation, drawing on multiple sources and source types, to strengthen the findings and enhance analytical reliability. This approach was applied to both the functional assessment of the innovation system and the complementary analysis of Malaysia's positioning within the global semiconductor value chain.

4.3.1. Secondary data

formed the foundation for mapping the historical and institutional trajectory of Malaysia. These include sector-specific research, government policy documents, archival materials, and research from industry agencies, as well as data on trade, exports, and human capital indicators. Academic literature provided additional context. The GVC analysis was conducted entirely through desk research, drawing on industry reports, market databases, and publications from semiconductor segment-specific associations. These sources were used to map the structure of the GVC, its governance modes, and the distribution of activities across geographic and functional segments.

4.3.2. Primary data: semi-structured interviews

The primary data consists of three semi-structured interviews that complement the secondary data and provide internally grounded perspectives on Malaysia's semiconductor innovation system. The interviews were conducted with actors who occupy strategically significant positions within the sector. All respondents are anonymized to ensure confidentiality. The backgrounds of each indicate high-level expertise and strategic insights into the evolution of the industry. The participants consisted of:

- The executive director of a leading Malaysian semiconductor association, thus representing industry interest and policy engagement.
- A senior researcher specialized in semiconductors at a national technological research institute with expertise in both domestic and global semiconductor dynamics.
- A senior director at a multinational circuit-design firm. Serving also as Penang site leader and international branch director, offering perspectives on operational and global coordination of a significant multinational firm that has activities in Malaysia.

The interviews were designed to gain first-hand accounts of the sector's development, functional strengths and weaknesses, and events and conditions that influenced Malaysia's positioning within the global semiconductor value chain. The interview was semi-structured around the seven functions of the TIS framework, while allowing flexibility for dynamic narratives based on the specific experience of the participant.

Audio recordings were transcribed and thematically coded according to the seven TIS functions over time and across value chain segments. Interview evidence was triangulated with secondary sources to enhance empirical robustness and validate findings. Illustrative paraphrased sentences are provided in the Appendix 8. The illustrative phrasing maintains the original intent of the interviewees while safeguarding their anonymity.

4.4. Indicators for Assessing TIS Functions

The functions are separately assessed with the help of indicators, sources, and interviews that are relevant for each.

TIS Function	Potential Indicators	Research Sources & Interview Targets
1. Knowledge Development & Diffusion	- Number of R&D centers - Tech-related university programs established - Patent activity - Joint research projects - Knowledge transfer programs	- Archival research: Government reports - University archives (curriculum evolution) - Interviews: Former academics, R&D managers in MNCs
2. Influence on Direction of Search	- Industrial policies - FDI trends in semiconductors - Global market signals - Tax incentives, subsidies	- Policy documents - Interviews: Industry experts, industry association representatives (MSIA)
3. Entrepreneurial Experimentation	- Number of local firm entries into semiconductor-related activities - Spin-offs from MNCs - Pilot projects - Government entrepreneurship schemes	- Company records: Early histories of local firms - Interviews: MNC employees
4. Market Formation	- Export volumes of semiconductor products - Presence or absence of domestic demand - Niche market initiatives	- Trade statistics - Interviews: industry associations, research institutes, MNC supply chain managers
5. Legitimation	- Political speeches, policy narratives - Media coverage of semiconductors - Formation of industry associations - Public-private partnerships	- Media archives: Newspapers, economic magazines - Government communications - Interviews: industry associations, regional policymakers
6. Resource Mobilization	- Availability of skilled labor (engineering/tech graduates) - FDI inflows - Presence of venture capital or state funding schemes - Infrastructure development	- Education statistics: Ministry of Higher Education - Investment data: MIDA archives - Interviews: Sr managers in MNCs, research institutes
7. Development of Positive Externalities	- Growth of supplier networks - Labor mobility from MNCs to local firms - Emergence of clusters - Knowledge spillovers - Formation of service providers	- Cluster studies: Literature on Penang/Kulim - Interviews: Industry veterans, supply chain managers, local chamber of commerce, former cluster coordinators

Table 4.1: TIS Functions data indicators - composed by author

Note: The selection of indicators for assessing each TIS function draws on established operationalisations in the TIS literature (Bergek et al., 2008; M. P. Hekkert et al., 2007; Suurs, 2009), as well as subsequent empirical application in manufacturing and high-tech sectors (Binz et al., 2016; Markard & Truffer, 2008). Where possible, sector-specific studies of electronics and semiconductor industries were consulted to ensure relevance to Malaysia's context (Lema et al., 2018; J. A. Mathews, 2002). These sources informed the choice of measurable proxies that are widely used in the literature to assess functional performance.

4.5. Data Collection for Global Value Chain Analysis

The GVC analysis in this thesis was conducted entirely through desk research. The mapping of the semiconductor value chain integrates segment-level analysis, geographic distribution patterns, governance structures, and Malaysia's empirical poisoning. The analysis draws on a wide range of secondary sources, including industry reports from market research firms, trade statistics, and publications from semiconductor sector-specific associations such as SEMI and the World Semiconductor Council. These were complemented by academic literature on GVC theory and semiconductor industry studies. The combined evidence was used to identify GVC characteristics relevant to Malaysia's innovation system trajectory.

5

Results and Findings

Part I - Global Value Chain Analysis

5.1. Semiconductor Segment Mapping

Raw material extraction

Raw material extraction is the most upstream segment of the GVC. The mined material resources are essential for subsequent semiconductor and equipment manufacturing. These materials include a variety of critical minerals such as silicon, cobalt, gallium, rare earth elements (REEs), and tantalum. Each plays a specific role in the functionality and production of semiconductors. The materials are deemed critical due to the strategic risks associated with their supply chains. The vulnerabilities stem from geopolitical tensions, regulatory restrictions, and environmental constraints, aggravated by the tight concentration of material extraction in a few, often politically unstable and tightly controlled, countries (Teer & Bertolini, 2022) (Goswami, 2023).

Given their strategic importance, countries including the United States, European Union, and China regularly update their critical raw material lists to reflect changing dependencies (Berg et al., 2024).

The following table 5.1 lists ten of these materials, describing their use and noting whether each is considered critical by the United States, European Union, and China.

Material	Use in Semiconductor Value Chain	US	EU	China
Silicon	The most widely used material for making semiconductor chips; it forms the base layer for electronic circuits.	No	Yes	No
Germanium	Used in high-speed electronic components and optical devices such as fiber-optic cables and infrared sensors.	Yes	Yes	No
Gallium	Combined with other elements to make materials used in LEDs, mobile networks (5G), and radar systems.	No	Yes	No
Indium	Used in thin, transparent layers for touchscreen displays and solar panels, and sometimes in chip connections.	Yes	No	No
Tantalum	Enables very small and stable capacitors, which store electrical energy in smartphones and computers.	Yes	Yes	No
Cobalt	Applied in advanced layers of microchips to improve electrical flow and reliability in small circuits.	Yes	Yes	Yes
Hafnium	Used to improve the energy efficiency and speed of transistors—the tiny switches in all electronic devices.	Yes	Yes	No
Rare Earth Elements	A group of elements used to polish chip surfaces, enhance certain chip properties, and power high-precision equipment.	Yes	Yes	Yes
Nickel	Used in protective layers and to help connect microchips to other parts of the device during packaging.	Yes	Yes	Yes
Arsenic	Combined with gallium to make materials that are faster and more heat-resistant than traditional silicon.	Yes	Yes	No

Table 5.1: Selected critical materials and their designation by major economies. Compiled by the author using information from (Baskaran & Schwartz, 2024; Bobba et al., 2020).

In addition to the designations by governments, the production of these materials is also highly concentrated in a handful of countries and firms, further amplifying supply risks, see table:5.2

Material	Dominant Countries	Leading Firms
Gallium	China (70% of global production)	Jinmei Gallium, Chalco (China)
Rare Earth Elements (REEs)	China (90% of global output), Australia	Northern Rare Earth Group (China), Lynas Rare Earths (Australia–Malaysia)
Cobalt	DRC (73% of mined cobalt)	Glencore–KCC (DRC), CMOC–Tenke Fungurume Mining (DRC)
Tantalum	DRC, Australia	Various regional operators
High-Purity Quartz	Norway, China, United States	Uninformed by firms (commodity market)

Table 5.2: Dominant firms and countries in the production of selected critical raw materials. Compiled by the author using data from (Austria, 2024; B. G. Survey, 2024; U. S. G. Survey, 2024).

China has not deemed many of these minerals critical. It benefits from a strong position in this segment, not necessarily due to extensive domestic mining, but through strategic international investments, ownership of mines, combined with infrastructure developments, and skilled labor. This strategy reduces China's exposure to typical supply risks that affect other nations (Capitalist, 2023; Goswami, 2023).

The extraction process, while resource-intensive, does not typically require advanced technological capabilities. Instead, it depends on geopolitical influence, capital investments, and environmental management (Spanjersberg, 2024). Relative to downstream segments, it involves lower innovation cycles and less proprietary knowledge. However, its economic and strategic importance lies in its position as a supply-chain choke point, due to production interdependencies and limited substitutes (Goswami, 2023).

This strategic significance far exceeds its direct economic contribution, as raw material extraction captures only a minor proportion of the total semiconductor value (see figure 5.1). Fluctuations in the supply of extracted materials can significantly affect inputs further along the value chain. China's strategic positioning at the extraction stage reinforces its dominance in the subsequent refining segment.

Material refining

Material refining, conversion, and processing involve transforming raw minerals into semiconductor-ready inputs, such as silicon wafers, specialty gases, and high-purity chemicals. This segment functions as a bridge between extraction activities and midstream activities, enabling wafer fabrication and equipment manufacturing. It converts minerals into inputs that meet the material-property standards required for further application. Key steps include the refinement of silica sand into polycrystalline silicon, purifying REEs, and producing gases like neon and argon (IEEE IRDS™, 2025).

The refining and processing segment is characterized by high technical barriers and capital intensity. Facilities that produce these materials, such as polysilicon plants and high-purity chemical refineries, require specialized chemical and metallurgical expertise alongside million-dollar investments. While not as costly as wafer fabrication, these facilities still demand long-term operation to recover costs. Furthermore, materials for semiconductors require high purity levels, as even the smallest impurities can damage device yields (Musso et al., 2025).

These high entry barriers are reflected in the highly concentrated market structure: only five suppliers (Shin-Etsu Handotai and SUMCO (Japan), Global Wafers (Taiwan), Siltronic (Germany), and SK Siltron (South Korea) collectively provide about 95% of global silicon wafers, and just three Japanese firms (JSR Corporation, Tokyo Ohka Kogyo (TOK), and Shin-Etsu Chemical) together control over 90% of advanced photoresist sales (Kleinhans & Hess, 2021). This extreme concentration amplifies supply risks, which result not from the physical scarcity of raw materials but from concentrated refining capacity. For example, China and Africa collectively supply around 70% of the world's raw tantalum and silicon, while China dominates nearly all global gallium refining and REE processing. Ukraine supplied over 70% of the world's neon. Disruptions in these concentrated supply chains, as demonstrated by the Russia-Ukraine war, have made the supply scarce and prices volatile (Spanjersberg, 2024). The EU has responded with the Critical Raw Material Act, which aims to reduce dependence on foreign suppliers (European Commission, 2023).

Although material refining and processing accounts for only about 5% of the semiconductor industry's total revenue (see figure 5.1), it is essential for converting raw inputs into electronics-grade materials. The segment is tightly interlinked with both upstream supply risks and downstream performance requirements.

Manufacturing equipment

The manufacturing equipment segment refers to the production of specialized machinery and instruments that are essential for making semiconductor devices. These tools perform the critical process steps that transform raw silicon wafers into integrated circuits. The tools include lithography scanners, deposition systems, etchers, and metrology instruments, among others. In total, chip fabrication requires over fifty types of such capital-intensive equipment. Industry-wide spending on semiconductor manufacturing equipment reached roughly $71 billion in 2020. Both the front-end wafer fabrication stage and the back-end assembly stage depend heavily on these tools, with front-end accounting for over 85% of equipment spending (CSIS, 2023). Even though the production of manufacturing equipment is not a direct step in the flow of material, it serves as a crucial parallel enabler of midstream production.

The technological requirements of this equipment are demanding. Wafer fabrication facilities operate at nanometer and even atomic scales, requiring equipment of extraordinary precision (CSIS, 2023). Developing such equipment entails significant R&D investments and engineering expertise, resulting in high entry barriers and a concentrated industry structure. Some equipment categories only have a few suppliers worldwide; for example, the latest extreme ultraviolet lithography systems (EUV), necessary for cutting-edge chips, are produced exclusively by a single company - ASML. The segment also faces high cost barriers: a single EUV-scanner costs around $150 million, and leading firms typically reinvest 10-15% of their revenues into R&D to keep up with innovations (Varas et al., 2021). These factors (technological complexity, long-term IP advantages, and high costs) underscore the barriers that define the equipment manufacturing segments.

From an economic perspective, the equipment segment creates value by enabling mid- and downstream manufacturing and captures value through the sale and servicing of its high-tech tools. Analysis of the value chain suggests that equipment manufacturers contribute approximately 12% of total value added. Smaller than that of chip design or wafer fabrication firms (see Figure 5.1). Value capture in this segment is driven by the capital value of equipment, supplier scarcity, and the essential enabling role in mid- and downstream processes. A key aspect of the economic model is the two-sided revenue stream: initial equipment sales and post-sale services. The services include maintenance, process tuning, and upgrades.

The equipment segment highlights the deep global interdependence of the value chain. While leading producers of semiconductor equipment are based in the United States, Japan, and parts of Europe (SEMI & VLSIresearch, 2024), their customer base is concentrated in East Asia (Taiwan, South Korea, and China), see Figure 5.2. Firms from the United States and Japan account for over 70% of global wafer fabrication equipment, and in some cases, up to 90% of their output is exported to the Indo-Pacific region. This not only makes cross-continent collaboration essential but also creates strategic vulnerabilities. Additionally, equipment suppliers often co-develop equipment in partnership with chip-makers to meet specific process requirements. Such arrangements lead to closed relationships and feedback loops, through co-investments and joint development programs (Filippo et al., 2022).

The capabilities of the equipment segment shape what is achievable downstream, setting the stage for the following phases of semiconductor production.

