China’s emerging role in the global semiconductor value chain

Seamus Grimes

Whitaker Institute, National University of Ireland Galway

East China Normal University

Debin Du

East China Normal University

Abstract

The global model of semiconductor development has resulted in an asymmetric and interdependent relationship between China’s critical role in semiconductor production and those regions such as the US which control the key inputs into the value chain. While this unbalanced relationship has facilitated many of the companies involved in the value chain in exploiting the comparative advantage of different locations for different functions and has allowed a complex ecosystem of supplier networks to emerge over time, the increasing influence of geopolitical considerations associated with the growing tensions between the US and China has created considerable uncertainty about the future evolution of this value chain. It is within this uncertain context that China’s efforts to achieve greater autonomy in the development of its own semiconductor sector will be examined in this paper.

Key words China   Semiconductor global value chain   asymmetric interdependency

1. Introduction

The semiconductor industry is one of the most globalised industries in the world and also one of great strategic importance. The geography of its global value chain is quite unbalanced, with much of the core intellectual property associated with designing semiconductors concentrated in the US, South Korea, Taiwan and some European locations, while much of the production, assembly and testing of products takes place in Asia and particularly China, which is the world’s biggest semiconductor market. This lack of balance is reflected in the geography of supply chains associated with the value chain with most suppliers of critical software and components being headquartered in more developed locations and with considerable outsourcing and offshoring of lower value added functions to China. Thus, despite the centre of gravity of production of semiconductors having increasingly shifted to China in recent years, together with related supply chains, much of the value-added associated with semiconductor production is captured by core companies headquartered outside China.

This global model of semiconductor development has resulted in an asymmetric and interdependent relationship between China’s critical role in semiconductor production and those regions such as the US which controls the key inputs into the value chain. While this unbalanced relationship has facilitated many of the companies involved in the value chain in exploiting the comparative advantage of different locations for different functions and has allowed a complex ecosystem of supplier networks to emerge over time, the increasing influence of geopolitical considerations associated with the growing tensions between the US and China has created considerable uncertainty about the future evolution of this value chain. It is within this uncertain context that China's own efforts to achieve greater autonomy in the development of its semiconductor sector will be examined in this paper. It will seek to do this by clarifying the distinction between China as the world's most important market for semiconductors and the nature of semiconductor production in China.

The current geopolitical tensions between the US and China are closely related to technology competition between these two economies and the growing concern in the US that China's technological progress may usurp its long-term hegemonic position globally. After a number of decades of relatively liberal policy towards US companies investing in China, which has contributed to greater integration of China into the semiconductor global value chain (GVC), the US has belatedly awakened to the new reality that some Chinese companies, such as Huawei are capable of developing world class technology. Since semiconductors play such a central role in so many industrial sectors in addition to their fundamental importance for national security, both China and the US are seeking to establish greater control and autonomy over this sector. This policy shift is giving rise to considerable concern globally about the possible de-coupling of technology development networks between the two countries, which would have huge implications for the future development of the semiconductor global value chain and for China's own ambitions to develop its own independent semiconductor industry.

Although the current tensions between the US and China might be seen as a unilateral attempt by the US to block China's attempts to achieve greater autonomy in semiconductors, China had been moving towards the goal of autonomy for some years, particularly since the Snowden revelations about cybersecurity issues, when a push for indigenous technology development was set in motion and was more recently followed by highly ambitious targets for autonomy in the Made in China 2025 programme. The previous long period of collaboration and integration of technology development between the US and China has now entered a new phase with significant risks of de-coupling of supply chains between both countries. In the earlier push for indigenous innovation, which many regarded as an attempt to replace the significant role played by global technology companies in China, Ernst (2016) highlighted the dangers of such an approach for China's own efforts to develop semiconductors, since it could isolate Chinese companies from what was essentially a global industry with a global value chain. With the US taking sanctions against key Chinese companies like Huawei more recently, China is likely to face an uphill battle to progress its programme for semiconductor autonomy.

Thus, while the US administration has been taking tough action against China's approach to promoting its own technology autonomy, China also has become somewhat disillusioned with its subservient role in the global semiconductor value chain, which, until recently was mainly focused on the lower value added functions of assembly and testing. This is despite the fact that China has benefitted significantly from its integration into the semiconductor value chain through the development of a complex ecosystem of supplier networks associated with semiconductor production in China. It is true that both export controls and the Wassenaar Arrangement affecting technology exports to China have resulted in foreign semiconductor companies restricting the introduction of leading-edge processes to China while, at the same time benefitting from lower cost production and a growing market, nevertheless, the progress to date of China's semiconductor sector has been closely associated with the role of foreign companies in China particularly in terms of upskilling the labour force. In fact, the current threat of decoupling supply chains between the US and China could be the biggest threat to date for the further development of China's semiconductor sector.

