Club Techno-Nationalism and Enterprise Knowledge Capital in the Semiconductor Industry: TSMC and the New Geopolitics of Technological Sovereignty

Techno-nationalisme de club et capital savoir de l'entreprise dans l'industrie des semi-conducteurs : TSMC et la nouvelle géopolitique de la souveraineté technologique

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ABSTRACT. Enterprise Knowledge Capital plays a central role in innovation strategies and technological leadership. This is particularly evident in semiconductors, a systemic technology characterized by globally distributed yet highly concentrated capabilities, generating strategic dependencies and geopolitical tensions. This conceptual article examines how states and leading firms co-develop, protect and mobilize knowledge capital to secure critical technological capabilities, with TSMC illustrating this firm-state dialectic. We argue that the systemic nature of semiconductor innovation makes technological sovereignty through national self-sufficiency unrealistic. Friend-shoring therefore provides an instrument for territorializing critical capabilities within trusted ecosystems. We introduce "club techno-nationalism" to characterize the broader governance mode through which allied states, in coalition with leading firms, selectively organize technological interdependencies while restricting strategic rivals' access to critical technologies. This inherently asymmetrical configuration makes technological sovereignty increasingly relational, combining domestic capabilities with secured access to complementary knowledge and technologies controlled by trusted partners.

RESUME. Le capital savoir de l'entreprise joue un rôle central dans les stratégies d'innovation et le leadership technologique. Cela apparaît particulièrement dans l'industrie des semi-conducteurs, technologie systémique caractérisée par des capacités réparties à l'échelle mondiale mais fortement concentrées, générant dépendances stratégiques et tensions géopolitiques. Cet article conceptuel analyse la manière dont les États et les grandes entreprises développent, protègent et mobilisent conjointement le capital savoir afin de sécuriser des capacités technologiques critiques, TSMC illustrant cette dialectique entre firme et État. Nous montrons que la nature systémique de l'innovation dans les semi-conducteurs rend irréaliste une souveraineté technologique fondée sur l'autosuffisance nationale. Le friend-shoring constitue dès lors un instrument de territorialisation des capacités critiques au sein d'écosystèmes de confiance. Nous introduisons la notion de « techno-nationalisme de club » pour désigner le mode de gouvernance par lequel des États alliés, en interaction avec des firmes leaders, organisent sélectivement les interdépendances technologiques tout en restreignant l'accès des rivaux stratégiques aux technologies critiques. Cette configuration asymétrique rend la souveraineté technologique de plus en plus relationnelle, combinant capacités domestiques et accès sécurisé à des connaissances et technologies complémentaires contrôlées par des partenaires de confiance.

KEYWORDS. Innovation Strategies, Technological Sovereignty, Club techno-nationalism, Semiconductor Industry, Geopolitical Competition, Enterprise Knowledge Capital.

MOTS-CLÉS. Stratégies d'innovation, souveraineté technologique, techno-nationalisme de club, industrie des semi-conducteurs, compétition géopolitique, capital savoir de l'entreprise.

Introduction

Semiconductors have become a technological backbone of the productive economy and of the twin digital and low-carbon transition [VER 24] [ARC 25]. They underpin the competitiveness of a wide range of strategic industries, including artificial intelligence, computing and cloud services, telecommunications, automotive and electric mobility, industrial equipment, energy, healthcare and defense. At the same time, their fragmented and geographically concentrated value chain has created deep interdependencies between a limited number of technological hubs, making localized disruptions capable of propagating across multiple industries and revealing systemic vulnerabilities.

Their strategic importance stems from both their technological characteristics and the organization of their global value chain. Following the seminal work of Bresnahan and Trajtenberg [BRE 95], semiconductors can be regarded as a General Purpose Technology (GPT), characterized by pervasive diffusion across industries, continuous technological improvements and strong innovational complementarities. They can also be analyzed as a systemic innovation, whose development relies on the coordinated evolution of scientific knowledge, manufacturing capabilities, complementary technologies and institutional arrangements [LAP 25]. Over the past decade, semiconductors have also become a central issue of economic security and geopolitical competition. Their globalized and specialized value chain is undergoing significant reconfiguration as shortages, geopolitical tensions and other disruptions have prompted policies based on export controls, investment screening, CHIPS-type programs, friend-shoring and partial regionalization [WON 24]. These policies affect the geography of production as well as the organization and circulation of technological capabilities and knowledge.

These transformations have revived debates on technological sovereignty and the role of industrial policies [EDL 23], on the emergence of a new economic nationalism linking industrial policy, technological competition, and national security [HAU 25], and on the evolving relationships between national and corporate innovation systems [LUN 22]. These perspectives provide important insights into the geopolitical transformation of industry, while leaving scope for a closer examination of the knowledge resources accumulated and controlled by leading firms and of their role in technological sovereignty.

Enterprise Knowledge Capital is understood here as the set of scientific, technological and organizational knowledge accumulated by firms and embodied in human skills, production processes, organizational routines, equipment and intangible assets [LAP 17]. In industries such as semiconductors, where innovation depends on the continuous recombination of multiple complementary technologies and actors, this knowledge capital constitutes a foundation of firms' competitive advantage and raises important questions about its relationship with public policy and technological sovereignty.

This article addresses the following research question: How does the relationship between Enterprise Knowledge Capital and public policy shape technological sovereignty in a context of internationally distributed technological capabilities? This question is examined in the semiconductor industry, whose highly specialized global value chain provides a relevant setting for analyzing these relationships.

We argue that the geopolitical centrality of the semiconductor industry can be understood through a dialectical relationship between firms and states. Firms benefit from public policies and institutional environments that support the creation, accumulation and protection of their knowledge capital, while states rely on the knowledge and technological capabilities accumulated by firms to strengthen their own capacity for action. In a systemic and internationally specialized industry, this dialectic extends beyond national innovation systems and involves selective relationships among allied states and firms. We conceptualize the governance of these relationships as club techno-nationalism.

Methodologically, this article adopts a conceptual approach, drawing on the academic literature and documentary evidence from institutional, policy and industry sources. TSMC is used as an illustrative case to examine the firm-state relationships underlying the proposed framework and to discuss their implications for technological sovereignty in the semiconductor industry. The article makes three main contributions. First, it places Enterprise Knowledge Capital at the center of the analysis of technological sovereignty. Second, it develops a dialectical framework explaining the reciprocal relationship between the knowledge capital accumulated by firms and states' technological capabilities. Third, it introduces the concept of "club techno-nationalism" to explain how selective technological interdependencies among allied states and leading firms are organized through a combination of openness, protection and asymmetrical power relations.

TSMC is used as an illustrative case because its trajectory captures several dimensions of the proposed framework. Founded in 1987 in Taiwan, the company pioneered the pure-play foundry model and became a world leader in advanced semiconductor manufacturing. Its technological capabilities were built within the Taiwanese innovation system and now constitute a strategic resource extending beyond the firm and Taiwan itself. Moreover, TSMC's expansion to the United States, Japan and Europe places the company at the intersection of several industrial policies and technological strategies. Its trajectory therefore provides a relevant illustration of how Enterprise Knowledge Capital is accumulated and protected, how it becomes a resource for states, and how its internationalization interacts with strategies of technological sovereignty.