IC design

Integrated circuit (IC) design is part of the upstream activities of the value chain. The segment involves functional specification, logic design, and physical layout of electronic circuits before they are physically manufactured. Using a variety of algorithmic tools, referred to as Electronic Design Automation (EDA), IC designers define the functionality, timing, and layout of the chips in digital form. Through these choices, designers determine much of the chip's final characteristics and economic potential (Organisation for Economic Co-operation and Development, 2019; Varas et al., 2021). The designs are typically delivered to foundries for physical realization through wafer fabrication. This way, IC design forms the conceptual foundation of more downstream activities, which are directly conditioned by the decisions made at this stage.

The segments are highly knowledge- and R&D-intensive. Its innovation cycles are demanding, and complexity increases exponentially with smaller nodes, following Moore's Law. At the leading edge, design cycles often exceed 12 to 18 months for a single chip. Designers must also align their logic and layout with the specific constraints of foundries, tightly connecting the segment with wafer fabrication (Organisation for Economic Co-operation and Development, 2019). Proving the segment's intellectual complexity is its economic landscape. The primary inputs are intellectual capital, costly expertise, and access to advanced design tools. A cutting-edge 5 nm chip may cost more than $450 million to design, compared to about $170 million for a 10 nm design just a few years earlier (Filippo et al., 2022), which underscores the fact that the rising costs and complexity. Unlike fabrication, IC design firms can operate with significantly less physical infrastructure.

From a value chain perspective, IC-design captures the highest proportion of value in the semiconductor industry. Recent analysis by (Varas et al., 2021) shows that design activities account for roughly 56% of total value, exceeding the shares of wafer fabrication and assembly (see figure 5.1). This value stems from IP and strategic control over product differentiations. Leading firms (for 65%-70% based in the United States) such as NVIDIA, AMD, and Qualcomm, command premium margins by developing core IP in specialized markets like AI, networking, and graphics processing. These firms are shielded from competitors by deep talent pools, IP protection, and rapid innovation cycles.

The IC design segment is heavily interconnected with both upstream, midstream, and downstream actors. On one side, it relies on EDA tool providers, dominated by three US-based companies that are tightly regulated under export control regimes (Organisation for Economic Co-operation and Development, 2019). Their software and updates are required to meet the foundries' requirements and design rules. On the other side, design choices are co-developed with foundries for alignment with fabrication capabilities. These collaborations often involve joint development agreements to synchronize design with lithography and etching tolerances. Moreover, innovations such as system-on-chip (SoC) and chip-based designs have intensified vertical coordination, as packaging considerations need to be integrated. These interdependencies underscore the central coordinating role played by IC design in the semiconductor value chain.

Wafer fabrication

Wafer fabrication, also referred to as front-end manufacturing, is part of the midstream segment of the value chain. It is the process of constructing the earlier designed integrated circuits on a semiconductor wafer through a complex set of steps involving film deposition, photolithography, ion implantation (doping), and etching. These processes are conducted in foundrieswhich define and interconnect transistors and other components on the wafer surface (Filippo et al., 2022). Each wafer carries thousands of identical chips, fabricated through more than 300 highly controlled processing steps within clean rooms that are approximately 1000 times cleaner than hospital operating rooms (STMicroelectronics, 2025). Front-end manufacturing forms the operational core of the semiconductor value chain, transforming circuit designs into functional microelectronic structures that serve as the foundation for all modern electronics.

Wafer fabrication is among the most technically sophisticated and capital-intensive segments of the semiconductor chain. Modern-day logic- and memory-chips are produced at nanometer-scale, with industry capacity ranging from cutting-edge (5-7nm) to mature (180nm) nodes. (Varas et al., 2021). Each incremental shrink in node dimensions requires major innovations in materials, equipment, and process technology, underscoring the continuous R&D required. The economic landscape of wafer fabrication is defined by large fixed costs and high economies of scale. The construction of modern fabs may require between $5 billion and $20 billion, with leading manufacturers often allocating around %40 of annual revenue to equipment and plant upgrades (Varas et al., 2021). The structure of the industry reflects these high entry barriers: only a few companies, such as TSMC, Samsung, and Intel, can operate cutting-edge facilities. Others rely on third-party foundries that fabricate chips on their behalf.

Wafer fabrication is the second-most valuable link in the semiconductor supply chain. It accounts for an estimated %19 of the total value added (see Figure 5.1) and plays a central role in monetizing upstream activities into tangible chips. Foundries capture value by charging for the technical differentiation and benefiting from limited competition. Profitability, however, is not guaranteed, as scale, yield, and technological leadership must be carefully balanced.

Wafer fabrication is closely linked to global supply networks but is primarily concentrated in East Asia(Taiwan, South Korea, Japan, and increasingly China). This geographical concentration exposes the segment to risks such as natural disasters, trade tensions, and geopolitical instability. These vulnerabilities motivated the United States and European Union to launch initiatives to attract new fabs through subsidies and strategic alliances. Leading chip makers, such as TSMC and Samsung, have started to build advanced fabs in the US and Japan, to mitigate geopolitical risks and be closer to key customers (Chen, 2025).

ATP

ATP represents the final segment of the semiconductor value chain. In this downstream stage, wafers from fabrication are diced into individual chips, assembled, assembled into packages, tested for performance and defects, and finalized for integration into electronic devices. These activities are performed either in-house by IDMs or by specialized third-party providers, known as Outsourced Semiconductor Assembly and Test (OSAT) firms. ATP serves as the bridge between wafer-level and deployment-level activities.

The ATP segment is essential for ensuring the electrical, thermal, and mechanical performance of semiconductor products. Even though it is often considered less technologically intensive than design, equipment, or wafer fabrication, the growing compactness and complexity of devices have made ATP increasingly sophisticated. This trend turned ATP into a segment of innovation in its own right, rather than merely a finalization step (CSIS, 2023).

ATP is less capital-intensive compared to upstream segments. Leading firms operate with capital expenditures of around 15% of revenues, versus about 35% for wafer foundries (Varas et al., 2021). These low expenditures make labor costs a key competitive variable, explaining why ATP activities are concentrated in regions with low labor costs, such as Taiwan, China, and Malaysia. The segment is undergoing a technological transformation through the rise of advanced semiconductor packaging. Novel innovations integrate multiple chips or wafers into compact modules. These methods reduce power consumption, increase bandwidth, and strengthen the thermal performance, key for high-performance computing and AI chips (Chen, 2025). With this increasing complexity, firms like TSMC, Intel, ASE, and Amkor are investing progressively in co-design and interconnection solutions, making ATP a more integrated and vital segment of the value chain.

Value-wise, ATP has historically captured a modest share of the industry's value, around 6% (see Figure 5.1). This reflects the lower capital intensity and commoditization of basic ATP tasks. However, the rise of advanced packaging, driven by AI, is beginning to change this. The global semiconductor packaging market is projected to reach US$136.1 billion by 2028, with advanced packaging expected to account for 58% of that (Tung, 2023).

Within the value chain, ATP is tightly coupled to midstream processes, particularly wafer fabrication. Yields and failures in fabrication directly affect the ATP success rates (Organisation for Economic Co-operation and Development, 2019). In turn, packaging innovations feed back into the design stage, requiring designers to consider the thermal and spatial constraints.

The relationships between firms in these segments are characterized by co-development and iterative cooperation. Major OSATs, such as ASE and Amkor, maintain long-term strategic partnerships with complementary firms to align packaging capabilities with evolving chip designs. Meanwhile, geopolitical diversification and regional demand are expanding ATP activities beyond traditional hubs (Varas et al., 2021).

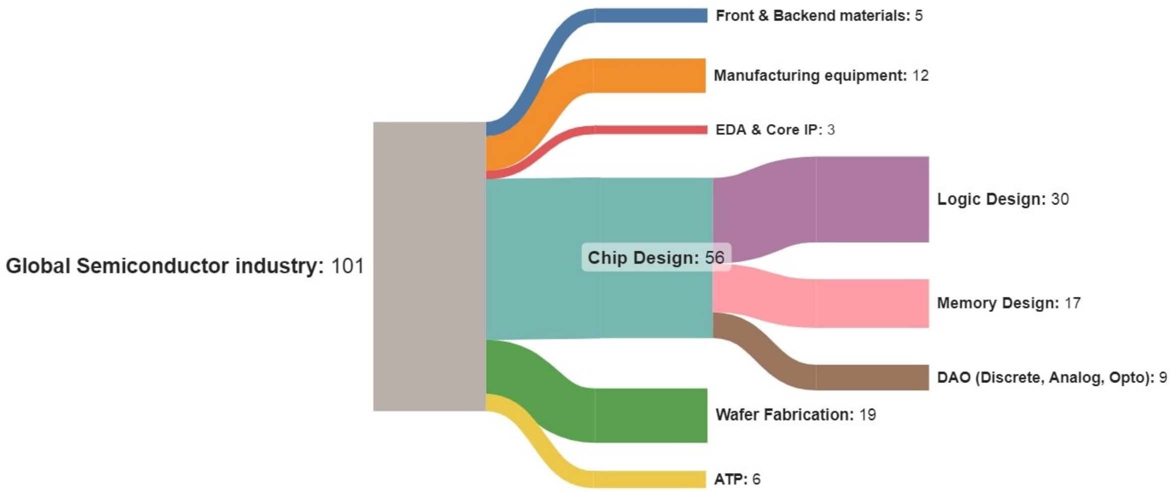

Figure 5.1: Semiconductor value capture by segment.
Compiled by the author using SankeyMATIC - data extracted from (Varas et al., 2021)

5.2. Global Distribution and Asymmetries

The value chain lays out the functions and structure of each segment of the semiconductor industry. This section goes on about the global distribution of the value chain segments. The production of semiconductors is a process that is highly fragmented across borders, while also deeply concentrated in specific countries. Mapping these concentrations gives an understanding of the geopolitical roles, exposures, and opportunities.

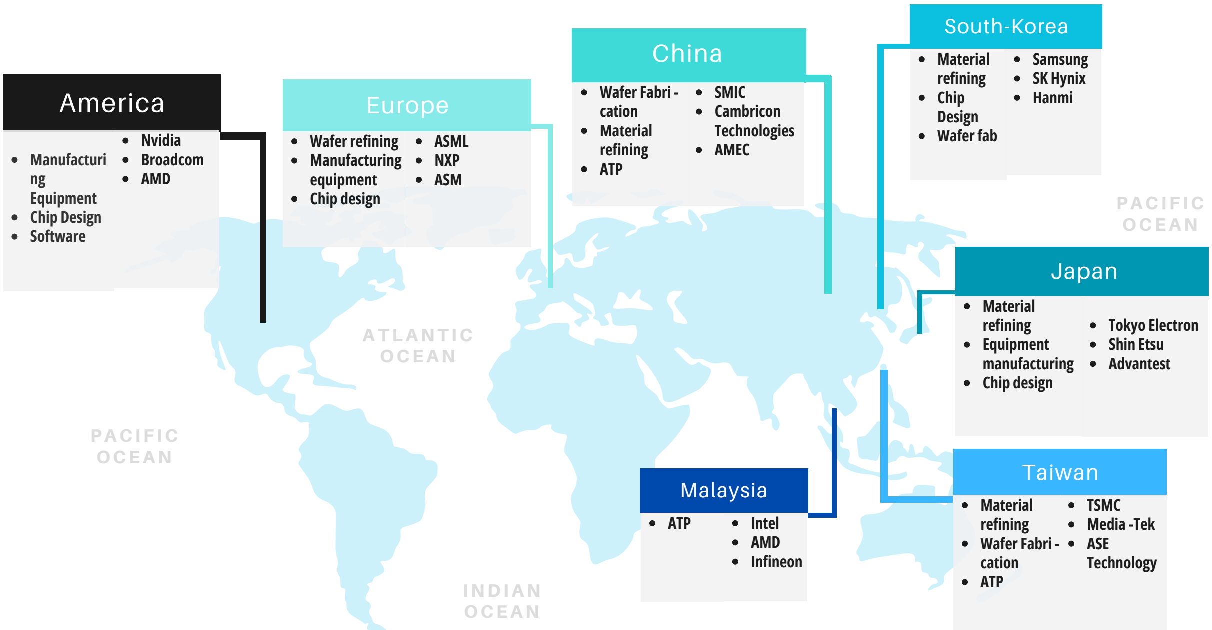

Figure 5.2: "Mapping the Semiconductor global industry"
compiled by: author - data extracted from: (Varas et al., 2021)

The global visualization (figure 5.2) highlights distinct geographic specialization, with a couple of regions that capture the majority of value across the value chain. The United States, with firms like NVIDIA and AMD, dominates in high-value design activities and Electronic Design Automation (EDA). South Korea, driven by Samsung and SK Hynix, has is upstream position, with high entry barriers captured through dominating in the segments: chip design, wafer fabrication, and advanced material refining. Taiwan plays a strategically central role, through TSMC's dominance in wafer fabrication, next to substantial activities in ATP and material refining. Japan possesses deep expertise in manufacturing equipment, specialized chip designs, and advanced material refinement. Leading in ATP and material refining is China, which is starting to build substantial competencies in wafer fabrication and chip design, through large investments and state-driven industrial policy. Europe, however, captured essential technological niches, mainly through specialized manufacturing equipment and material refining, led by companies like ASML and NXP. Malaysia is mainly specialized in ATP activities, via multinationals like Intel, AMD, and Infineon, capturing 13% of this segment's global value.

While the preceding figure (see figure:5.2) illustrates the concentration of semiconductor activities, it does not fully capture how value is distributed across the value chain. Not all positions in the value chain yield the same economic returns: high-income, innovation-driven regions tend to dominate the most profitable segments, while others remain confined to lower-value roles. Table 5.3 highlights this uneven geography of value capture by segment and identifies the leading national economies in each.

The table reveals patterns of concentration and asymmetries across the segments. The highest value is captured in knowledge- and capital-intensive activities such as chip design and manufacturing equipment, dominated by the United States, Europe, Japan, and South Korea. These segments are characterized by high entry barriers, often reinforced through control over IP, and standards (Sturgeon & Kawakami, 2011b). However, the labor-intensive operations like ATP account for much smaller shares of total value. These segments also show a more balanced regional distribution.