Tensions emerged, particularly in the post-global crisis period both in the US and in China regarding the benefits being derived from the globalised technology value chain, whereby global technology companies, deriving much of their intellectual property and higher value added functions from their headquartered locations, but having the flexibility of exploiting the comparative advantage of lower cost locations for lower value-added functions. Trump's electoral success partly reflected these tensions because of the considerable loss of technology manufacturing jobs from the US to China. The urgency in China to move up the value chain as its competitive advantage in labour costs began to decline, created a greater determination among its policymakers to push for indigenous innovation which was seen as a programme to replace foreign technology companies with Chinese companies. These tensions contributed to the current geopolitical issues between the US and China.

This paper will review the literature on global value chain participation and the challenges facing latecomer locations like China in seeking to upgrade its semiconductor sector. It next examines some methodological issues such as data inconsistencies. It then identifies the key companies according to revenue and market share globally for different segments of the semiconductor global value chain and the geography of company headquarter locations. Next it seeks to contextualise China's role in different segments of the semiconductor global value chain and makes some conclusions on China's overall contribution.

2. Global Value Chain participation

As global corporations outsourced/offshored lower value added functions to locations in Asia and particularly China they facilitated the integration of these new locations into technology global value chains (GVCs) which had both positive and negative effects (Baldwin, 2017). With the emergence of global production networks and global value chains, the competitiveness of locations became denationalised as intermediate components and different functions were traded between locations, with lower cost locations predominantly carrying out low value-added functions such as assembly and testing.

While integration into global technology value chains facilitated the emergence of local technology sectors, the fear of policymakers was the challenge facing local companies in upgrading capabilities and moving up the value chain. Despite the more complex geography of value chains that emerged with more globalised economic activity, many policymakers continued to view international trade predominantly in terms of trading completed goods between domestic economies rather than in terms of the more complex movement of components related to the global trade in 'tasks'.

While Baldwin's (2017) analysis traces the global implications of technology GVCs, Lee (2019) has focused more on the catch-up challenges facing less developed regions that became integrated into global value chains. Despite participation in GVCs being increasingly prescribed for developing countries to achieve economic growth, many countries remain predominantly involved in low-value-added functions which gives rise to doubts about the effectiveness of such participation for upgrading their economies. Thus, Lee (2019) argues that to achieve effective outcomes, GVC participation needs to be controlled, managed and perhaps reduced at certain stages of the process over time in order to strengthen indigenous industries.

Despite having a large market and state control of operators, Vialle et al (2012) argue that China failed in its earlier attempts to escape path-dependence across two generations of mobile standards because of divergence of interests and policy inconsistencies resulting in tensions between techno-nationalism and techno-globalism. Yet, Gao and Liu (2012) argued that because of late-comer disadvantages in the era of globalisation, in addition to acquiring core competencies, local companies required government support in their efforts to catch up with global leaders.

Noting the significant risk for oversimplification in in specifying the conditions for success or failure for technological catching-up, Lee and Lim (2001) explain that technological and market conditions in different sectors affect those conditions and that outcomes resulted from an interplay between many factors, including R&D, government, technology transfer, market conditions, absorption capacity and the nature of the technological knowledge. In a similar vein, among the market-related and technological factors which Macher and Mowery (2004) argued had contributed to increased vertical specialisation in the semiconductor sector since 1985, were scale economies falling production costs, increased manufacturing capital requirements, a shorter design cycle and more uncertain product lifecycles increasing the risks of investing in dedicated capacity. The overall effect of these factors was a lower level of access for latecomer companies and high levels of appropiability for incumbent firms.

Specifically in relation to the semiconductor sector, Lee et al (2017) explain some of the reasons why a latecomer country like China would find it very difficult to develop a competitive industry. Unlike the mobile sector, in which China did succeed over time, low-end semiconductor markets cannot be easily distinguished from high-end ones, which means that they cannot be leveraged by indigenous companies. Among the reasons suggested why China succeeded in wireless telecommunications but continues to struggle in the semiconductor sector was the more effective state intervention in wireless.

Leading-edge technologies in the semiconductor industry are not easily accessible although it was possible for countries like Korea, allied to the US, to license outdated versions of production technologies during the earlier stages of its semiconductor sector development. The strategy of lead companies which dominate patent portfolios is to restrict companies in latecomer countries from acquiring the most recent technology and with the oligopolistic structure of the semiconductor sector, it is characterised by intense competition between market leaders and frequent IPR lawsuits over patents, which makes it difficult to progress from lower to more sophisticated levels of technology which include higher levels of wafer capacity and increased density of semiconductors.

Another difficulty facing latecomer companies is that because technological and organisational knowledge in semiconductor development is highly cumulative, first-mover advantages are critical, resulting in a ‘success-breeds-success’ process further solidifying the ability of lead companies to dominate the market. Because semiconductor product life cycles are short, for a company to lead the market in terms of innovation, it must recoup its investment as revenues as quickly as possible in order to re-invest earnings in R&D.