The remainder of the article is organized as follows. Section 1 examines semiconductors as a General Purpose and Systemic Technology and analyzes the co-evolution of firms' strategies and public policies in the transformation of the global semiconductor value chain and the emergence of strategic dependencies. Section 2 develops the analytical framework centered on Enterprise Knowledge Capital and the firm-state dialectic, illustrated by the case of TSMC. It then examines the limits of technological sovereignty and techno-nationalism at the national level, discusses friend-shoring as an instrument for reorganizing technological capabilities among trusted partners, and introduces club techno-nationalism as a governance mode for selective and asymmetrical technological interdependencies.

1. Semiconductors: From General Purpose Technology to Strategic Asset

1.1 Semiconductors as a General Purpose and a Systemic Technology

Semiconductors have long been recognized as one of the archetypal General Purpose Technologies (GPTs). According to the seminal framework developed by Bresnahan and Trajtenberg [BRE 95], GPTs are characterized by three main features: their pervasive diffusion across a wide range of industries, their continuous technological improvements, and their strong complementarities with downstream applications. Semiconductors fully meet these characteristics. Initially developed for electronic applications, they have progressively become indispensable to almost every sector of the economy, including artificial intelligence, cloud computing, telecommunications, electric mobility, industrial automation, healthcare and defense [LAP 23]. Continuous improvements in performance, miniaturization and energy efficiency have sustained their diffusion, while their complementarities with software, digital infrastructures, advanced manufacturing and communication technologies have continuously generated new waves of innovation and productivity gains.

However, the GPT framework alone does not fully explain the strategic importance of semiconductors. While it highlights their diffusion throughout the economy, it pays less attention to the complexity of their development and to the multiple interactions required to sustain technological progress. From this perspective, semiconductors can also be understood as a systemic innovation [LAP 25]. Their development does not result from isolated technological breakthroughs but from the coordinated evolution of scientific knowledge, manufacturing technologies, equipment, materials, design tools, standards and organizational capabilities. Innovation therefore emerges from the continuous recombination of complementary assets distributed across numerous firms, research organizations and public institutions, whose interactions have historically played a major role in the development of the semiconductor industry [MOW 11].

Figure 1 illustrates this systemic nature by representing semiconductors as a scientific and technological tree. The roots are embedded in a dense knowledge base combining solid-state physics, materials science, chemistry, applied mathematics and electronic engineering. This scientific foundation is continuously enriched by advances in manufacturing technologies, process control, advanced packaging and, environmental constraints related to water, energy efficiency and recycling. The trunk represents the common technological platform, including fabrication processes, process design kits (PDKs), reliability standards and design rules, that enables the integration of complementary technologies. Finally, the branches correspond to the wide diversity of downstream applications, illustrating the diffusion of semiconductors throughout the economy.

Semiconductors encompass a wide diversity of technologies and products. The OECD [OEC 24] distinguishes four broad categories (logic, memory, analog and other semiconductors) with further subcategories reflecting their specific functions and applications. These categories rely on different technological generations and process nodes and serve a wide range of applications, from advanced computing and digital infrastructures to automobiles, consumer electronics and industrial equipment. The most advanced nodes are concentrated primarily in logic and memory applications, while mature-node semiconductors remain essential for many industrial and everyday applications [OEC 24, 25]. The strategic importance of semiconductors therefore stems from the diversity and complementarity of components across technological generations, from advanced nodes to mature technologies, which together underpin contemporary technological system.

Viewed together, the GPT and systemic innovation perspectives provide a comprehensive understanding of the semiconductor industry. The former explains why semiconductors have become a foundational technology for economic development, whereas the latter explains why their continuous evolution depends on the coordination of multiple scientific, technological, industrial and institutional capabilities. Their strategic importance therefore derives first from their widespread diffusion across industries, but also from the exceptional concentration of knowledge, competencies and complementary assets required for their continuous development. This knowledge-intensive nature has profoundly transformed the organization of the semiconductor industry, leading firms to adopt specialized business models and contributing to the emergence of a highly fragmented global value chain.

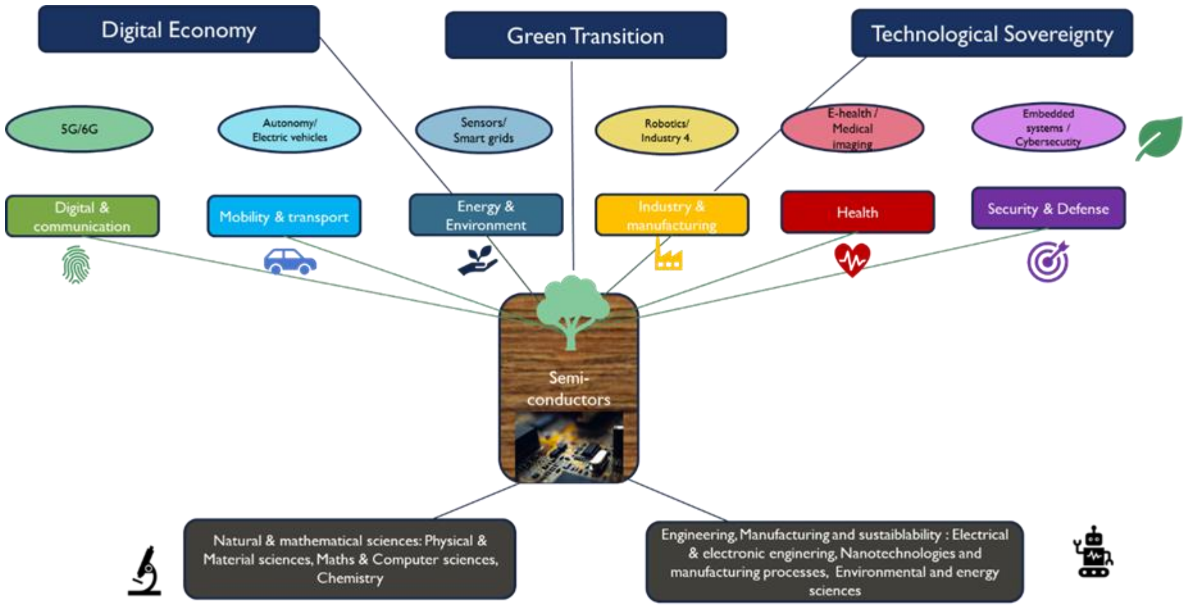

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Figure 1: Figure 1: Semiconductors as a scientific and technological tree

1.2 The Globalization of the Semiconductor Value Chain: Business Model Transformation and Growing Dependencies

Before examining its globalization, it is useful to clarify the meaning of the semiconductor value chain adopted here. Following the French industrial economics tradition of the filière (which is only imperfectly captured by the English term "value chain") we adopt a meso-economic perspective that goes beyond the technical succession of production stages. A filière can be understood as an organized system of interdependent activities and actors, structured by technological and commercial flows, but also by strategic relationships, institutional arrangements and modes of governance [UZU 22] [LAP 24]. This perspective is particularly relevant for systemic technologies, where innovation depends on interactions among heterogeneous firms, research organizations and public institutions, combining cooperation, competition and complementarity [LAP

25]. The semiconductor value chain is therefore considered here both as a technical architecture and as a relational and institutional system.