Main Segment	Sub-Segment	Value Capture (%)	Top 3 Countries (%)
Raw Materials & Materials	Mining & Extraction	2	China, DRC, Indonesia*
	Frontend & Backend Materials refinement	5 (incl. above)	23% Taiwan, 19% China, 17% Korea
Manufacturing Equipment (SME)	Lithography, Etching, etc.	12	42% US, 27% Japan, 21% Europe
EDA & Core IP	Design Software & IP Cores	3	72% US, 20% Europe, 3% China
Chip Design	Logic Design	30	67% US, 9% Taiwan, 8% Europe
	Memory Design	17	58% Korea, 28% US, 8% Japan
	DAO (Discrete, Analog, Opto)	9	37% US, 21% Japan, 18% Europe
Wafer Fabrication	Frontend Manufacturing	19	21% China, 19% Taiwan, 17% Korea
Assembly, Packaging, Testing	Backend Manufacturing	6	38% China, 19% Taiwan, 13% Malaysia
Product Integration	Final Product Assembly		Not available
Pre-competitive R&D	Gov-funded Research	Not included	Not applicable

Table 5.3: Semiconductor Value Chain: Value Capture and Top 3 Country Shares
Made by the author - data extracted from: (CompaniesMarketCap.com, 2025; Yeung, 2023))

5.3. Malaysia's Global Value Chain Position

Malaysia's integration into the global semiconductor value chain has, from the beginning, been anchored in the assembly, testing, and packaging segment. These downstream segments are intensive with comparatively lower technological and capital entry barriers than wafer fabrication and IC design (Ernst, 2005a; Sturgeon, 2002). Early FDI inflows have consolidated Malaysia's role as one of the largest ATP hubs, supported by competitive labour costs and a reliable infrastructure (Chandran et al., 2009; Rasiah & Wong, 2021).

Participation in upstream segments is more limited. Wafer fabrication activities are present but operate at a smaller scale, focusing primarily on mature-node production and niche foundry services (Lall, 1996; Rasiah & Wong, 2011). The R&D and IP-intensive segment, IC design, remains at an early stage of development. Existing design activities are concentrated in application-specific integrated circuits, both undertaken by foreign multinationals and a small number of domestic firms (C. W. Lim, 2019; Rasiah, 2010). Local capabilities are constrained by limited design ecosystems, shortages of specialized talent, and the dominance of established global design clusters (Ernst, 2005b).

Since the early 2000s, industrial policy documents have proposed the ambition for expanding upstream participation (Economic Planning Unit (EPU), 2015; Ministry of International Trade and Industry (MITI), 2012). Malaysia's current position is therefore concentrated in downstream ATP, with selective successes and attempts in wafer fabrication and specialized design activities.

Part II - Technological Innovation System Analysis

5.4. Malaysia Timeline and Milestones

Malaysia's historical specialization in semiconductor ATP operations and new government initiatives to expand into front-end activities (like chip design and fabrication) are outlined here as background for the TIS mapping.

The evolution of Malaysia's semiconductor industry can be summarized on a high-level chronological level by a few key milestones that defined that period of time - see also Figure5.3.

- When the future, Intel, CEO Andy Grove, got stuck with his car in a muddy paddy pool, he decided that that would be the place to establish its first overseas assembly plant in Penang in 1972. (Ibrahim, 2024). This marked the birth of Malaysia's semiconductor industry, after which multinationals, such as AMD, Hewlett-Packard, and Hitachi, followed in the early 1970s, attracted by Malaysia's low labor costs and tax incentives.
- Throughout the 1980s the government expanded Free Trade Zones (FTZs) and introduced the first Industrial Master Plan (1986-1995) to promote electronics manufacturing (GRIPS Development Forum, 2006) New export processing zones in places like Penangs Bayan Lepas enabled a growing cluster of semiconductor ATP operations, as rising costs, of neighboring South East Asian countries, drove more multinationals to Malaysia.
- By the 1990s, a number of local assembly/test firms emerged as industry players alongside the multinationals, for example, Carsem and Unisem grew into notable ATP companies. The government also established supporting institutions such as the Malaysian Institute of Microelectronic Systems (MIMOS) in 1985, to build R & D capacity in microelectronics.
- Malaysia began to venture into upstream semiconductor production in the late 1990s. The first domestic wafer fabrication plant, Silterra, was conceived in 1995, with government backing. Around the same time, a second foundry, 1st Silicon, was initiated in Sarawak, signaling Malaysia's ambition to establish front-end manufacturing capabilities.
- In 2023, the government unveiled the National Semiconductor Strategy as part of a new industrial policy push. This strategy aligned with the New Industrial Master Plan (NIMP)2030, set out for ambitious front-end goals. One of these goals is to attract at least one leading global wafer fabrication facility to Malaysia and to foster home-grown chip design and advanced packaging firms. The NSS marks public support (around RM25 billion) through targeted incentives, to upgrade Malaysia's semiconductor ecosystem and move beyond traditional back-end stronghold(Said & Tan, 2024).

Also highlighted in the previous narrative timeline, Penang has been the epicenter of Malaysia's semiconductor industry since the 1970s, driven by a mix of local initiative and supportive national policies. The Penang state government, under the leadership of Chief Minister Lim Chong Eu, pioneered Malaysia's first FTZ at Bayan Lepas in 1972, collaborating with federal authorities. This local federal alignment was crucial, as the Penang Development Corporation (PDC) provided industrial infrastructure and land investors, while national institutions, like the Ministry of International Trade and Industry (MITI) and its investment arm, the Malaysian Investment Development Authority (MIDA), ordered fiscal incentives and facilitated foreign investment approvals to attract semiconductor multinationals. Because of this coordinated approach, Penang cultivated a dense electronics ecosystem, also called the "Silicon Valley" of Malaysia, with a skilled workforce and a supplier network suitable for high-tech manufacturing.

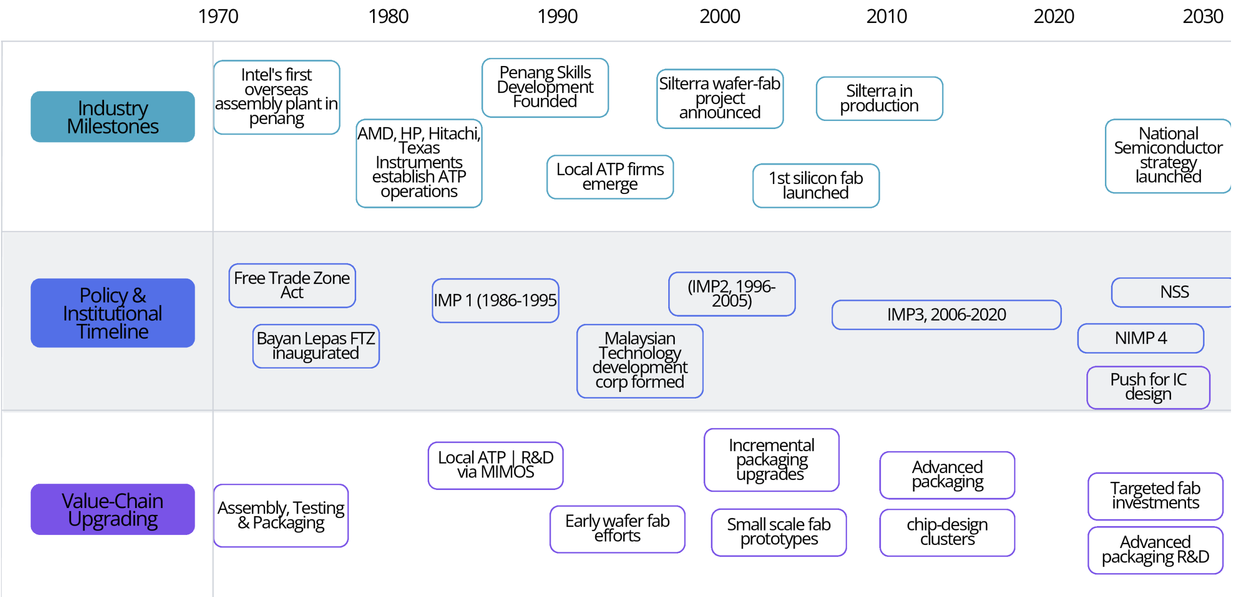

Figure 5.3: Malaysia's semiconductor system timeline
composed by author - extracted from: (Ahmad, 2023a; Rasiah & Yap, 2015a)

5.5. Structural TIS Mapping Malaysia

5.5.1. Actors

Firms

Malaysia's semiconductor industry at the beginning of 1980 was led by multinationals like Intel (Penang, 1972), AMD, HP, and Hitachi. They became attracted by Free Trade Zone incentives (Ahmad, 2023c). Local firms were rare, with Carsem (1972) being one of the few. Most technology remained foreign-controlled (MIMOS Berhad, 2023). From the mid-1980s, the government promoted linkages between multinationals and local suppliers. Though entrepreneurship remained limited.

By the late 1990s, local firms such as Carsem, Unisem (1992), and Globetronics (1991), often founded by multinational employees, grew significantly. Malaysia also initiated wafer fabrication ventures: Silterra (1995, opened 2000) and 1st Silicon (1998). Motorola and Siemens (Infineon) expanded into R&D and design. By 2000, Malaysia's semiconductor industry featured both multinational and emerging local firms (Rasiah & Yap, 2015b).

In the 2000s and beyond, Malaysia continued to attract major investments from global players. Intel expanded its presence with new facilities in Penang and Kulim, including advanced packaging and testing facilities worth over US$7 billion (The Edge Malaysia, 2025b). Infineon established a technologically advanced fabrication plan in Kulim. Other notifiable entrants include ASE Technology, which opened their fifth advanced packaging plant in Penang. Also, AT&S began high-volume production of IC substrates in a Kulim facility in 2024. (ATS, 2025).

Looking at the domestic Malaysian firms that emerged in recent years, we see that Ametron has expanded OSAT activities and introduced advanced packaging solutions. Vitrox and Pentamaster became suppliers of automated test equipment and machine vision systems. And in 2023, Oppstar Technology, a domestic IC design service company, went public as the country's first listed fables firm (The Edge Malaysia, 2025b).

Universities and research institutes

In the 1980s, universities like the University of Malaysia, Uni Sains Malaysia, and Universiti Teknologi Malaysia produced electronic engineering graduates. However, specialized semiconductor training was limited. In 1985, Malaysia's national Applied Research and Development Center (MIMOS) was established to focus on local microelectronics R&D, creating Malaysia's first integrated circuit in 1992 (MIMOS Berhad, 2023). SIRIM (Standard and Industrial Research Institute of Malaysia) supported standards and testing.

During the 1990s, universities expanded semiconductor-specific programs and research labs. Examples are the USM's Collaborative Microelectronic Lab and Multimedia University in 1999. MIMOS grew significantly, contributing to major projects like the Multimedia Super Corridor (MIMOS Berhad, 2023). Next to that, an increase in established wafer fabs, an increase in electronics PhDs, and strengthened university-industry actions.

From 2010 forward, several institutions upgraded as an attempt to strengthen their infrastructures. The earlier mentioned MIMOS underwent a reorientation to align with frontier technologies like AI (MIMOS Berhad, 2023). Penang saw the launch of the Penang Chip Design Academy in 2024, to target talent towards IC design knowledge, and the CREST expanded 200 R&D projects spanning IC design, packaging, and sensors (Alcaraz, 2024).

Financial actors

In the 1980s, semiconductor financing occurred mostly through FDI and government incentives. The appearance of venture capital was at a minimum. Traditional institutions provided industrial loans, but equity financing for tech startups was rare. The financial environment started improving in the 1990s with the establishment of Malaysian Technology Development Corporation (MTDC) in 1992, Malaysia's first public Venture Capital, focusing on technology SMEs (World Bank, 2023). More venture capital firms and public funding, like: Intensification of Research in Priority Areas IRPA grants emerged, supporting semiconductor ventures (Economic Planning Unit, Prime Minister's Department, 2001). State bodies like Khazanah Nasional funded significant wafer fabs, making way for better financial conditions

After this, in the 2000s, financial structures expanded and solidified further. Malaysia Venture Capital Management Berhad (MAVCAP) was founded in 2001 to support local tech startups(World Bank, 2023). Also, public investment funds, such as Khazanah Nasional Employees Provident Fund and Permodalan Nasional Berhad, arose to finance strategic infrastructure, such as Kulim's wafer-fab park. The NSS opened a new incentive to target public-private investments, which include IC design, wafer fabrication, and advanced packaging (Rasiah & Yap, 2015b)

Demand-side actors

In the Malaysian semiconductor innovation system, demand-side actors have played an important but limited role in shaping technological direction. Starting in the 1970s and 1980s, the semiconductor output was almost entirely produced for foreign equipment and device manufacturers, with offshore-determined product specifications. The, by then, small-scale Malaysian electronics and telecommunications sector kept domestic demand to a minimum (Ahmad, 2023c). Malaysia's role in global electronics supply started to deepen by the 1990s and 2000s. Most dominant actors were the consumer electronics, industrial automation, and telecommunication applications (World Bank, 2023). Downstream industries remained embedded in imported systems or assemblies. From the 2010s, demand diversified with the global rise of 5G infrastructures, IoT, and automotive electronics (The Edge Malaysia, 2025b). The more recent demand expansions have emerged from AI accelerators, data center infrastructures, and GPU-related packaging (ATS, 2025). While the demand-side actors have started to take shape, the main source for domestic buyers (telecom operators, electronic assemblers, and industrial equipment manufacturers) remained offshore, with buyers acting as adopters of foreign-designed components.

note on scope: Demand-side influences are mapped in structural terms. Their effects on the functions of the innovation systems are addressed in the functional analysis chapter (mainly in relation to market formation (F4) and legitimation (F5)). The absence of domestic lead markets has been a consistent structural feature that has increased reliance on global production networks.

5.5.2. Networks

One of the first developments was the Penang Skills Development Center (PSDC) in 1989. This partnered with Penang state, other multinationals, and academia to train skilled local technicians. Expansion of Free Trade Zones in Penang and Selangor. Next to that, companies began associations linked to the Federation of Malaysian Manufacturers and agencies. MIDA facilitated industry-government interactions (Yusuf & Nabeshima, 2009).

During the late 1990s and 2000s, collaboration within Malaysia's semiconductor sector became more structured, supported by government programs like the Industrial Linkage Program (ILP) and Global Supplier Program (GSP), which strengthened partnerships between MNCs and local SMEs World Bank (2023). Firms such as Carsem, Unisem, and Globetronics grew by forming ties with MNCs, while R&D activities expanded through the establishment of design centers by companies like Intel and Motorola Rasiah (2017b). Public-private attempts to develop wafer fabrication, including Silterra and 1st Silicon, to deepen technological capabilities, though with limited success. Cluster organizations, especially the PSDC, continued to support industry needs through advanced training, and industry associations provided platforms for coordination and knowledge sharing Yusuf and Nabeshima (2009)

From the 2000s onward, Malaysia saw a more structured collaboration between public and private networks. The PSDC expanded its role as an industry training hub. And the earlier-mentioned CREST emerged. Also, programs for specific sectors, such as the Industrial Linkage Program and Global Supplier Program, were introduced to strengthen ties between multinationals and SMEs. National coordination was facilitated by the Malaysian Semiconductor Industry Association (MSIA) and the Malaysian Investment Development Authority (MIDA) (GRIPS Development Forum, 2006).

5.5.3. Institutions

In the 1980s, Malaysia's institutional framework focused on attracting foreign investment through Free Trade Zones (FTZs), offering tax incentives and exemptions from the New Economic Policy (NEP) ownership rules, which facilitated MNC-led export growth with minimal state intervention (Rasiah, 2017b). Midway through the decade, concerns over weak domestic linkages led to policy adjustments, including relaxed export rules in 1986 and the introduction of the Vendor Development Program (VDP) in 1992 to encourage partnerships between MNCs and local SMEs, though initial outcomes were limited due to restrictive criteria (Yusuf & Nabeshima, 2009). Workforce development was addressed by the Human Resource Development Fund (HRDF) Act of 1992, expanding training efforts pioneered by the PSDC (World Bank, 2023).

The institutional framework in the period hereafter focused on technological upgrading and cluster development, guided by the Second Industrial Master Plan (IMP2) and IMP3, and was supported by agencies like SMIDEC and MTDC, which provided financial incentives and technology grants (World Bank, 2023). Policies shifted to encourage R&D, advanced manufacturing, and the attraction of skilled foreign talent, while infrastructure developments such as Kulim High-Tech Park aimed to foster high-tech investment (Rasiah, 2017b).

From the 2000s, after the IMP2 and IMP3 were formally completed, the New Industrial Master Plan 2030 (NIMP 2030) laid out missions for advanced packaging, design, and wafer fabrication. Later in 2024, the government introduced the National Semiconductor Strategy. This road map includes visions for a wafer-fab park, an IC design start-up program, and advanced manufacturing infrastructure (GRIPS Development Forum, 2006).

5.6. Functional Performance Analysis - Malaysia

5.6.1. Function 1: Knowledge development and diffusion

Knowledge development and diffusion address the creation of new technical knowledge and its distribution among actors in the innovation system, representing its industry learning mechanisms and knowledge base. In the context of Malaysia's semiconductor industry, this encompasses R&D activities, workforce training, foreign and domestic technology transfer, and the establishment of supporting institutions.

Functional development over time

Malaysia's entry into the semiconductor industry in the 1970s was marked by labor-intensive ATP activities run by foreign multinationals, with limited spillovers for domestic knowledge development. (Yusuf & Nabeshima, 2009). Initial knowledge creation occurred mainly within firms. By the 1980s, foreign firms in Malaysia started upgrading manufacturing processes (introducing statistical process control and automation) and advancing local talent training, which facilitated the diffusion of technical know-how throughout the industry. (Rasiah, 2007). Intel, in particular, initiated this by hiring and training with no prior experience (Interviewee 1, 2025).

In response, Malaysia took measures to build domestic innovation capacity. MIMOS was founded as a public R&D center to induce local microelectronics research. (Economic Planning Unit, Prime Minister's Department, 2001). Likewise, the Penang Skills Development Center (PSDC), launched in 1989 as Malaysia's first industry-led training center, pooled contributions from key MNCs such as Intel and Altera alongside local government to facilitate a talent base and promote tacit knowledge diffusion (Rasiah & Yap, 2015b).

By the late 1990s and 2000s, Malaysia aimed to expand its knowledge base into upstream activities. This was demonstrated by the establishment of Silterra, a state-owned wafer foundry in 1995, which facilitated some technology acquisition through international partnerships(Rasiah, 2007). Several MNCs also established regional engineering or design centers in Malaysia during this period, with Infineon's R&D and fabrication plant in Kulim (opened in 2006) as a prominent example (Ahmad, 2023b). Nonetheless, formal R&D indicators remained weak: R&D expenditures in the electrical & electronics sector remained 0.4% of GDP (well below levels in Singapore (1.9%) and India (1.2%)) and patenting by Malaysian semiconductor actors was limited, with only 322 patents filed in 2002, compared to over 10.000 for Germany, France and UK in that year (OECD, 2023b).

Recognizing these limitations, policy efforts intensified, including the launch of CREST (Collaborative Research in Engineering, Science and Technology) as an industry-led R&D platform to link firms and universities. CREST focused on areas such as IC design, optoelectronics, and advanced packaging. By 2020, it had facilitated 146 collaborative R&D projects and trained over 6.000 graduates, signaling a notable expansion in national knowledge infrastructure (World Bank, 2021a).

Enablers and barriers

Several institutional enablers underpinned the performance of this function. Government and industry established organizations and networks to facilitate learning. Penang's ecosystem exemplifies this: as of 2023, it hosts 10 of the world's top 20 medical device firms, with many of their senior employees being ex-Intel, or having a background from other semiconductor-related companies (Interviewee 1, 2025; Rasiah & Yap, 2015b). The Human Resource Development Fund (HRDF) provided training subsidies, and universities such as Universiti Sains Malaysia scaled up engineering programs to meet sectoral demand (Abad et al., 2015a; Interviewee 2, 2025). Government incentives, such as double tax deductions and the Industrial Technology Assistance Fund, further encouraged R&D engagement. On the corporate side, knowledge transfer from foreign lead firms occurred both through internal learning and through structured external vendor development programs (Chandran et al., 2009; Interviewee 3, 2025).

In the last few years, triple helix collaborations have also emerged as a key enabler. With over 80 member organizations and access to government funding, CREST has helped bridge the gap between academia and industry, creating new knowledge hubs in strategic niches like LEDs and IC-design (Rasiah & Yap, 2015b).

Conversely, numerous systemic barriers constrained the full development of this function. A primary constraint remains the lack of advanced domestic R&D capacity; Malaysia did not develop semiconductor-focused research university programs (Interviewee 2, 2025; Interviewee 3, 2025; Rasiah, 2007). Industrial R&D investment by foreign firms remained limited due to high costs, insufficient R&D talent, IP protection, and bureaucratic bottlenecks for accessing incentives (Interviewee 1, 2025; Interviewee 3, 2025; Krause et al., 2015). Surveys and interviews suggest that public research institutes like MIMOS AND SIRIM have had limited success in shaping public research to industry needs (Chandran et al., 2009; Interviewee 2, 2025). Another critical constraint is human capital; while Malaysia produced capable talents, they were not sufficiently retained within Malaysian firms, leading to a form of brain drain (Interviewee 1, 2025; Interviewee 2, 2025; Krause et al., 2015). Finally, the uneven geographical distribution of industry activity has produced uneven diffusion effects. While Penang's ecosystem thrived, other regions have lagged with weaker knowledge networks (Interviewee 2, 2025).

Enablers	Barriers
Dedicated R&D and training institutions	Weak semiconductor R&D in universities
Vendor training by foreign lead firms	Low R&D by MNCs due to cost, returns, and IP risks
Structured MNC knowledge transfer	Misaligned public research institutes
HR policies: training subsidies, USM engineering	Brain drain: poor engineer retention
R&D incentives: grants, tax deductions	Bureaucratic hurdles to access funds
Academia–industry bridges	Localized diffusion; weak outside Penang
Workforce mobility and tacit networks	Low R&D intensity and patents globally

Table 5.4: Enablers and Barriers of Knowledge Development and Diffusion (F1)

5.6.2. Function 2: Influence on the direction or search

This function concerns the factors that orient actors towards specific technological paths. This includes government policies, visions, and road maps, as well as economic signals and expectations set by industry leaders. Together, these guide the focus of innovation efforts. In the context of Malaysia's semiconductor industry, this function addresses how Malaysia identified and prioritized certain segments of the value chain, and what factors pushed or pulled firms in those directions.

Functional development over time

Over time, Malaysia's strategic direction has been shaped by a combination of industrial policies and external market signals. The creation of FTZs in 1972 signaled the state's preference for low-cost export manufacturing, drawing major MNCs such as Intel, AMD, and Altera to establish operations in ATP by the early 1980s (Ahmad, 2023b).

As the industry matured, policymakers gradually began to shift attention toward higher-value activities. The First Industrial Master Plan (1986-1995) identified electronics as a priority industry and promoted linkages between foreign and local firms to facilitate technology transfer (Krause et al., 2015). However, the government's role remained largely symbolic, providing incentives for a supportive business climate, rather than intervening to change the innovation system (Interviewee 1, 2025; Rasiah, 2015).

By the 1990s, a more assertive stance emerged. The Action Plan for Industrial Technology Development (1991) and the IMP 2 (1996-2005) advocated functional upgrading in more capital-intensive strategic industries, such as wafer fabrication and chip design, and promoted clustering to support innovation ecosystems (Interviewee 3, 2025). This was reflected not long after in the launch of Silterra in 2000, modeled on Taiwan's foundry strategy, representing an upstream push into more advanced production (Rajah Rasiah, 2024).

Around the same time, policies also began emphasizing design capabilities through initiatives, such as the Multimedia Super Corridors (MSDC) and various R&D grant programs. Progress, however, was uneven; the 1997 Asian financial crisis slowed investments and delayed high-tech ambitions, reducing the impact of IMP2. In the 2000s, a more pragmatic focus started to take shape. Setbacks in developing domestic fabs, partly due to weak financial support mechanisms for strategic investments (Interviewee 1, 2025), forced Malaysia to look for foreign-led upgrading. By offering upfront grants and investment packages, Malaysia attracted Infineon, which opened a semiconductor fab, followed by others such as Texas Instruments and Osram. Next to that, some IC design firms were attracted, mainly Intel and Altera (Interviewee 3, 2025).

Global shifts also influenced Malaysia's strategic focus. The rise of China and other Asian nations in ATP forced Malaysia to wake up and to consider either differentiating or moving up the value chain to maintain competitiveness (Interviewee 2, 2025). The Tenth Malaysia Plan (2011-2015) and the Economic Transformation Program designated electronics and electrical as national key economic areas, with targeted efforts to nurture domestic IC-design firms and to add a high-value segment to semiconductor clusters. The launch of CREST further institutionalized this shift, attempting to bridge academia and industry (World Bank, 2021a).

By the 2020s, Malaysia's direction of search has been articulated in forward-looking national strategies. The recent National Semiconductor Strategy and the NIMP2030 aim to strengthen upstream and downstream capabilities, targeting the creation of homegrown IC-design champions, the establishment of at least one leading-edge wafer fab, and the expansion of advanced ATP activities (Said & Tan, 2024). These goals are reinforced by political rhetoric shaped by geopolitical trends, such as the US-China technology rivalry and supply chain shift. This is reflected in recent policy interest in AI and advanced packaging, which align with Malaysia's existing processes while targeting new frontiers (Interviewee 1, 2025; Said & Tan, 2024).

Enablers and barriers

Several factors enabled the influence of the direction of search over time. Most notably, the long-term policy plans. The export-oriented industrialization drive of the 1970s to the current NIMP2030 has provided visions for the private sector to follow (Said & Tan, 2024). The Industrial Master Plans and the role of MIDA in investment promotion created an environment in which firms could align their goals with national goals. A complementary enabler was the use of targeted incentives and infrastructure to steer investments. The FTZs and the development of Kulim High-Tech Park served as instruments for industrial activity, while tax holidays and grants for design centers encouraged higher-value activities (Interviewee 3, 2025; Rasiah, 2015).

Sub-national leadership also contributed. Penang's proactive state administration under Lim Chong Eu in the 1970s and 1980s aggressively courted electronic firms and supported upgrading initiatives (Interviewee 2, 2025; Said & Tan, 2024). Over time, Malaysia developed meso-level institutions (such as MIMOS, MIGHT SME Corp) to bridge high-level policy goals with actionable programs targeting specific segments. These institutions assembled stakeholders, identified emerging technologies, and coordinated targeted interventions (Krause et al., 2015).

Nevertheless, several barriers hindered the full realization of these ambitions. While plans as IMP 2 and IMP 3 formulated strong objectives, the instruments for execution were often too generic or underdeveloped (Interviewee 1, 2025; Said & Tan, 2024). Moreover, the persisting orientation pull toward export-led growth incentives firms to remain in ATP, reinforcing Malaysia's specialization in lower-value segments (Interviewee 1, 2025; Interviewee 2, 2025).

A further misalignment emerged between policy ambition and domestic capabilities. Efforts to create a national wafer fab (Silterra) were hampered by the lack of experienced leadership and deep semiconductor expertise, in contrast to Taiwan's TSMC, which was led by highly capable technologists (Interviewee 2, 2025). Universities and research institutes also failed to sufficiently adapt their curricula to meet the demand of higher value segments(Interviewee 2, 2025; Interviewee 3, 2025).

These limitations in domestic capacity lagged behind the impact of the otherwise well-formulated government strategies. Finally, external market forces occasionally overshadowed domestic priorities: global downturns (such as the 2001 tech crash) and a growing Asian competition limited Malaysia's ability to maneuver up the value chain. A lack of alignment between industrial focus on emerging complementary sectors, such as automotive electronics, further constrained progress (Interviewee 1, 2025; Interviewee 2, 2025).

Enablers	**Barriers**
National policy visions (export-oriented, NIMP2030)	Weak execution of IMP2/IMP3
Master Plans and MIDA aligning private–public goals	Export focus locking in low-value ATP segments
Targeted incentives: FTZs, tax holidays, design grants	Policy ambitions exceeding domestic capabilities
Penang's leadership under Lim Chong Eu	Outdated curricula in universities and R&D
Meso-level agencies (MIMOS, MIGHT, SME Corp)	Market shocks, Asian competition limiting upgrading
Clustering and coordination (CREST, MSC)	Poor alignment with emerging sectors (e.g., auto electronics)
Geopolitical shifts (US–China rivalry)	Reliance on foreign-led upgrading; weak domestic investment

Table 5.5: Enablers and Barriers of Influence on the Direction of Search (F2)

5.6.3. Function 3: Entrepreneurial experimentation

This function describes the level of exploratory activities by firms and entrepreneurs. It covers the entry of new firms, pilot projects, and prototypes, as well as the diversification attempts of existing firms.