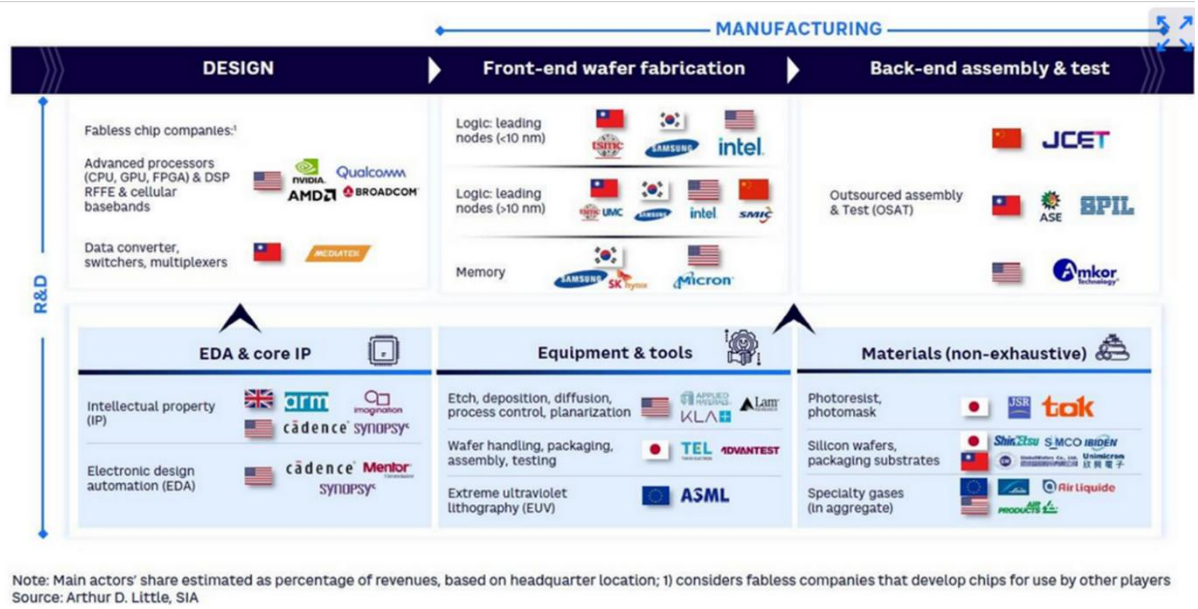
The current organization of the semiconductor industry is the outcome of the co-evolution of firms' business models, industrial strategies and public policies over the past four decades [MIL 22] [LAP 23]). During the early stages of the industry, most semiconductor firms operated as Integrated Device Manufacturers (IDMs), combining design, fabrication, assembly and testing within a single organization. However, the continuous increase in R&D expenditures, the soaring costs of fabrication facilities, the growing technological complexity of semiconductor manufacturing and the cyclical nature of the semiconductor market progressively challenged this vertically integrated model [AUB 14].

To remain competitive, firms specialized in the stages where they possessed the strongest technological capabilities. This transformation gave rise to the Fabless-Foundry model, in which fabless firms concentrate on research, chip architecture, software development and intellectual property, while manufacturing is entrusted to specialized foundries. The emergence of TSMC, today the world's leading semiconductor foundry, particularly in advanced logic manufacturing, played a decisive role in this transformation by demonstrating that semiconductor manufacturing could operate as a specialized business distinct from chip design. The model rapidly diffused throughout the industry and profoundly modified the geography of semiconductor production.

This evolution was particularly marked in the United States and Europe. Rather than investing in costly manufacturing facilities, many firms progressively concentrated on knowledge-intensive activities, including R&D, Electronic Design Automation (EDA), chip design and intellectual property, while relocating fabrication and, later, assembly and testing activities to Asia. These corporate strategies were not driven solely by firms' search for efficiency and specialization. They developed in a context of trade liberalization and increasing internationalization of production, leading to fragmented and globally coordinated value chains [GER 05]. At the same time, several Asian economies, particularly Taiwan and South Korea, and more recently China, implemented long-term industrial policies combining investment incentives, education, research infrastructures, technology transfer and capability building to develop advanced semiconductor manufacturing. These policies played a decisive role in fostering technological upgrading, strengthening domestic industrial capabilities and attracting critical segments of the global semiconductor value chain [CHE 96] [OUY 06] [BOW 24].

This specialization generated substantial economic benefits by allowing firms to deepen their technological expertise, exploit learning effects [IRW 94], develop strategic mechanisms for appropriating returns from cumulative innovation [HAL 01], and build manufacturing capabilities through cumulative experience and continuous improvements in production processes [MAC 98].

The combined effect of these corporate and public strategies is the highly specialized global value chain illustrated in Figure 2. Today, no single firm or country controls the entire semiconductor value chain. According to various reports on the semi-conductor and digital industries [BCG 21] [ART 24] [BRI 25] [OEC 23], the United States retains leadership in Electronic Design Automation (EDA), core intellectual property, chip design and advanced semiconductor equipment. Europe occupies key positions in research, equipment and some manufacturing technologies, notably through companies such as ASML, while East Asia dominates wafer fabrication. Taiwan alone concentrates the overwhelming majority of the world's manufacturing capacity for the most advanced logic nodes, whereas South Korea dominates memory chips. China has become a major actor in assembly, packaging and testing (OSAT) while progressively expanding upstream through massive public investment.



Source : [ART 24]

***Figure 2:** Figure 2: The highly globalized value chain of the semi-conductors*

Recent OECD analyses based on international input-output tables (TIES) and Trade in Value Added (TiVA) indicators provide a quantitative assessment of this geographical concentration. These analyses show that the semiconductor industry is one of the most upstream and geographically concentrated industries in the global economy. Around 75% of global value added is generated by only five economies, four of which are located in Asia, while several key segments, including advanced logic manufacturing, memory chips and semiconductor equipment, are dominated by a handful of firms and countries [OEC 25].

However, this organization has also produced new forms of strategic dependence. The geographical concentration of critical stages of the value chain has created a series of technological chokepoints. Advanced lithography depends almost exclusively on ASML in the Netherlands; leading-edge fabrication is dominated by TSMC in Taiwan and Samsung in South Korea; Electronic Design Automation software is controlled by a handful of American firms; while several critical materials and manufacturing equipment are supplied by a very limited number of companies. These chokepoints have become powerful instruments of both economic competitiveness and geopolitical influence because they determine access to the technologies required to produce the most advanced semiconductors [WON 24]. These strategic dependencies extend beyond manufacturing capacity to critical knowledge, design capabilities, equipment and standards.

The semiconductor value chain therefore constitutes an internationally distributed system of specialized and interdependent technological capabilities. It reflects the co-evolution of firms' business models and public policies that have progressively organized an international division of technological capabilities. While this organization has considerably accelerated innovation and economic efficiency, it has also concentrated critical technological capabilities in a limited number of firms and territories. As recent crises have shown, strategic control concerns the scientific, technological and organizational capabilities embedded within critical stages of the value chain, beyond access to production capacity itself.