Functional development over time

In the first few decades of Malaysia's semiconductor industry, hardly any entrepreneurial activities occurred. The industry's growth stemmed almost entirely from foreign multinationals rather than domestic startups (Interviewee 1, 2025). Entrepreneurial initiatives emerged as the industry matured, when individuals with experience from MNCs started Malaysian-owned OSAT firms. For example, Globetronics was founded in 1991 as a spin-off from Intel and was established by former MNC engineers and managers. Such firms entered the value chain by providing multinational clients with specialized packaging and testing services. (Rasiah, 2014).

The late 1990s saw more state-driven entrepreneurial attempts in upstream segments. Silterra, for example, was a government-backed experiment to jump-start domestic wafer fabrication capabilities. Comparable private attempts didn't take place, as the capital and technological barriers were too high to overcome (Interviewee 3, 2025). Despite the lack of self-sufficient private experimentation, such institutional entrepreneurship marked an initial step toward participating in wafer processing and learning by doing.

Entrepreneurial activities in OSAT continued to grow. Firms such as Vitrox, Pentamaster, and Aemulus, which were established in the 2000s, were again founded by locals with experience from MNCs (Interviewee 3, 2025). These firms targeted innovative solutions in automation, testing equipment, and inspection technologies.

In the following years, small-scale design and R&D entrepreneurial efforts also emerged. Fabless startups emerged, such as Oppstar, founded in 2014, which has a homegrown IC-design service firm serving international clients and was publicly listed in 2023.

In addition to experience from MNCs as an enabling factor, public policy also tried to stimulate entrepreneurial experimentation. In 1992, the Multimedia Super Corridor (MSC) offered seed funding for tech startups, including microelectronics design firms. Institutions like the Malaysian Technology Development Corporation (MTDC) invested in promising local firms and supported various incubators, for example, Technology Park Malaysia, in Kuala Lumpur, and SME hubs in Penang (Interviewee 3, 2025; Rasiah, 2015). The establishment of CREST in 2012 further pushed research-based entrepreneurship by funding university-industry collaborations in areas such as sensor technology and LED lighting systems (World Bank, 2021b).

Multinational cooperation also indirectly contributed by encouraging spin-offs to perform outsourcing tasks for current or former employees (Interviewee 1, 2025; Interviewee 3, 2025)

However, several barriers constrained entrepreneurial dynamics. The overall scale of experimentation in Malaysia's semiconductor sector has remained moderate. Most domestic firms operated on a small scale and did not succeed in competing with global players in core technologies. A key constraint was the absence of a local consumer electronics market as a complementary asset (and advantage that China or Taiwan did not have), which reduced initial demand for homegrown semiconductor products (Wu & Lee, 2020). Financial limitations further hindered experimentation, as high-risk capital ventures in fabrication and design were scarce. The government's venture capital initiatives were cautious; the MTDC funded only a handful of established firms, and failed to create broad university linkages or a startup boom (Interviewee 1, 2025; Interviewee 2, 2025). Private venture capital gave preference to less R&D-heavy sectors, resulting in a financing gap that discouraged potential entrepreneurs from attempting or failing to establish IC-design firms or foundries.

Finally, the absence of a strong industry strategy hindered functional performance. Until 2010, institutes rarely developed strategies for technological spin-offs (Interviewee 1, 2025; Interviewee 2, 2025).

To put things together, Malaysia's broader innovation system has produced an increasing number of local ventures, particularly in OSAT and testing-related entrepreneurial experimentation. However, activities higher up the value chain remain limited due to persistent structural barriers.

Enablers	**Barriers**
MNC-trained founders starting local firms (Globetronics, Vitrox)	Small scale; few compete in core technologies
State-led upstream experiments (Silterra wafer fab)	High capital and tech barriers limit private entry
Policies: MSC, seed funds for microelectronics	No domestic consumer electronics demand
Institutional support: MTDC, incubators, CREST	Limited VC activity; weak university linkages
MNC outsourcing to former employees	VC bias toward low-tech, low-R&D sectors
OSAT/testing niches enabling specialized ventures	Lack of strong spin-off strategies pre-2010

Table 5.6: Enablers and Barriers of Entrepreneurial Experimentation (F3)

5.6.4. Function 4: Market formation

Market formation involves the creation and expansion of demand for new technologies within innovation systems. In developing industries, markets are often underdeveloped, requiring so-called nursing markets and supportive conditions to spur adaptation. In the context of Malaysia's semiconductor industry, this function concerns how domestic complementary and export market opportunities were captured and used for industry growth.

Functional development over time

Malaysia's semiconductor industry, like others globally, developed as part of a broader electrical and electronics export push. Malaysia integrated into the GVC early on by hosting ATP operations for MNCs. The creation of FTZs (such as Bayan Lepas in Penang) and favorable export conditions made the country attractive to external firms (Harvard Business School - Institute for Strategy and Competitiveness, 2023; Interviewee 3, 2025). As a result, semiconductor exports grew rapidly, from about $5 billion in 1981 to $ 35 billion by 2011 (Harvard Business School - Institute for Strategy and Competitiveness, 2023). By 1990, Malaysia briefly accounted for 15% of the world's semiconductor exports, which later stabilized at around 7% by 2010. This export-oriented market formation made E&E Malaysia's most dominant export industry; by 2022, E&E products captured 38.8% of Malaysia's total exports (US$134.8 billion), with semiconductors and integrated circuits together contributing roughly two-thirds of this share (Malaysia External Trade Development Corporation (MATRADE), 2023). After 5 decades of participation in the industry, Malaysia has become the world's sixth largest semiconductor exporter, accounting for approximately 7% of global semiconductor trade and an estimated 13% of global ATP output.

Enablers and barriers

Several factors enabled this export-led market formation. As one interviewee noted, Malaysia is a trading nation, with too small a population to consume the goods it produces domestically, making export the natural tendency for growth (Interviewee 2, 2025). This perspective was reflected in early industrial policies, which created export zones and industrial parks to enable early integration into global production systems (Said & Tan, 2024). Also, institutional actors such as MIDA and Matrade further supported market formation by promoting high-value foreign investment, which gave local E&E firms access to international markets (Malaysia External Trade Development Corporation (MATRADE), 2023). For aligning the public and private interests, industry associations such as the MSIA and the Malaysian-American Electronics Industry Group also played a coordinating role. With a growing supplier network of SMEs servicing multinational clients, Malaysia earned credibility as a reliable global production base (Interviewee 2, 2025; Malaysia External Trade Development Corporation (MATRADE), 2023).

However, several barriers limited the breadth and depth of market formation. Most significantly, domestic demand remained weak. With few electronics OEMs or major consumer electronics producers located in Malaysia, semiconductor firms relied heavily on external demand and, with it, remained vulnerable to global cyclical shocks, as exemplified by the COVID-19 pandemic (Interviewee 1, 2025). This limited the number of opportunities for developing local niche applications that could stimulate homegrown chip innovation (Krause et al., 2015). In addition, there was insufficient proactive policy support to foster a domestic champion (Interviewee 2, 2025). Technological constraints posed another limitation. The low amounts of knowledge spillovers from foreign MNCs to local firms made it difficult for domestic innovation to thrive (Interviewee 3, 2025). Lastly, the earlier-mentioned talent gap continued to hinder diversification into more R&D-intensive, and with it higher-value, segments. To put in numbers, Malaysia's R&D researcher density stands at around 1,065 per million inhabitants, which is significantly lower than international benchmarks (Krause et al., 2015).

Enablers	**Barriers**
Export-oriented policies: FTZs, industrial parks	Weak domestic demand; no major OEMs
MIDA and Matrade promoting FDI and exports	Exposure to global demand shocks (COVID-19, financial crisis)
Trade-oriented culture in small market context	Few local niche applications or innovation
Industry associations aligning public–private goals	Lack of national industry champions
SME supplier networks boosting credibility	Low spillovers from MNCs to local firms
Export growth and GVC integration building scale	Talent gap limits R&D and diversification
	Shifting priorities undermined long-term strategy

Table 5.7: Enablers and Barriers of Market Formation (F4)

5.6.5. Function 5: Legitimation

Legitimation covers the extent to which the technology sector gains implicit approval, support, and credibility. Within this TIS, it refers to how the semiconductor industry became socially and politically accepted, and how stakeholders (governments, investors, firms, and the public) view them as desirable and aligned with developmental goals..

Functional development over time

From the 1990s onward, Malaysia's semiconductor industry benefited from a strong legitimacy context. At that time, the arrival of MNCs in Penang was seen not only as foreign involvement but also as a potential pathway to industrialization for what was then still an agrarian economy. The new electronics factories quickly demonstrated this promise, reducing unemployment from 8.1% in 1970 to 2.7% in 1990 and attracting supporting industries, which generated public goodwill and acceptance (Rasiah, 1995).

As years went by, Vision 2020 was introduced by then Prime Minister Mahatir Mohamed, which formalized the state's aspiration to develop Malaysia into a technology-driven, high-income nation by 2020. Mahatir referred to the E&E sector as the central focus of this vision. A secretary, A. Selvaraj, supported this message by stating: "He wanted Malaysia to be an advanced high-tech country where the majority of Malaysians would find employment in technology-related jobs before the year 2020" (Yoshida, 2003). The establishment of national technology institutes, like MIMOS, reinforced this commitment. In the late 1990s, Malaysia took bold and costly actions to solidify these visions, creating two state-owned semiconductor wafer facilities (First Silicon and Silterra) as flagship projects to push Malaysia up the value chain. Even though the ventures struggled commercially in their early phases, initiatives, driven by Mahatir, to organize a marshaled functioning of over 1$ billion for First Silicon's 200 mm fab, signaled a strong belief in the strategic importance of domestic semiconductor capabilities(Interviewee 3, 2025).

This legitimation continued in 2010 under new administrations. The Economic Transformation Program elevated E&E to one of twelve key national economic areas, and high-ranking officials continually framed the sector as central to moving up the chain (Yoshida, 2003). Emerging public-private partnerships reinforced this message, most notably through the creation of the CREST center. Industry associations, like MSIA and MAEI, also played an advocacy role, working closely with industry leaders. For example, MAEI chairman, Dato Wong Siew Hai, publicly highlighted the doubling of R&D investments by MNCs in Malaysia, from RM1 billion in 2007 to RM2 billion in 2012, and the increase in Malaysian design engineers from 200 to 5,500. Framing Malaysia as a credible location for higher-value semiconductor work (Arend, 2013).

By the late 2010s, semiconductors were firmly integrated into the national narrative, with the industry contributing 5.5% of GDP and employing nearly 600.000 workers (Malaysia External Trade Development Corporation (MATRADE), 2023).

Enablers and barriers

Several systemic factors contributed to the legitimation of Malaysia's semiconductor industry. A dominant enabler has been the consistent high-level policy focus, from the early IMP to the present-day NIMP 2030. Institutions such as MIMOS, TalentCorp, and the E&E Center of Excellence attempted to provide infrastructural support for the realization of the policy vision. Advocating coalitions, such as MSIA, created feedback loops between government and industry, helping to identify bottlenecks in flexibility and talent shortages (Arend, 2013).

The MNCs also played an enabling role. Leading multinationals expanded their presence in Malaysia to include product development, regional supply chain management, and mentoring of local supplier firms. The example of Oppstar, as an independent IC-design house, illustrates how such mentorship catalyzed domestic entrepreneurship (Interviewee 3, 2025). However, several barriers have constrained the full realization of semiconductor-focused legitimation. Doubts arose on Malaysia's capacity to advance semiconductor expertise because of a consistent shortage of specialized human capital(Interviewee 3, 2025). The country continues to produce relatively few advanced semiconductor researchers, with only 1000 R&D personnel per million population (Abad et al., 2015b). These doubts were reinforced by the limited involvement of local firms in breakthrough innovation, as it remains dominated by foreign firms and state-led ventures(Interviewee 3, 2025). Next to that, skepticism arose due to the lack of long-term semiconductor-specific strategies in institutions like MIMOS and within the industrial master plans(Interviewee 1, 2025; Interviewee 2, 2025). Early missteps in flagship projects drew media and policy criticisms, portraying them as costly and inefficient (Lin et al., 2015).

Global competition has further introduced challenges. Other nations launched aggressive semiconductor strategies that forced Malaysia to work harder to maintain its image as a preferred investment destination. This external pressure is accompanied by a shift in public perception: among younger Malaysians, the E&E sector is sometimes associated with low-skill assembly work, rather than a high-tech knowledge knowledge-intensive industry. These perceptions risk undermining the image of the sector and could hinder further development (Said & Tan, 2024).

To come to a conclusion, Malaysia's semiconductor industry enjoys long-term evolving political and economic legitimacy, supported through institutional initiatives and advocacy. Yet, the credibility of further advancements into higher-value segments remains fragile, constrained by persistent talent bottlenecks and an ongoing conflict between the public and corporate perception.

Enablers	Barriers
Policy vision framing semiconductors as central (IMP–NIMP2030, Vision 2020)	Shortage of specialized talent; low R&D density
Institutional support: MIMOS, TalentCorp, E&E CoE	Limited local firm role in innovation; foreign/state dominance
Advocacy coalitions (MSIA) addressing bottlenecks	Lack of long-term semiconductor strategies in institutions
MNC mentoring and fostering entrepreneurship (Oppstar)	Failures in early flagship projects (First Silicon, Silterra)
Public–private partnerships (CREST, MAEI) showcasing high-value hub	Rising global competition for investment
Semiconductors integrated into national narrative (GDP, jobs)	Perception of E&E as low-skill assembly persists

Table 5.8: Enablers and Barriers of Legitimation (F5)

5.6.6. Function 6: Resource mobilization

The resource mobilization examines how financial, human, and infrastructural resources have supported the development of Malaysia's semiconductor innovation system. It covers the attraction of capital, the build-up of skilled talent, and the provision of enabling infrastructure.