1.3 From Global Value chain to strategic asset

The efficiency of this specialized and globally fragmented value chain has been challenged by a succession of economic and geopolitical shocks. The semiconductor shortages and bottlenecks of 2020-2022 revealed the dependence of multiple industries on a limited number of suppliers, technologies and territories [RAM 22] [OEC 23]. The pandemic, followed by growing geopolitical tensions and disruptions in logistics and energy markets, highlighted the economic consequences of shocks affecting such a highly upstream input. At the same time, technological advances in areas such as leading-edge nodes and advanced packaging have increased requirements for specialized skills, infrastructures and equipment, reinforcing interdependencies and the potential for disruptions to propagate across industries [WON 24] [OEC 25].

These vulnerabilities have contributed to reinforcing the vision of semiconductors as a strategic asset. They extend the strategic issue from firms' access to the components required for production to states' and industries' capacity to maintain reliable access to the technological capabilities on which large parts of their economies depend. The semiconductor industry therefore illustrates a broader shift from concerns about the efficiency of global value chains towards concerns about technological sovereignty. Technological sovereignty does not imply technological self-sufficiency. It refers to the capacity to maintain reliable access to technologies considered critical, either through domestic capabilities or through stable external partnerships, while avoiding excessive or unilateral dependencies [EDL 23].

This evolution has been accompanied by a renewed role for industrial policy. After several decades marked by market liberalization and global specialization, particularly in Europe and the United States, industrial policy has regained prominence, extending beyond the correction of market failures towards the building of technological capabilities and the orientation of innovation towards strategic economic and societal objectives [MAZ 13] [MAZ 18] [JUH 24]. In the semiconductor industry, the vulnerabilities associated with the international division of production and innovation activities have led governments to reconsider the balance between specialization, efficiency and security that had underpinned the globalization of the industry [LAP 23]. Export controls, investment screening, CHIPS-type programmes, friend-shoring and partial re-regionalization seek to strengthen domestic or allied technological capabilities and secure access to critical segments of the semiconductor value chain. The US CHIPS and Science Act, the European Chips Act and Japanese support schemes illustrate this reorientation. Public intervention combines traditional objectives of innovation and competitiveness with the securing of strategic technological capabilities and the reduction of critical dependencies.

The vulnerabilities revealed by the semiconductor value chain extend beyond the geographical distribution of production capacities. As shown in the previous section, its most critical segments concentrate scientific and technological knowledge, manufacturing know-how, design capabilities, equipment and organizational competencies within a limited number of firms. The strategic issue therefore encompasses both the location of semiconductor production and the control of the knowledge and capabilities required to design, manufacture and continuously improve them. In this context, technological sovereignty more and more depends on the relationships between states and the firms that accumulate and organize these strategic knowledge resources.

Understanding this relationship requires examining how knowledge is accumulated, organized, protected and mobilized at the firm level, and how public policies contribute to these processes. This leads to the concept of Enterprise Knowledge Capital, which provides the analytical starting point for the second part of the article.

2. Enterprise Knowledge Capital, Technological Sovereignty and Club Techno-Nationalism

2.1 Enterprise Knowledge capital and the firm-state dialectic

Enterprise Knowledge Capital can be defined as the stock of scientific, technical and organizational knowledge accumulated and organized by the firm in order to innovate [LAP 17]. It encompasses tacit and codified knowledge embedded in people, their skills and experience, equipment and technological tools, organizational processes and routines, as well as intangible assets such as data, patents, trade secrets and internal standards. Knowledge capital is built through the transformation of information and knowledge flows (generated through R&D, technological monitoring, cooperation and training) into resources that firms can mobilize to design, produce and disseminate innovations (Figure 3). It is cumulative and path-dependent, but also subject to depreciation when it is not continuously maintained and renewed. Its accumulation therefore contributes to shaping firms' technological trajectories [BOU 23].

The semiconductor industry provides a particularly relevant context to analyze how Enterprise Knowledge Capital of major firms is built and protected. As discussed in the first part, semiconductor innovation relies on strong complementarities between scientific knowledge, process technologies, equipment, materials, software and standards. Critical knowledge is distributed across multiple actors while remaining deeply embedded in firms' capabilities, equipment, routines and organizational processes. Large firms organize and control knowledge flows extending beyond their organizational boundaries and interacting with national innovation systems [LUN 22]. Competitive advantage therefore depends on firms' capacity to combine proprietary technologies and intellectual property with the access, organization and continuous renewal of heterogeneous knowledge resources.

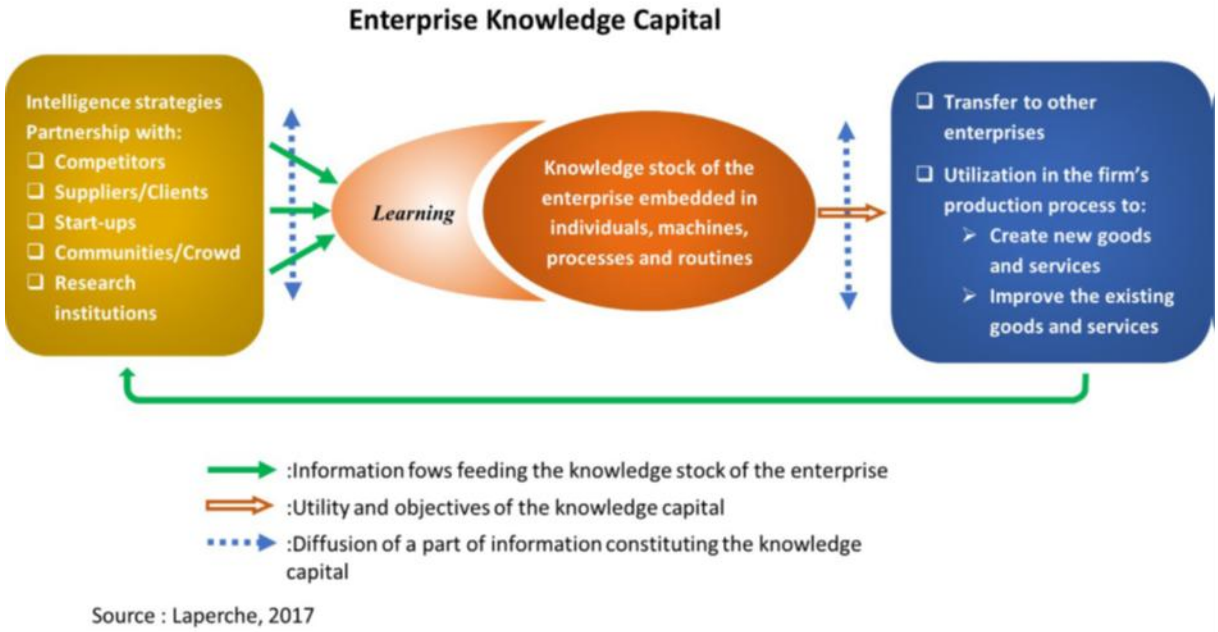


Figure 3: *Enterprise Knowledge Capital*

The accumulation and renewal of this knowledge capital are closely embedded in firms' institutional environment. They rely on scientific and technological infrastructures, education and training systems, research funding, standards and access to highly skilled labor. Moreover, access to scientific knowledge does not automatically translate into technological capabilities. Even when scientific information is openly available, its effective use requires absorptive capacities, in-house research efforts and a prior stock of tacit and codified knowledge [LUN 26]. Public policies therefore contribute to creating the conditions in which firms can accumulate and renew their knowledge capital. This relationship is particularly important in semiconductors, where the scale of investment, the complexity of technological infrastructures and the cumulative nature of learning make interactions between firms, universities, research institutions and public authorities essential.