Functional development over time

Malaysia's semiconductor industry was fundamentally built on FDI during its early years. FDI accounted for roughly four-fifths of total capital investments in the electronics sector through the 1990(Ismail, 2001). These were stimulated by governmental measures, including tax incentives and the creation of FTZs, such as Penang's Bayan Lepas, which offered duty-free export facilities and basic infrastructure to attract MNCs (Electrical and Electronics Productivity Nexus (EEPN), 2024; Interviewee 3, 2025). Alongside, Malaysia offered abundant low-cost workers with basic technical and English language skills, which aligned with foreign firms' requirements for operation (Interviewee 1, 2025; World Bank, 2021c). To upgrade the quality of this workforce, the PSDC was established to train technicians, which was financially supported by MNCs and public infrastructure spending. Domestic private investments remained minimal while public institutions laid the groundwork for higher-value activities. Examples are the founding of MIMOS in 1985 to spearhead R&D and incubate national wafer fabs. By 1990, electronics accounted for nearly 50% of Malaysia's manufacturing exports, underscoring the scale of resources mobilized into the sector (Ismail, 2001).

The following years were further characterized by proactive and capital-intensive steps to move up the value chain. The launch of Silterra marked a pivotal commitment to initiate Malaysia's wafer fabrication capabilities, backed by over 1$ billion in investment through Khananh Nasional and MIMOS (Interviewee 3, 2025; Yoshida, 2003). Innovation financing instruments also began to emerge, including MAVCAP in 2001, with RM500 million dedicated to local tech startups (Lyons & Kenney, 2007). Complementary schemes such as the MTDC and Multimedia Super Corridor were rolled out to stimulate entrepreneurship in IC design and other knowledge-intensive areas. Despite the efforts, foreign multinationals remained the dominant source of investment through the 2000s, expanding their Malaysian operations and introducing more knowledge-intensive innovation projects. However, this was typically contained within the firm boundaries (Interviewee 1, 2025; Interviewee 3, 2025). As a reaction, the universities expanded their engineering faculties and scholarship programs. In 2010, Malaysia had become one of the world's top exporters of semiconductors with local facilities for advanced assembly and some product engineering. (*National Semiconductor Strategy*, 2024) Local venture capital, however, remained limited, as risks for non-government-backed opportunities were too high.

More recently, from 2010 to the present, resource mobilization has focused on emerging opportunities in automation, chip design, and advanced packaging. Programs such as TalentCorp and advancements in STEM education positively pushed the supply of skilled workers (*National Semiconductor Strategy*, 2024). University-industry collaborations, such as CREST in 2012, further support R&D developments. Meanwhile, FDI continued to flow, especially into Penang and Kuala Lumpur, where multinational reinvestment supported new chip ATP lines. Geopolitical tensions (with recent, the US-China tech rivalry) have strengthened Malaysia's position as a neutral production base, evidenced by announcements for new advanced testing and packaging plants (The Edge Malaysia, 2024).

Meanwhile, local firms, such as Unisem and Inari, have reinvested profits in attempts to acquire advanced equipment and aim at high-value segments. Yet financial and human resource constraints persist. R&D intensity remained relatively low, around 1% of GDP (substantially below international benchmarks), and technology transfer from MNCs to local firms remains limited (Interviewee 3, 2025; *National Semiconductor Strategy*, 2024).

Enablers and barriers

Several factors enabled Malaysia's resource mobilization trajectory over time. A stable investment climate, facilitated through agencies like MIDA, and strategic state-level initiatives (PDC in Penang), provided this (World Bank, 2021c). The steady flow of foreign capital into semiconductor manufacturing was enabled by regulatory incentives, tax deductions, and well-developed logistics and physical infrastructures. The support for advanced operations was offered by human capital development, including PSDC and HRDF.Institutional complements such as MTDC, MAVCAP, and CREST added depth to the innovation system by mobilizing financial and knowledge resources.

Despite these enablers, several identified barriers constrained resource alignment. The combination of an overly reliance on FDI, with high risks for domestic investments, created an imbalance in resources (Interviewee 1, 2025). While the state focused on large upstream ventures, local investors struggled to overcome high capital barriers. The underdevelopment of venture capital and entrepreneurship ecosystems further limited private sector participation, as overly rigid public schemes failed their purpose (Lyons & Kenney, 2007). Talent shortages were further increased through brain drain. As promising engineers remained in MNCs or emigrated abroad (Interviewee 3, 2025). Furthermore, domestic firms continued to focus on Malaysian talent, overlooking potential expertise for knowledge development from across the border (Interviewee 1, 2025).

Enablers	**Barriers**
Stable investment climate via MIDA, PDC	FDI dependence; weak domestic investment
Foreign capital inflows aided by incentives, logistics	Local investors face high barriers, limited mechanisms
Human capital programs: PSDC, HRDF, STEM	Weak VC and rigid public funding schemes
MTDC, MAVCAP, CREST mobilizing finance and know-how	R&D intensity (1% GDP) lags global norms
Public investment in upstream ventures (Silterra)	Poor MNC-to-local technology transfer
MNC reinvestment aided by geopolitical neutrality	Talent shortages, brain drain, narrow workforce base
Local reinvestment by firms (Unisem, Inari)	MNC-bound innovation, limited spillovers

Table 5.9: Enablers and Barriers of Resource Mobilization (F6)

5.6.7. Function 7: Development of positive externalities

The development of positive externalities (F7) refers to the self-enforcing benefits and spillovers that arise within innovation systems. This thesis includes the emergence of pooled labor markets, local supplier networks, knowledge spillovers, and supportive institutions that provide advantages for the industry beyond the direct inputs of the actors.

Functional development over time

In the initial decades, the Malaysian semiconductor sector began to display the first signs of potential positive externalities through the formation of localized clusters. Mainly in Penang, MNCs started to concentrate their activities, facilitated by government policies. Penang's Chief Minister Lim Chong Eu urged MNCs like Intel to subcontract tasks to local SMEs in complementary service fields. This supported the rise of a bunch of local supplier firms (Interviewee 3, 2025). By 1985, almost all of the 38 Penang-registered supplementary electronics firms were contracted as suppliers to MNCs (Hutchinson, 2025). This marked the beginning of future network externalities, as local firms started to benefit from external know-how. On-the-job training in MNCs created experienced talents that circulate across firms over time through job switching (Interviewee 1, 2025; Interviewee 3, 2025).

The establishment of PSDC in 1989 (mentioned earlier) further solidified this by offering general technical training that benefited the entire cluster (Hutchinson, 2025). By the 1990s, the Penang electronic workforce had become relatively experienced, and its engineers and managers increasingly distributed tacit knowledge as they moved between firms.

Around this time, entrepreneurial spillovers also began to appear. A key example is Globetronics, which was founded in 1991 by a former Intel executive and a partner. They offered special IC testing services, and became a dominant player in the industry (The Edge Malaysia, 2024). However, despite this success, (Hutchinson, 2025) noted that only a small number of local firms succeeded in scaling during this period.

In the first two decades of the 21st century, positive externalities became clearer as the ecosystems evolved. Having started with just the 'eight samurai' firms in 1981, by 2000, Penang housed dozens of global electronics firms and local SMEs that gave input into the value chain. By 2019, Penang was home to over 350 semiconductor-related MNCs and supported by 3000 manufacturing-related SMEs in the surrounding supply chain (InvestPenang, 2021). This growth created a thick inter-firm network that had a positive effect on costs (due to local supply base), on reducing lead times, and fostering outsourcing(Interviewee 3, 2025). This had a positive effect on Penang's attractiveness as a production location.

A case exemplifying the effect is Vitrox Corporation, which was started in 1998 by two engineers who left their former job at Hewlett-Packard Penang and started with minimal resources to develop a machine-vision inspection system. By 2021, Vitrox had grown into an RM7 billion dollar market-cap firm and a key global player in automated test equipment (ViTrox Corporation Berhad, 2021). These successes made engineers coming from Penang highly sought after by national and international firms looking for technologists. (Interviewee 2, 2025)

Around this time, government and academia also tried to facilitate positive externalities. Initiatives such as CREST facilitated 161 collaborative R&D projects to advance the technical expertise of the talent pool (Collaborative Research in Engineering, Science Technology, 2025). This was successful as the industry grew into more advanced packaging and more precise testing activities, but participation in higher-value VC segments remained low.

Looking at the more recent years, Penang has grown further, earning the title 'Silicon Valley of the East' with an estimated 5% of global semiconductor export in 2019 and around 32% of Malaysia's total exports in 2020 (ViTrox Corporation Berhad, 2021). Also, new clusters began to show up. The Kulim High Tech park in Kedah developed specialized competencies around Silterra's wafer fab, while the Kuala Lumpur area, supported by the Multimedia Super Corridor initiative, attracted design-oriented firms (Interviewee 3, 2025; Malaysian Industrial Development Authority, 2007). Yet constraints continue to exist. Despite the presence of skilled workforces, only a few Malaysians have successfully founded chip design or fabless firms. Many engineers contribute to high-value activities within MNCs, but the outcomes are contained in foreign firms and are rarely translated into domestic capabilities (Interviewee 3, 2025; The Edge Malaysia, 2025a).

Enablers and barriers

A number of factors have contributed to the development of positive externalities in Malaysia's semiconductor TIS. Early government visions on creating and facilitating an electronic cluster were crucial, setting the stage for pooled resources that continue to benefit the industry. A strong physical infrastructure and openness to international trade complemented this (Interviewee 3, 2025). Culturally, the workforce's ability in the English language and openness to MNC work practices facilitated the externalities(Interviewee 2, 2025). A debatable factor is the retrieved goodwill towards MNC entry, which arguably acted as both an enabler (by driving innovation and talents) and a constraint (by setting the industry's dependent structure).

On the barrier side, one overarching constraining aspect has been the compartmentalization of actors, networks, and institutions. Production clusters were minimally linked to industrial institutions. Universities and public research institutes contributed little to the evolving industry. While collaborations with MNCs and national knowledge developments were often barricaded, which causes knowledge to flow vertically (within firms), instead of horizontally (across the system)(Interviewee 3, 2025). Many firms kept core R&D outside Malaysia, which is reflected in low domestic invention rates and low patent citation numbers. This is partially due to its GVC position in ATP, but also reflects policy choices that discouraged the attraction of non-Malaysian talents. World Bank, 2021c even observed that venture capital policies ethnically discouraged cross-national entrepreneurship.

To conclude, Malaysia's knowledge development is characterized by successful cluster formation with belonging benefits. However, these positive externalities have largely enforced its existing GVC position, instead of enabling significant upgrading into higher-value segments.

Enablers	**Barriers**
Early policy support for clusters (e.g., Penang)	Fragmented actors and weak horizontal flows
Strong infrastructure and trade openness	Misaligned universities and public research
English proficiency and MNC practices aiding transfer	Vertical MNC knowledge flows; core R&D abroad
Goodwill to MNCs: supplier growth, labor mobility	Low domestic invention, weak innovation dynamics
Localized entrepreneurial spillovers (Globetronics)	GVC position limits upgrading to high-value segments
New clusters (Kulim, KL design firms) diversifying regions	VC and policy discourage foreign talent attraction
Public–private R&D and workforce initiatives (CREST)	Advanced MNC activities rarely benefit locals

Table 5.10: Enablers and Barriers of Development of Positive Externalities (F7)

6

Discussion

6.1. Synthesis of Findings along the Research Questions

Finding for SQ 1

The results of the thesis pose an answer to the question: *How did key actors, networks and institutions in Malaysia's semiconductor innovation system evolve, and what roles did they play in ATP, wafer-fab and design?*. The Malaysian semiconductor innovation system evolved under the strong influence of foreign MNCs, which acted as key actors in establishing the ATP as Malaysia's core competence. MNCs bought in technology, capital, and global market access, while domestic actors primarily took roles as suppliers, assemblers, and service providers. Wafer fabrication and IC-design were scarce, and the ones that there were were captured by MNCs; domestic actors were largely absent or played a marginal role in these, with limited national champions to establish success.

The network structure of the innovation system developed around geographically concentrated clusters, most notably Penang and Kulim. These clusters fostered vertical linkages between MNCs and local suppliers but were characterized by weak horizontal linkages among domestic firms, universities, and research institutions. The vertically oriented systems reinforced dependency on foreign-led value chains and limited indigenous capability development.

The Malaysian government played an institutional proactive role in creating enabling conditions through FTZs, investment incentives, and a human capital program. However, institutional support was unevenly distributed across segments. ATP was strongly facilitated, but insufficient guidance, sustained funding, and institutional legitimacy constrained further advancements. Initiatives such as MIMOS and CREST illustrate attempts with limited systemic impact.

Findings for SQ 2

A second question that the thesis aimed to answer is: *How did the underlying functions of the innovation system perform over time, and how did this performance vary across ATP, wafer fabrication, and design segments?*.

The functional analysis reveals a clear asymmetry in the performance of innovation system functions across segments. In ATP, the system performed relatively well in resource mobilization (F6), development of positive externalities (F7), and legitimation (F5). Resource mobilization is considered strong as sustained inflows of foreign capital and public investment created and expanded FTZs, industrial clusters, and firm footprints. These are complemented by long-running human-capital schemes such as the HRDF and PSDC. Development of positive externalities is assessed as strong based on the long-standing concentration of activities in Penang and Kulim, which facilitated pooled labor markets, supplier networks, and inter-firm knowledge diffusion. Legitimation is strong, indicated by repeated prioritization of the E&E sector in national strategies such as the IMPs, the ETP, and NIMP2030, together with the establishment of meso-institutions like CREST and active industry associations. Together, these functions supported stable market formation (F4) through the export-oriented integration of Malaysian ATP capacity into global production networks under captive-modular governance.

However, knowledge development and diffusion (F1), entrepreneurial experimentation (F3), and influence on the direction search (F2) showed relatively weak system performances. Knowledge development and diffusion are assessed as weak due to the thin upstream R&D base, together with a low volume of Malaysian-assigned semiconductor patents, the reliance on expat engineers, and the late establishment of specialized postgraduate programs. Entrepreneurial experimentation is considered weak because upstream activities were limited to a small number of state-backed ventures that failed to achieve competitive scale or generate significant domestic entrants. While some design and wafer fabs emerged, most remained embedded within foreign subsidiaries. The influence of direction search is judged as relatively weak because developments remained towards export-oriented ATP, rather than incentivizing upstream R&D and design ventures.