Firms also contribute to shaping their knowledge environment. Firms endowed with substantial knowledge capital can themselves influence the production and direction of scientific and technological knowledge. Research-intensive firms may become privileged users of scientific knowledge while simultaneously stimulating and orienting research in universities. Leading firms can thus operate as both lead users and lead producers of science, contributing to the direction of emerging technological trajectories [LUN 26]. Enterprise Knowledge Capital therefore reflects firms' capacity to position themselves within, organize and influence knowledge networks.

At the same time, the accumulation of knowledge raises the question of its appropriation. Intellectual property rights, trade secrets, data governance and control over technological interfaces contribute to protecting knowledge against uncontrolled dissemination and enable firms to capture part of its economic value. Firms consequently combine openness and protection: they can participate in open science and open innovation while keeping their most strategic knowledge in-house or protecting it through intellectual property rights [LAP 25] [LUN 26]. Firms thus need openness to build and renew their knowledge capital and protection to appropriate its value. The balance between these two dimensions is necessarily dynamic: excessive protection may restrict the circulation and recombination of knowledge on which systemic innovation depends, whereas excessive openness may weaken firms' capacity to appropriate the returns from their accumulated knowledge.

States, in turn, depend on the knowledge capital accumulated by leading firms to transform national technological capabilities into economic and strategic power. Firms' knowledge capital contributes to innovation and competitiveness, but also to security of supply and technological autonomy and, when critical technologies and capabilities are concentrated within a limited number of firms, to states' negotiating and standard-setting capacities.

The relationship between firms and states can therefore be understood as dialectical: on the one hand, firms benefit from public policies and institutional environments that support the creation, accumulation and protection of their knowledge capital; on the other hand, states rely on the knowledge and technological capabilities accumulated by firms to strengthen their own capacity for action. This dialectic takes on a specific significance in the context of techno-nationalism and renewed concerns about technological sovereignty. Governments seek to strengthen domestic capabilities while reconsidering the dependencies resulting from international technological specialization and the conditions under which access to key technologies can be secured [EDL 23]. In the semiconductor industry, technological capabilities are distributed across an internationalized value chain while being concentrated within a limited number of leading firms. Technological sovereignty therefore involves states' capacity to support, access and mobilize the Enterprise Knowledge Capital of firms occupying key positions in the global innovation system. TSMC provides a particularly revealing illustration of this firm-state dialectic.

2.2 TSMC: Entreprise Knowledge Capital as an economic and geopolitical asset

TSMC provides a particularly illustrative example of the firm-state dialectic described above. Headquartered in Hsinchu Science Park (Taïwan), the company pioneered the pure-play foundry model, establishing semiconductor manufacturing as a specialized business distinct from chip design, and progressively became a world leader in advanced semiconductor manufacturing [LIU 21]. The emergence of this model profoundly transformed the organization of the semiconductor industry by allowing fabless companies to rely on specialized manufacturing partners rather than developing their own fabrication capabilities. TSMC's competitive advantage, however, does not rest on a single technology or asset. It results from the accumulation and continuous combination of process knowledge, manufacturing know-how, highly skilled human resources, equipment integration, design interfaces and relationships with customers and suppliers. Its knowledge capital is notably embedded in processes, Process Design Kits (PDKs), integration and packaging platforms, and the governance of interfaces between design and manufacturing.

The accumulation of these capabilities has been a long-term and cumulative process. Miller [MIL 22] shows how TSMC's specialization in semiconductor manufacturing allowed the firm to develop its technological capabilities through scale, continuous learning, process improvement and sustained investment in R&D. This cumulative learning process is central to the formation of Enterprise Knowledge Capital, as technological capabilities are progressively embedded in the firm's knowledge base, manufacturing experience and organizational routines.

The construction of this knowledge capital was closely embedded in the Taiwanese innovation system in which TSMC emerged. Taiwan's semiconductor industry resulted from sustained public intervention and specific institutional arrangements. Ouyang [OUY 06] shows the central role played by government agencies and public officials in the development of the industry and emphasizes the institutional conditions that made this intervention effective. In particular, the Industrial Technology Research Institute (ITRI) provided an institutional mechanism for acquiring, developing and transferring technological capabilities to industry. Jan and Chen [JAN 06] show how the Taiwanese R&D system combined government-supported research institutes, industrial firms and universities, with ITRI playing a central role in technological development and transfer. TSMC and UMC themselves emerged as ITRI spin-offs before progressively developing their own internal R&D capabilities.

TSMC's trajectory illustrates the first dimension of the firm-state dialectic: public institutions contributed to the initial development and transfer of technological capabilities, which the firm subsequently accumulated, combined and extended within a broader innovation system. The strength of this knowledge environment is reflected in the concentration and circulation of technological knowledge within the Hsinchu cluster [HU 11]. This concentration remains visible today, with Taipei-Hsinchu ranking 25th among the world's science and technology clusters in terms of patenting and scientific publication activities [WIP 24].

As TSMC accumulated technological capabilities, the second dimension of the firm-state dialectic became more prominent: the firm's Enterprise Knowledge Capital itself became a strategic resource for Taiwan. Its central position in advanced semiconductor manufacturing gives the Taiwanese economy a critical role in a global value chain on which numerous industries and countries depend. This position is particularly important for the most advanced logic nodes, where only a very small number of firms possess the required technological and manufacturing capabilities [WON 24]. TSMC's knowledge capital is therefore simultaneously a private productive asset and a resource with broader economic and geopolitical implications. In Taiwan, this technological centrality has notably given rise to the debated idea of a "silicon shield", according to which international dependence on Taiwanese semiconductor capabilities may increase the economic and strategic costs of coercion [WEI 24].

TSMC's position also illustrates the international character of Enterprise Knowledge Capital. Its technological trajectory relies on interactions with suppliers of equipment and materials, design and EDA companies, universities, customers and other technological partners located across different innovation systems [TSM 22]. TSMC has institutionalized these interactions through its Grand Alliance, which brings together customers and partners in IP, EDA, design services, cloud and advanced packaging, as well as key equipment and materials suppliers [TSM 20] [TSM 24] . Through its Open Innovation Platform (OIP), a core component of the Grand Alliance, TSMC combines internal capabilities with knowledge and technologies originating from external partners (Box 1). Its strategic position thus rests on its capacity to organize and combine highly specialized knowledge distributed throughout the global semiconductor ecosystem.

Box 1. TSMC's Grand Alliance and the organization of distributed knowledge

TSMC's Grand Alliance provides a concrete illustration of how the firm organizes technological capabilities and knowledge extending beyond its organizational boundaries. Built around the Open Innovation Platform (OIP), the Grand Alliance connects TSMC with customers and specialized partners through the IP Alliance, EDA Alliance, Design Center Alliance, Cloud Alliance, Value Chain Alliance and TSMC 3DFabric Alliance, as well as with key equipment and materials suppliers. These relationships cover complementary capabilities ranging from chip design and electronic design automation to intellectual property, manufacturing, packaging and materials. For example, the 3DFabric Alliance includes major specialized firms such as Synopsys and Cadence in EDA, Micron, Samsung Memory and SK hynix in memory, and Amkor and ASE in outsourced semiconductor assembly and testing (OSAT).

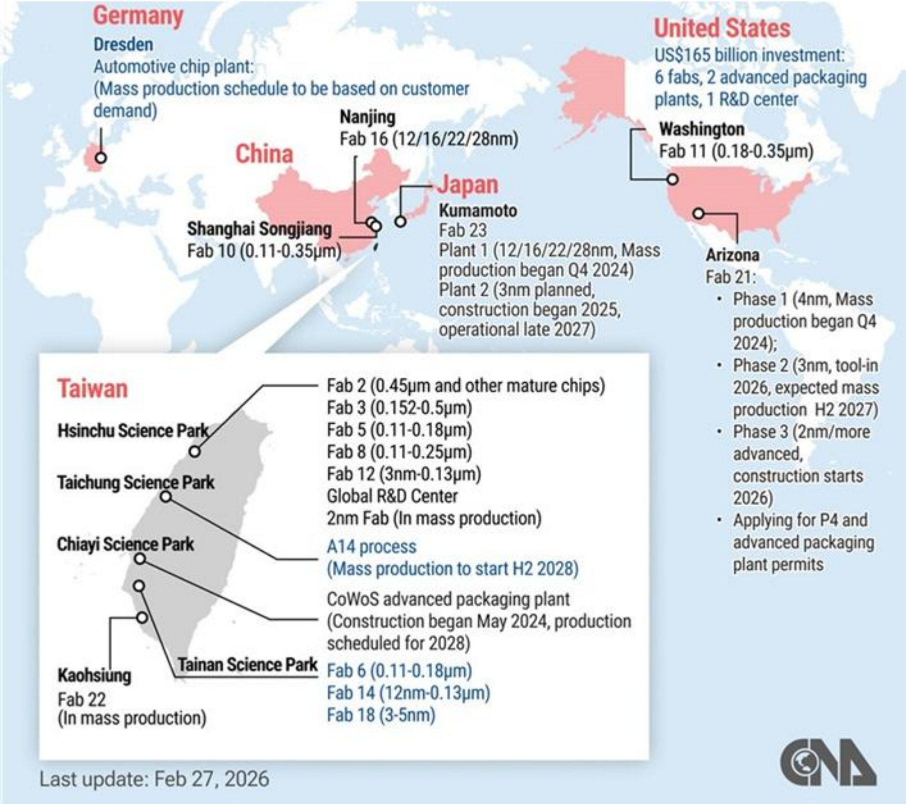
The scale and development of this ecosystem illustrate the cumulative character of TSMC's knowledge infrastructure. In 2024, TSMC's OIP connected customers with 16 EDA partners, seven Cloud partners, 40 IP partners, 29 Design Center Alliance partners, eight Value Chain Aggregator partners and 23 partners in the TSMC 3DFabric® Alliance. TSMC also reported providing customers with more than 52,000 technology files and 3,699 Process Design Kits (PDKs), covering technologies from 0.5 micron to 2 nanometers, while its library and silicon IP portfolio comprised more than 83,000 items [TSM 24]. This industrial ecosystem is complemented by research and training relationships with universities. TSMC reports close collaborations in semiconductor-related research with major Taiwanese universities and international institutions including MIT, Stanford University, UC Berkeley, Arizona State University and the University of Tokyo. These collaborations contribute both to semiconductor research and to the development of a sustainable pipeline of specialized talent [TSM 22].

From an Enterprise Knowledge Capital perspective, these arrangements illustrate how TSMC combines internally accumulated knowledge with complementary capabilities distributed across firms, universities and other actors of the semiconductor innovation system. The Grand Alliance and related partnerships therefore constitute an organizational infrastructure through which external knowledge can be accessed and combined while TSMC retains control over core manufacturing capabilities and technological interfaces.

Source: based on TSMC Annual Reports [TSM 22] [TSM 24] and TSMC Open Innovation Platform, https://www.tsmc.com/english/dedicatedFoundry/oip.

The international expansion of TSMC makes this firm-state dialectic particularly visible (Figure 4). In the United States, the development of manufacturing capacity in Arizona is supported by the CHIPS policy and accompanied by university partnerships aimed at workforce development and process-related R&D. In Japan, the Kumamoto investment through Japan Advanced Semiconductor Manufacturing (JASM), involving Japanese industrial partners, combines public subsidies with integration into local materials, electronics and automotive value chains. In Europe, the European Semiconductor Manufacturing Company (ESMC) project in Dresden, developed with Bosch, Infineon and NXP and supported by public funding, seeks to strengthen semiconductor capabilities for automotive and industrial applications [TSM 24].

Figure 4: TSMC's Global Network



Source: https://focustaiwan.tw/business/202604160015

Figure 4: *TSMC's Global Network*

These investments illustrate how governments seek not only additional semiconductor production capacity but also access to the knowledge, skills and technological interactions associated with a leading foundry. Financial incentives are combined with investments in training, research infrastructures, supplier development and complementary technological capabilities. The objective is therefore to embed TSMC's activities within national or regional innovation systems in ways that may contribute to local learning and capability building. Conversely, these new locations provide TSMC with access to complementary technological resources, skills, customers and industrial ecosystems. The accumulation of Enterprise Knowledge Capital thus remains a reciprocal process between the firm and the innovation systems in which it operates.

Geographical diversification entails only a partial transfer of TSMC's knowledge capital. A substantial part of this capital is tacit, cumulative and embedded in engineering teams, organizational routines, process integration and long-term interactions. The distinction is important because hosting production capacity is not equivalent to controlling the technological capabilities underlying that production. TSMC's international investments may therefore contribute to capability building in host economies without reproducing the complete knowledge base accumulated by the firm and its Taiwanese ecosystem.

TSMC's internationalization thus brings the relationship between Enterprise Knowledge Capital and technological sovereignty beyond the national framework. States seek to attract and anchor the capabilities of a strategically important firm, while TSMC itself relies on knowledge, technologies and complementary assets distributed across several countries. The central issue concerns which technological capabilities can be anchored locally, which remain controlled by the firm, and how access to complementary knowledge can be secured through international relationships. These interdependencies provide the basis for examining techno-nationalism and friend-shoring, and for introducing the concept of club techno-nationalism in the following section.

2.3 From techno-nationalism to "club" techno-nationalism

The growing strategic importance of semiconductors has brought technological sovereignty to the center of industrial and innovation policies. Technological sovereignty is understood here not as technological self-sufficiency, but as the capacity to act on the basis of both domestic capabilities and reliable external networks, thereby limiting unilateral dependencies while benefiting from secure interdependencies [EDL 23]. This perspective emphasizes that states seek to ensure reliable access to technologies considered critical, either through domestic capabilities or through stable partnerships and common institutional frameworks. In systemic and highly specialized technologies such as semiconductors, technological sovereignty therefore necessarily involves finding an evolving balance between openness and protection.