These functional constraints illustrate how the system has been unable to generate the necessary conditions for sustained upgrading beyond ATP. Persistent strengths in ATP-oriented functions and recurring weaknesses upstream reveal an asymmetric performance over time, reflecting the interdependencies within the system and its reliance on established segment dynamics, which limited the development of complementary advancements for higher-value activities.

Findings for SQ 3 The results of the thesis also addressed the question: *How is the global semiconductor value chains structured across functional geographic segments and where is Malaysia positioned within this structure?*

The global semiconductor value chain consists of functional segments, including upstream research and development, integrated circuit design, wafer fabrication, and downstream ATP. These segments are characterized by significantly different entry barriers, governance modes, and geographic concentrations. Upstream segments, such as IC design and wafer fabrication, are characterized by high capital intensity, strong IP, and reliance on tacit knowledge. These activities are dominated by firms in nations like the United States, Taiwan, South Korea, Japan, and the Netherlands.

Downstream ATP activities have lower capital requirements, shorter technological innovation cycles, and more modularized governance structures. This makes them more accessible to latecomer economies. Their geographic footprint is more dispersed, but still coordinated by lead firms through global production networks.

Malaysia's participation is concentrated in the ATP segment, where it has established a globally competitive base since the 1970s, supported by strong cluster development in Penang and Kulim. The country also participates in certain backed semiconductor services, such as test development. However, these remain closely tied to MNC-led operations. Domestic participation in wafer fabrication is minimal, while activities in IC design remain nascent and confined to niche applications.

Malaysia's value chain position is further shaped by the governance modes of the segments it engages in. The ATP segment is largely captive-modular, enabling MNCs to integrate Malaysian facilities into global networks while holding on to strategic control over technology and design. In upstream segments, hierarchical and highly integrated governance hinders domestic entry.

Overall, Malaysia's position reflects both the successful integration and dominance into downstream activities and the struggling role in upstream, knowledge-intensive segments. The structural asymmetry of the global semiconductor value chain illustrates this duality, where upgrading opportunities are unevenly distributed across the globe.

Findings for SQ 4

The thesis also sought to discover: *Which functional enablers and barriers, both domestic and value chain-related, characterized Malaysia's semiconductor innovation system, and how did they influence its upgrading trajectory?*

The main enablers for Malaysia's trajectory were its effective mobilization of foreign investments and resources, its institutional capacity to create effective clusters, and its societal legitimation for the early recognition of participating in globalized industries. These factors allowed Malaysia to achieve and sustain a globally competitive position in ATP.

However, several barriers hindered the advancement of its innovation system. The domestic innovation capacity and functional spillovers were constrained by retained technology and knowledge flows by MNCs. Also, the accumulation of domestic capabilities was undermined by the weak, vertical-focused networks and fragmented institutional support. The lack of sustained attention to knowledge development and insufficient legitimation left wafer fabrication and IC design underdeveloped. These barriers reinforced Malaysia's position as a specialized downstream participant in the GVC, without significant functional upgrading.

6.2. Functional Interactions in Malaysia's Semiconductor Innovation System

The analysis of Malaysia's semiconductor innovation system reveals several appearances of interacting dynamics across the functions. The functions of the TIS did not operate in isolation, but shaped and constrained one another, which resulted in the occurrence of reinforcing and constraining feedback loops. These loops have shaped the trajectory of the sector's development and highlight systematic lock-ins. The feedback loops were constructed through an interpretive synthesis of the functional analysis and the GVC findings. The temporal and segmental assessment of each function was reviewed to identify instances where a change in one function had a clear enabling or constraining effect on another. Only the interactions are included that were supported by at least two independent evidence sources (interviews, policy documents, industry or trade data). These links were then traced over time to determine whether they formed a causal pattern. One or more functions that consistently strengthened one after the other were classified as a reinforcing loop, or as a constraining loop if it limited functional performance or upgrading potential.

For example, in the FDI-driven growth loop described below, interview evidence and policy archives confirmed that inflows of foreign investment (F6) in the early 1980s accelerated export market formation (F4). Trade and production data show that this export success increased the sector's legitimacy (F5), which made Malaysia more attractive to additional FDI (F6). The chain of interaction over time and the coverage of multiple sources meet the criteria for inclusion as a reinforcing loop.

Reinforcing loops

Several interactions or loops among the functions have had a supportive effect on Malaysia's semiconductor sector as a globally recognized ATP base.

First of all, a FDI-driven growth loop emerged where a strong inflow of foreign investment (F6) enabled rapid export and early market formation (F4). This success enhanced the legitimacy of the sector (F5), which made Malaysia an attractive destination for further FDI (F6), which then enforced Malaysia's stable integration into the GVC (F4). While this loop has effectively built Malaysia's position as a competitive ATP-hub, it has also created structural dependency on external demand and constrained diversification, as high capital intensity and IP concentration in upstream segments have made entry into higher-value segments far more challenging.

Second, a cluster spillover loop can be identified. Early clustering in Penang facilitated pooled labor markets and tacit knowledge diffusion (F1) through job-switching. These elements encouraged entrepreneurial experimentation (F3) through spin-off and SMEs, which in turn enforced the positive externalities (F7) and sustained the resilience of the cluster. However, the GVC results indicate that these spillovers have remained contained within ATP-related activities, limiting the ability to bridge into IC design and wafer fabrication activities.

Third, there is a legitimation-policy alignment loop, whereby high-level political visions institutional support (F5) shaped long-term policy directions and industrial road maps (F2). These contributed to the orchestration of the mobilization of public and private resources (F6), which reinforced the sector's legitimacy (F5). Evidence through interviews indicated that this alignment has been mainly symbolic, rather than strategically focused on the impact on advancements of the innovation system.

Constraining loops

Several interactions between the functions of the innovation system have also constrained Malaysia's innovation system, and its capabilities within positioning in the GVC and for upgrading.

Most notable is the ATP lock-in loop. Early export success in low-cost ATP segments (F4) has legitimized the system's specialization in assembly operation (F5). This contributed to the shape og policy priorities (F2), which focused on maintaining its strong position and competitiveness in existing segments (F4) rather than enabling strategic upgrading. The GVC analysis shows that this lock-in has been further reinforced by the characteristics of the upstream sectors, creating high entry barriers. This loop has therefore created a lock-in for its role in ATP, rather than facilitating a transition towards higher-value activities.

Second, a weak R&D loop was revealed. Weak horizontal knowledge spillovers (F7) limited the domestic R&D capacity (F1), which, as a result, constrained high-value experimentation (F3). This, in turn, had constraining effects on the private investment and an institutional effect for advanced activities (F6). The GVC results confirm that the concentration by a few dominant firms in knowledge-intensive segments which amplified Malaysia's dependence on foreign technology and the inability to build domestic competitive upstream capabilities. This weakens the knowledge creation, which reinforces the loop.

The system was further constrained by a brain drain loop, whereby persistent shortages and brain drain of skilled engineers (F6), weakened Malaysia's credibility as a site for advanced domestic semiconductor activities (F5) and limited its ability to attracted and sustain higher-end R&D. The GVC insights highlight how talent is clusters in leading upstream in leading upstream hubs (such as Taiwan and the United States) creating a strong pull effect drawing away engineers form Malaysia.

Synthesis

Taken together, these reinforcing and constraining loops uncover the systemic interactions in Malaysia's semiconductor innovation trajectory. The identified mechanisms illustrate how early structural decisions and interaction have created dependency patterns in their specific role within the GVC. At the same time, they highlight the opportunity that could be leveraged to create industrial advancements. Understanding these interactions is crucial for informing more targeted policies aimed at enabling functional upgrading and preventing constraining spirals.

6.3. Synthesis of TIS, GVC, and Latecomer Industrialization

The analysis of Malaysia's semiconductor innovation system through the functional TIS framework has highlighted several systemic enablers and constraints that shaped its position in the semiconductor GVC. The functional perspective offers a detailed insight into how innovation system dynamics have evolved domestically and the effect the external forces of the GVC have had. This broadens the theoretical debates on latecomer industrialization.

While Malaysia's current innovation system has substantially progressed since the 1970s, it has continuously exhibited struggles in advancing into more knowledge-intensive and upstream segments of the GVC. Its specialization in ATP and limited progress in upgrading into wafer fabrication and IC-design reflect a functional misalignment. The functional performance analysis reveals that strong resource mobilization and positive externalities in ATP have not been sufficiently supported by knowledge development, entrepreneurial experimentation, and legitimation to support higher-value segments. The GVC analysis underlines that these upstream activities are characterized by hierarchical governance in wafer fabrication, knowledge monopolies, and exceptionally high capital requirements. These features increase the difficulty of functional upgrading. This underscores that weaknesses in the performance of TIS functions can constrain the results of the innovation system for functional upgrading and industrial advancements in the value chain.

The Malaysian case illustrates how governance regimes shape the position within globalized value chains. The captive and hierarchical governance structures in the semiconductor GVC reinforce Malaysia's dependency on foreign actors for strategic direction and technology access. The dependency limits the diffusion of tacit knowledge and tightens functional bottlenecks. Malaysia's trajectory shows that incremental upgrading in low-value segments can fall short of achieving strategic capabilities if systemic functions necessary for innovation are underdeveloped.

The trajectory of Malaysia's semiconductor industry also exposes limits to conventional latecomer theories. The literature emphasizes catching up to be dependent on learning, linkage, and state-led industrial policies. However, the semiconductor characteristics through IP regimes, capital intensities, and concentrations of tacit knowledge extend the criteria for latecomers aiming to upgrade in high-tech industrial sectors. Malaysia's functional TIS analysis can therefore not only be understood as an assessment of internal developments, but also as emergent properties of globally governed innovation landscapes, where critical knowledge and value capture are structurally restricted.

The integration of the three analytical perspectives thus suggests two key insights. First, the functional dynamics of technological innovation systems are tightly coupled with the governance and upgrading opportunities defined by the structure of the GVC. Second, latecomer industries aspiring to move beyond low-value roles should pursue combining a strong performance and alignment of the innovation systems functions, together with a strategic engagement with GVC governance characteristics.

In sum, Malaysia's semiconductor trajectory offers instructive lessons for latecomer economies navigating similar constraints in globalized high-tech industries. The synthesis of TIS, GVC, and latecomer industrialization proposes a more integrated understanding of innovation system evolution embedded in globalized contexts, by underscoring the need for context-sensitive strategies that strengthen systemic functions while shaping its role within the GVC.

6.4. Thematic Lessons for Latecomer Economies

Malaysia's trajectory within the globalized semiconductor industry offers valuable insights for latecomer economies aiming to enter and upgrade in similar sectors. The integrated TIS-GVC analysis shows that these lessons center on the need to develop systemic capabilities, while strategically engaging with GVC governance. This is particularly relevant for economies such as Vietnam and India. They have recently introduced targeted polices to attract investment in IC-design, advanced packaging, and wafer fabrication, but remain in the early stages of capability formation, with limited domestic R&D and high dependencies on foreign ventures. Next to that, Kenya and South Africa have ambitions to position themselves within the semiconductor value chain, as part of broader industrial ambitions; however, they do face constraints in skills, infrastructure, and institutional capacity. These economies share entry conditions that are comparable to Malaysia's initial focus on assembly and testing, making its experience potentially instructive for recognizing the opportunities of early integration and anticipating the risks of functional asymmetries and path dependency.

1. Avoiding functional asymmetry

The case of Malaysia shows that initial integration into GVCs can be achieved with strong performance of solely a limited set of functions; In the case of Malaysia, resource mobilization (F6), legitimation (F5), and positive externalities (F7). The risk is, however, that persistent weaknesses in other functions can create bottlenecks that hinder progression into higher-value segments; In the case of Malaysia, knowledge development and diffusion (F1), entrepreneurial experimentation (F3), and direction of search (F2). Latecomers to the value chain, who are looking to expand the sector-specific activities, should therefore target balanced development across functions.

2. Strategic GVC governance engagement

Malaysia's ATP success is enabled by integration into modular-captive GVC segments, by attracting FDI inflows. However, this governance structure also limited the horizontal knowledge spillovers and reinforced dependence on foreign ventures. This underlines the importance of capturing engagement terms that enable domestic capability building. Examples for this are: conditional incentives for domestic R&D, co-development projects (with foreign ventures), or IP sharing arrangements. Even while this might be difficult to realize in real life, public agencies must actively broker access to global design and fabrication networks rather than fully relying on MNC-led progressions.

3. Building domestic demand linkages

The limited domestic lead market in Malaysia meant that market formation (F4) depended almost entirely on external demand. This reinforced the dependence on global customers and external shocks. Latecomers could mitigate such risks by identifying complementary domestic demand niches (such as healthcare and automotive in South Africa). This can potentially serve as stable support for domestic firms while still linking into global supply chains.

4. Coordinating policies

In the case of Malaysia, policy legitimation (F5) was consistently apparent, but at times more symbolic than strategically targeted. This led to mismatches between long-term upgrading goals and resource allocations. For latecomers, this highlights the value of meso-level coordination bodies that are aligned with policy intent, institutional support, and industry capacity building. These bodies should be supported under stable conditions that span talent, technology, and market development.

All in all, these suggestions for lessons point to the importance of the long-term process of systemic capability formation and governance navigation.

7
Conclusion

This thesis examined how the functional dynamics of Malaysia's semiconductor innovation system shaped its position within the global semiconductor value chain. Thereby identifying what lessons this holds for latecomer economies seeking to strategically upgrade in high-technology industries. The global semiconductor sector is highly complex and strategically important, characterized by intense competition and constrained by concentrated governance structures. This makes the challenge of upgrading critical for latecomer economies. Understanding how technological innovation systems function and interact with global governance regimes, therefore, offers relevant insights into innovation-driven industrial development.

The thesis addressed a research gap by integrating the functional TIS framework with insights from a GVC analysis and latecomer industrialization theory. The methodological approach combined a functional TIS analysis of Malaysia's semiconductor sector with a contextual examination of GVC governance structures and industrial upgrading dynamics. This integrated approach provided a deeper understanding of how Malaysia's innovation system functions evolved, how it interacted with global structures, and how these dynamics shaped the country's upgrading trajectory.

The findings reveal significant asymmetries in the performance of innovation system functions across different segments of Malaysia's semiconductor industry. Malaysia succeeded in establishing and maintaining a competitive position in the ATP segment because the innovation system performed strongly on resource mobilization, development of positive externalities, and societal legitimation. However, weaknesses in knowledge development and diffusion, entrepreneurial experimentation, and direction of search constrained the development of domestic capabilities and limited Malaysia's ability to advance into higher-value, knowledge-intensive activities. These functional asymmetries were amplified by the hierarchical and captive governance, the high entry barriers, and concentrated control over tacit and codified knowledge of the GVC.

The analysis identified dynamic interlinkages among systemic functions that reinforced Malaysia's specialization in ATP. Feedback loops driven by FDI inflows, clustering effects, and policy-legitimation strengthened its integration in ATP. The presence of MNCs provided Malaysia with essential capital, process discipline, and cluster externalities. Yet the same governance regime constrained horizontal knowledge diffusion, cemented FDI, and path dependency, limiting strategic autonomy. But also created dependencies on external actors and technology. These challenges are compounded by hierarchical and captive relationships dominated by multinational firms, which restrict horizontal knowledge flows and strategic autonomy.

Malaysia's trajectory holds important lessons for latecomer economies and contributes to academic and policy debates on upgrading in globally embedded high-tech industries. Practically, the findings reveal that latecomers must align and strengthen the full range of innovation system functions beyond the requirements for initial integration, while at the same time deliberately engage and navigate the governance regimes within GVCs. Theoretically, the thesis demonstrates the value of integrating functional TIS analysis within an embedded context in GVCs and latecomer industrialization perspectives to fully comprehend the evolution of innovation systems in these high-tech globalized production structures.

7.1. Limitations

This thesis faces several limitations in terms of theoretical framing, methodology, and empirical scope. The applied dual framework design that combines the TIS and the GVC offered complementary insights but also introduces blind spots. The TIS lens is applied to Malaysia's semiconductor sector, which allows the analysis to capture innovation processes in depth, while it places less emphasis on the international linkages through which knowledge, capital, and capabilities exist and emerge. At the same time, the GVC framework maps the global structure and governance of semiconductor production; however, it gives limited attention to the domestic institutional arrangements and frameworks. Certain influential factors fall in between these two scopes, such as regionally specific cluster interactions, informal supplier-buyer relationships, or intra-firm learning mechanisms. The challenge for integrating these two frameworks is that neither lens fully captures the interaction between these global governance constraints and local functional dynamics. This limitation is also reflected in the feedback loop analysis in chapter 6.2, which focuses primarily on internal interactions between innovation system functions. External influences are treated only peripherally in the current analysis, while they have undoubtedly shaped these dynamics. Systematically incorporating such external factors could offer a more complete picture of how global and regional interactions perform.

The empirical base of the thesis rests on three semi-structured interviews with senior actors, complemented by extensive secondary data. This combination has provided strategic insights but may have made the analysis biased towards elite viewpoints and underrepresented smaller firms and worker-level experiences. Next to that, the reliance on secondary data as the main source and the low number of expert interviews may have limited the empirical quality.

The temporal and spatial scope also affects the generalisability of the research. The thesis draws clear implications for strengthening innovation in Malaysia's semiconductor industry, but the extent to which these recommendations transfer to different spatial contexts is uncertain. Latecomer economies all face different structural constraints and possibilities, which means that a lesson that applies in one context might falter in another. Lastly, global market cycles, political and geopolitical shifts, and technological discontinuities could not be analyzed in depth, but might have interacted significantly with the identified mechanisms.

7.2. Suggestions for Future Research

Building on the thesis, future research could deepen and broaden the analytical scope in three ways. First of all, comparative research across multiple industries, such as renewable energy and electric mobility, could test both the transferability and the limitations of the integrated framework. Applying the dual-framework to different contexts would reveal whether the observed relationships between systemic functions and value chain positioning also emerge elsewhere than in the semiconductor industry. Secondly, longitudinal analysis in other spatial contexts could illustrate how systemic functions evolve under varying institutional and geopolitical configurations. Examining these contexts over extended periods would provide valuable insights into how internal systemic dynamics interact with changing external environments. Third, more specific investigations into the mechanisms for specific TIS functions in globally governed sectors could yield actionable policy recommendations. By fostering more symmetrical systemic performances, specific policies can be formulated for economies to position themselves to move into higher-value activities within the GVC.

Pursuing these ways for future research would not only validate and refine the conceptual integration of the thesis, but also contribute more to a more nuanced understanding of how innovation systems interact with global production structure os over longer periods. This would strengthen the analytical and practical relevance for policymakers and industry stakeholders who navigate these complex high-tech sectors.

8

Appendix A - Interview Coding

Code ID	Time-stamp	FTIS Function	Quotation (excerpt)
F1_1	0:55 – 1:40	Knowledge development &	"Because Intel came in 1972… a lot of Malaysian businesses… started by ex-Intel people."
F1_2	3:24 – 4:05	F1	"Intel… would say, 'I will help you get started'; that doesn't happen anymore."
F1_3	16:16 – 17:04	F1	"Ten out of the top 20 medical-device firms in Penang… factory heads are ex-Intel or ex-semi."
F1_4	35:44 – 37:43	F1	"Talent in Malaysia is quite high… Taiwanese, Korean, Indian firms come to hire Malaysians."
F2_1	11:42 – 12:25	Direction of search	"Government did not have a strategy… until last year, after 50 plus years we have our own semiconductor
F2_2	12:37 – 14:21	F2	"PM ordered a strategy by end of May… we had < 2 months; it's a living document."
F2_3	24:22 – 24:59	F2	"It will still be export-focused… even as the ecosystem grows."
F3_1	10:43 – 11:42	Entrepreneurial experim	"Growth of local companies… may just happen by accident; government had no strategy."
F3_2	48:17 – 49:19	F3	"We want Malaysia to be a mini-Netherlands in equipment; I'm working closely with ASML."
F3_3	0:55 – 1:40	F3	(same quote as F1_1)
F4_1	16:30 – 19:44	Market formation	"Automotive sector and semiconductor co-existed without linkages… Malaysian car makers never complained
F4_2	26:23 – 27:02	F4	"Multinationals dictate where products go… 70–80 % of industry still MNC-controlled."
F5_1	12:28 – 12:37	Resource mobilisation	"Now we will be having specific incentives just for semiconductors."
F5_2	33:17 – 34:35	F5	"Foreign investors: we want your factory, money, IP—keep your talent… we make it difficult for talent t
F5_3	36:52 – 37:28	F5	"Declining STEM enrolment, but quantity still sufficient—for the time being."
F6_1	4:35 – 6:01	Legitimation	"We produced a 14-min documentary, 'Against All Odds: Rise of Silicon Penang'."
F6_2	11:42 – 12:00	F6	"Government will claim they actually have a semiconductor strategy—but they don't."
F6_3	12:37 – 13:25	F6	"Prime Minister's directive created the task-force—high-level political endorsement."
F7_1	0:55 – 4:26	Positive externalities	Intel's early procurement practices "helped you get started" → local supply-chain capability.
F7_2	16:16 – 17:04	F7	Medical-device cluster synergy (see F1_3).
F7_3	18:54 – 19:44	F7	Call for tighter linkage between automotive and semiconductor sectors.

<table>
<tr><th>Code ID</th><th>Time-stamp</th><th>FTIS Function</th><th>Quotation (excerpt)</th></tr>
<tr><td>**F1 _3**</td><td>| 22:41 – 23:15</td><td>| Knowledge development & diffusion</td><td>| “Too little, too little and recent … the university programme **just started to roll out a year ago – these people probably ha</td></tr>
<tr><td>**F1 _4**</td><td>| 24:07 – 24:16</td><td>| Knowledge development & diffusion</td><td>| “**MIMOS and CREST are insufficient** … they cover so many things that it’s not focused on semiconductors.”</td></tr>
<tr><td>**F1_1**</td><td>| 22:20 – 22:34 |</td><td>Knowledge development & diffusion</td><td>| “Whatever I’m learning in university … has **no real value** if I want to work in the semiconductor industry.”</td></tr>
<tr><td>**F1_2**</td><td>| 20:55 – 21:09 |</td><td>Knowledge development & diffusion</td><td>| “I think there is a **lack of research centres or innovation centres** that cultivate or train talent.”</td></tr>
<tr><td>**F2 _3**</td><td>| 5:25 – 5:45</td><td>| Influence on direction of search</td><td>| “We hear a lot about investments pouring into Vietnam and India … **a wake-up call for the government**.”</td></tr>
<tr><td>**F2_1**</td><td>| 5:47 – 6:33 |</td><td>Influence on the direction of search</td><td>| “This new administration **realised the significance** of the semiconductor industry and … pushed for the rollout of the NIMP 2</td></tr>
<tr><td>**F2_2**</td><td>| 10:28 – 10:41 |</td><td>Influence on the direction of search</td><td>| “NIMP also stresses on trying to build **design capabilities**, which Malaysia is lacking at the moment, but it is a **tangible</td></tr>
<tr><td>**F3 _3**</td><td>| 13:56 – 14:14</td><td>| Entrepreneurial experimentation</td><td>| “The government started to **let it cruise on its own without too much support**.”</td></tr>
<tr><td>**F3_1**</td><td>| 13:37 – 14:14 |</td><td>Entrepreneurial experimentation</td><td>| “Traditionally … we **don’t have local talent sufficient** to lead a company like TSMC … government let it cruise on its own.”</td></tr>
<tr><td>**F3_2**</td><td>| 14:55 – 15:13 |</td><td>Entrepreneurial experimentation</td><td>| “A lot of our brain drain ends up in **Singapore** … they pay in value so much higher.”</td></tr>
<tr><td>**F4 _2**</td><td>| 9:53 – 10:11</td><td>| Market formation</td><td>| “NIMP mentions **renewable energy, EVs and more advanced packaging**—that is the right direction because it plays on what our</td></tr>
<tr><td>**F4_1**</td><td>| 15:56 – 16:08 |</td><td>Market formation</td><td>| “Malaysia sees itself as a **trading nation**, which necessarily means we should be export-oriented … That’s a **strength** for</td></tr>
<tr><td>**F5 _2**</td><td>| 32:16 – 32:35</td><td>| Legitimation</td><td>| “Vietnam is incredibly **aggressive … an all-of-government approach**; that’s different from Malaysia.”</td></tr>
<tr><td>**F5_1**</td><td>| 6:33 – 6:59 |</td><td>Legitimation</td><td>| “NIMP … is very focused on **building strength from within rather than trying to compete abroad**, and in a way that’s good.”</td></tr>
<tr><td>**F6 _2**</td><td>| 28:06 – 28:22</td><td>| Resource mobilisation</td><td>| “The semiconductor industry is **hugely capital-intensive … the government has to be all-in**.”</td></tr>
<tr><td>**F6_1**</td><td>| 18:28 – 19:37 |</td><td>Resource mobilisation</td><td>| “A fresh graduate could get **7 000 ringgit** here; in Singapore it’s **8 000 US dollars** … huge difference.”</td></tr>
<tr><td>**F7 _2**</td><td>| 32:46 – 33:08</td><td>| Development of positive externalitie</td><td>s | “Penang’s hub **came out of a state-level initiative**, not federal policy.”</td></tr>
<tr><td>**F7_1**</td><td>| 25:15 – 26:25 |</td><td>Development of positive externalities</td><td>| “Obviously the hub is in **Penang**, but over time there has been more facilities popping up across Malaysia … yet you’re **rem</td></tr>
</table>

Code ID	Time-stamp	FTIS Function	Quotation (excerpt)
F1_1	10:43 – 11:03	Knowledge development & diffusion	"The syllabus … was mainly focused on theories … **very little content that actually gave students hands-on** silicon-
F1_2	14:13 – 14:33	Knowledge development & diffusion	"I probably spent close to **three years in the US … to build that capability** and then bring it back to Penang."
F2_1	11:21 – 11:42	Influence on direction of search	"Only within the last 4-5 years you'll see the **government … giving incentives to startups** … building the ecosystem."
F2_2	5:26 – 5:45	Influence on direction of search	"The **government started to realise** that beyond manufacturing, Malaysia probably has a role in silicon design and
F3_1	8:54 – 9:09	Entrepreneurial experimentation	"Design-services companies … **were primarily trying to supply contractors to Intel and Altera**."
F3_2	26:19 – 26:34	Entrepreneurial experimentation	"Over the last five years, you see that **now the ecosystem is much richer** … talent is moving across different
F4_1	33:00 – 33:32	Market formation	"The semiconductor industry is **very much focused in Penang … export-oriented** in many respects."
F4_2	21:46 – 22:13	Market formation	"It worked out well for Intel … **cost-effective execution partner** to the design teams in the US."
F5_1	22:46 – 23:05	Legitimation	"The **local leaders had the foresight** … proposing that we start a design team in Malaysia—and it worked out well."
F5_2	32:46 – 33:08	Legitimation	"The semiconductor hub in Penang **came out of a state-level initiative, not federal policy**."
F6_1	28:37 – 28:54	Resource mobilisation	"The **main instruments are tax breaks** … Malaysia Digital … visas for foreign workers in IC design."
F6_2	32:13 – 32:35	Resource mobilisation	"You need **the same amount of compute and EDA licences**; the advantage of doing it out of Penang is the
F7_1	25:15 – 25:30	Positive externalities	"Companies … setting up outside Penang are **removed from the most efficient supply chains**."
F7_2	26:52 – 27:14	Positive externalities	"Talent is moving across the different companies … **the ecosystem is much richer** now."
**F1_3	15:27 – 15:52	Knowledge development & diffusion	"Both Intel and Altera have **very strong control of IP protection … all employees go through training every year**."
**F1_4	41:45 – 42:23	Knowledge development & diffusion	"Open-source EDA capabilities … Google is creating silicon-design tools … **EDA is becoming less of a bottleneck**."
**F3_3	24:24 – 25:22	Entrepreneurial experimentation	"If they wanted to start a new department … they would have to **go on a talent war with Intel and Altera**."
**F3_4	39:48 – 40:05	Entrepreneurial experimentation	"We became a **duopoly naturally … incentive to prevent talent from leaving** rather than to build the
F6_3	32:13 – 32:35	Resource mobilisation	"You need the same compute and EDA licences; **the advantage of Penang is cheaper labour**."
F7_3	16:31 – 17:01	Development of positive externalities	"Fundamental skill sets—design methodology, RTL writing—are **what people take between companies**, not

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