The convergence of industrial policy and national security has led governments to treat technological capabilities not only as sources of competitiveness, but also as strategic assets essential to economic sovereignty and national security [HAU 25]. In the current context, techno-nationalism combines the strengthening of domestic technological capabilities with greater control over the international circulation of critical knowledge and technologies and restrictions on strategic rivals' access to them [LUN 26]. Export controls, investment screening and restrictions on technology transfers illustrate this logic. In the semiconductor industry, Enterprise Knowledge Capital thereby becomes a resource of public power: the capabilities accumulated by leading firms contribute to states' capacity to secure supply, negotiate access to critical technologies and influence technological standards.

The organization of the semiconductor industry places strong limits on techno-nationalism conceived exclusively at the national level. Its systemic character, the international specialization of the value chain and the diversity of semiconductor technologies distribute essential capabilities across countries, firms, technological segments and generations. Design, EDA, equipment, materials, fabrication and packaging depend on highly specialized knowledge bases accumulated over several decades. Reproducing these capabilities domestically would require massive duplication of investments and could reduce access to the international knowledge flows and complementarities on which innovation depends. Strategic vulnerabilities and technological performance thus originate in the same system of interdependencies.

Friend-shoring refers to the reorganization of production and sourcing towards countries considered reliable or geopolitically aligned, with the aim of reducing exposure to geopolitical risks and securing access to critical inputs and capabilities [OEC 23]. In knowledge-intensive industries such as semiconductors, friend-shoring extends beyond the geographical relocation of production to the selective territorialization of critical technological capabilities. It involves attracting not only manufacturing capacity but also skills, suppliers, research infrastructures and technological interactions associated with production. In semiconductors, TSMC's investments outside Taiwan illustrate this process: states seek first to attract additional fabrication capacity, but they also seek to secure access to some of the skills, technological interactions and complementary capabilities associated with the firm's presence. Friend-shoring can thus be understood as an instrument through which states seek to territorialize and secure critical capabilities while maintaining the international complementarities required for innovation.

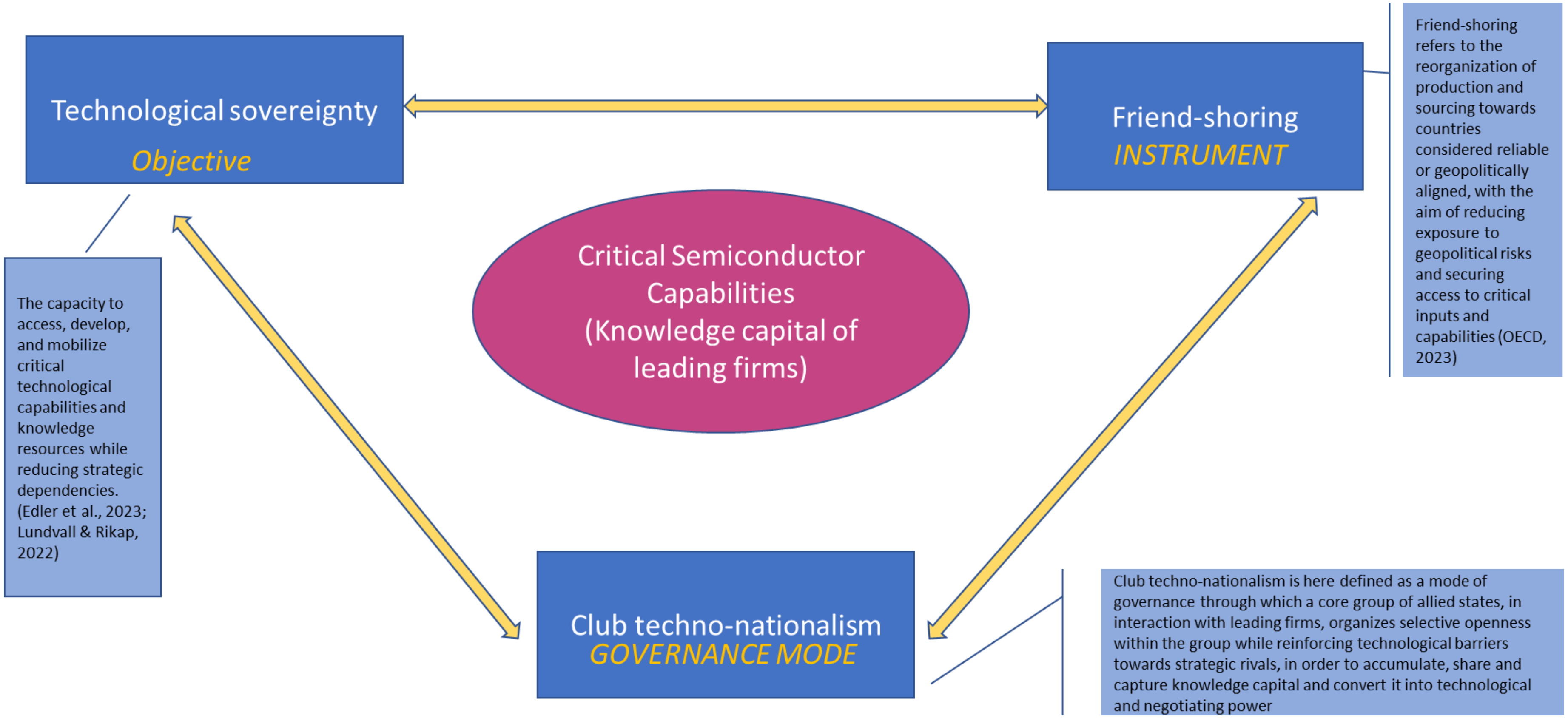
Friend-shoring, however, describes the instrument of this reorganization. It does not in itself explain how knowledge and technological capabilities circulate among trusted partners, how strategic technologies are protected from competitors, or how power is distributed within the coalition. Moreover, relations between partners cannot be assumed to be symmetrical. Different countries and firms control different and often non-substitutable technological capabilities, creating differentiated degrees of dependence and bargaining power. The reorganization of semiconductor value chains therefore involves a hierarchy within the network of partners.

We define club techno-nationalism as a mode of governance through which a core group of allied states, in interaction with leading firms, organizes selective openness within the group while reinforcing technological barriers towards strategic rivals, in order to accumulate, share and capture knowledge capital and convert it into technological and negotiating power. Sovereignty is therefore no longer solely a national attribute but also a relational capacity structured by the technological resources and interdependencies shared within the club.

Each member seeks to strengthen its freedom of action through a combination of domestic capabilities and secured access to the knowledge, technologies and markets of trusted partners. While technological sovereignty constitutes the objective and friend-shoring one of its principal instruments, club techno-nationalism describes the emerging governance mode through which these selective technological interdependencies are organized (Figure 5).

Club techno-nationalism therefore rests on a combination of selective openness and targeted protection. Within the club, technological cooperation, investment, knowledge circulation and access to complementary capabilities are encouraged where they contribute to the accumulation and renewal of knowledge capital. Towards strategic competitors, access to the most critical technologies and knowledge is increasingly restricted through export controls, investment screening, restrictions on technology transfers and other safeguards. The openness/protection dialectic identified at the level of Enterprise Knowledge Capital thus acquires a geopolitical dimension: the issue becomes not only which knowledge should circulate or be protected, but also between whom it should circulate and under what conditions.

This configuration is asymmetrical because technological capabilities are unevenly distributed among states and firms, and control over difficult-to-substitute assets confers bargaining and regulatory power. In the semiconductor industry, the United States occupies a leading position, as also highlighted by recent analyses of semiconductor industrial policy and economic statecraft [BOW 24] [CAI 25]. Its strengths in semiconductor design, EDA and equipment are combined with its capacity to mobilize industrial policy, export controls and access to its domestic market. Through these instruments, the United States coordinates technological relations with major semiconductor economies and firms in Taiwan, South Korea, Japan and Europe. We interpret this configuration as a hierarchical system of controlled interdependencies, structured around differentiated technological capabilities and unequal capacities to define the conditions of access to strategic technologies.



Source: Author

Figure 4: *Technological Sovereignty, Friend-Shoring and Club Techno-Nationalism: A Conceptual Framework*

TSMC illustrates both the functioning and the complexity of this configuration. Its international expansion strengthens semiconductor manufacturing capabilities within countries aligned with the United States, while the firm itself remains dependent on complementary technologies and markets distributed across the global value chain. At the same time, U.S. export controls extend beyond American firms because access to critical semiconductor equipment and technologies is embedded in internationally interconnected production systems. This gives the United States considerable leverage over the conditions under which advanced semiconductor capabilities can be accessed and developed, but does not eliminate the commercial interests and technological dependencies linking firms to markets outside the emerging club.

Indeed, club techno-nationalism does not produce a complete separation of technological blocs. Wong et al. [WON 24] show that U.S. industrial and export-control policies are contributing to a reorganization of semiconductor value chains in East Asia, while Korean and Taiwanese firms continue to adapt their strategies in order to remain connected, to varying degrees, to both U.S. and Chinese markets. Advanced technologies and capacities tend to be protected or located within trusted environments, whereas commercial relations involving less sensitive technologies can persist beyond them. The result is a differentiated geography of technological interdependence in which geopolitical alignment shapes the location, accessibility and technological level of semiconductor activities.

The limits of this configuration should nevertheless be emphasized. Restrictive policies may conflict with the commercial interests of firms whose revenues continue to depend on global markets, creating tensions between security alignment and economic interests [CAI 25]. These tensions are illustrated by the continued importance of the Chinese market for major semiconductor equipment suppliers. A recent U.S. congressional investigation reports that sales to China accounted for 39% of the aggregate worldwide revenue of five major U.S., Dutch and Japanese equipment manufacturers in 2024, including ASML and Tokyo Electron [USC 25]. Restrictive policies may also generate additional costs through the duplication of production capacities and affect some of the knowledge flows that sustain systemic innovation. Efforts to restrict China's access to the most advanced semiconductor technologies moreover coexist with the development of Chinese capabilities across other segments of the industry. China has made progress in mature-node semiconductor manufacturing and continues to develop capabilities across different technological segments, although the pace and extent of catch-up vary between foundry, logic and memory technologies [WON 24]. China also retains important positions in the supply of some critical materials used by semiconductor and other high-technology industries. Club techno-nationalism may therefore constrain technological catch-up in selected segments while dependencies and technological competition persist across the broader semiconductor system. Its capacity to reduce strategic vulnerabilities must consequently be assessed across the semiconductor system as a whole rather than solely through control of the most advanced process nodes.

Conclusion

Semiconductors have become a central component of technological sovereignty because they combine three characteristics that are rarely found to such a degree in a single industry: they constitute a general-purpose and systemic technology, their production and innovation processes rely on highly specialized and internationally distributed capabilities, and some of these capabilities are concentrated within a limited number of firms and territories. The resulting interdependencies have supported technological specialization and innovation, while creating strategic vulnerabilities that states seek to address through industrial and technological policies.

This article has argued that these transformations involve more than the geographical reorganization of semiconductor value chains. Understanding the value chain not simply as a technical succession of production stages, but as an organized system of interdependent actors, strategic relationships and institutional arrangements, also draws attention to the way knowledge and technological capabilities are accumulated, combined, protected and controlled. The concept of Enterprise Knowledge Capital provides a way of analyzing this knowledge dimension of the value chain. Firms accumulate scientific, technological and organizational knowledge through their own activities and through interactions with universities, research organizations, suppliers and public institutions. Their knowledge capital is therefore both firm-specific and relational, as its accumulation and renewal depend on their position within broader innovation and production networks. States contribute to the construction and protection of this knowledge capital and, in turn, rely on the capabilities accumulated by leading firms to pursue their objectives of technological sovereignty. TSMC illustrates this dialectical relationship: its technological capabilities emerged within the Taiwanese innovation system and subsequently became a strategic asset whose importance extends far beyond Taiwan.

The systemic character and technological diversity of semiconductors make national technological self-sufficiency unrealistic. Technological sovereignty therefore requires states to combine the reduction of strategic dependencies with access to complementary knowledge and capabilities located abroad. Friend-shoring constitutes one instrument for managing this tension by seeking to territorialize selected capabilities and part of the knowledge capital of leading firms within trusted ecosystems.

On this basis, we have proposed the concept of club techno-nationalism to characterize this emerging mode of governance. While technological sovereignty constitutes the objective and friend-shoring one of its principal instruments, club techno-nationalism describes how selective technological interdependencies are organized among allied states and leading firms. It combines national technological objectives with selective openness within trusted networks and targeted protection towards strategic competitors. This configuration is asymmetrical because technological capabilities and control over key interfaces are unevenly distributed. In the semiconductor industry, the United States occupies a central position through the combination of technological capabilities, market power, industrial policy and mechanisms of technological control.

Club techno-nationalism does not produce a closed or stable technological bloc. Firms continue to pursue global markets, technological interdependencies extend beyond geopolitical alliances, and restrictive policies can contribute to the development of alternative capabilities among competitors. The persistence of dependencies across different segments of the semiconductor system also limits the possibility of securing technological sovereignty through control of leading-edge technologies alone. Club techno-nationalism therefore selectively reorganizes technological interdependencies rather than eliminating them. Technological sovereignty becomes relational: states seek to strengthen their freedom of action by combining domestic capabilities with secured access to the knowledge capital, technologies and markets of trusted partners, while restricting such access for strategic rivals.

The article is primarily conceptual and relies on documentary sources to illustrate the proposed framework. This approach opens several avenues for empirical extension. Further research could examine how club techno-nationalism materializes through the international expansion of leading semiconductor firms and how different territories seek to embed and leverage their knowledge capital. A comparative analysis of TSMC-related developments in the United States, Japan and Europe could investigate how pre-existing technological capabilities, industrial policy strategies and local conditions shape different forms of territorial embedding. Such research could assess whether friend-shoring produces complementary configurations within a broader architecture of club techno-nationalism and how the resulting capabilities, benefits and dependencies are distributed among its members.

More broadly, the framework developed here raises a question extending beyond semiconductors. For systemic technologies characterized by highly concentrated yet internationally distributed knowledge, technological sovereignty rests on the capacity to build domestic capabilities while securing a strategic position within selective international technological interdependencies and influencing their governance.

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