Partly related to the need to respond to frequent technology disruptions, the sector is notoriously cyclical, being subject to changes in levels of supply and demand, leading to periods of shortages and over-supply and major changes in pricing. The semiconductor industry is also characterised by an oligopolistic ownership structure with marked consolidation in recent years because of the rising cost of designing smaller processing nodes. Such high design costs together with difficulties accessing venture capital and fewer fabless companies being established have contributed to creating significant barriers to entry for latecomer countries such as China. The level of concentration of ownership in the semiconductor industry also reflects the high levels of risk associated with huge investment and the obstacles to acquiring the increasing tacit knowledge associated with innovations in the technology. Thus Intel dominates in the microprocessor sector and Samsung dominates in dynamic random access memory (DRAM).

Also the cost of equipment for producing the latest versions of the technology becomes considerably more expensive. Incumbent larger firms are usually in a better position to develop the next stage in the technology while latecomer firms struggle to catch up. Firms with leading edge R&D and sophisticated fabrication technology are more likely to survive than those that are trying to catch up. As a new generation of memory chips is launched, they can quickly replace the previous generation which usually suffers a significant fall in price. Because they are easy to transport the global market for memory chips cannot be divided into high-end and low-end. This will make it difficult for Chinese firms to catch up in the memory market as there is not protected low-end market for indigenous products.

But in addition to these factors, China has been further disadvantaged by being prevented from acquiring the most recent versions of technology by the 1996 Wassenaar Arrangement, which restricted the home countries of leading semiconductor companies from exporting leading-edge technologies to Communist countries (Rho et al. 2015).

3. Methodology

Since our objective is to provide insights into the global value chain of the semiconductor sector both globally and specifically into that part of the GVC which is located in China, we focus on the key companies involved according to their revenue and market share, paying particular attention to the headquarter location of each company. The analysis initially examines the global picture of the semiconductor GVC and identifies the key companies that dominate overall and in particular segments of the GVC. By disaggregating the total GVC into key segments it is possible to identify the geography of the dominant company headquarters. A more detailed examination is then made of these segments within China by identifying the key companies and their headquarter locations. The primary objective here is to identify the extent to which Chinese companies have succeeded in gaining market share, both globally and within China and the extent to which they have progressed in different segments of the GVC. Another objective is to gain insights into the extent to which the geography of the semiconductor value chain is unbalanced between regions that control much of the intellectual property and higher value added functions of the value chain and those regions which are mainly involved in lower value-added functions.

Data sources were derived from companies such as PriceWaterHouseCoopers (pwc); ICInsights is a key source of data on semiconductor companies; Statista which is an important source of changes in the sector; Macrotrends; and World Semiconductor Trade

Statistics (WSTS). Insofar as possible the focus in this paper is on the year 2018, to gain insights into the most recent developments in what is a very dynamic and fluid sector.

A major data issue, however, is inconsistency between different sources in terms of revenue figures and market share which may be related to definitional differences for different types of semiconductor products or company types with possible differences also between companies according to their financial year, affecting revenue figures. Specific challenges in interpreting data relating to China's semiconductor industry have been highlighted by Hwang (2019). Accounting for the significant proportion of income coming from license fees may also result in differences. Mergers and acquisitions between companies have been common in recent years and can add to some data confusion.

4. The semiconductor global value chain

Although certain locations play key roles in the semiconductor global value chain (GVC), understanding the evolving GVC is complicated by the fact that the development of a semiconductor product can involve up to 1200 process steps over a six- to eight-week cycle and travel over thousands of miles between different locations and companies involved in the production process. According to the Semiconductor Industry Association (2016), the production process could involve the following stages: designed in the US; next silicon ingots are formed from pure silicon and sliced into wafers in Japan; then back to the US where the bare wafer is made into a fabrication wafer; also in the US, the fabrication wafer is sorted, cut into die, on which circuits are fabricated; next to Malaysia where the die is assembled, packaged and tested and the final product is shipped for inventory in Singapore; the chip in then integrated into consumer goods in China and the customer in the US buys the end product (Duhalde and Liu, 2018).

With the evolution of the semiconductor sector over time, two distinct production models have emerged, the integrated device manufacturer (IDM) and the fabless-foundry company. IDM companies carry out all four main stages of production, which include design, manufacturing, assembly, testing and packaging. Intel and Samsung Electronics are the two most significant IDM companies in terms of revenue. With increased globalisation of the semiconductor value chain, different production functions were increasingly outsourced and offshored to specialist companies in lower cost locations, with Taiwan developing specialisations in both foundry and assembly and testing functions.

In the fabless-foundry model the production process is split between companies, with design companies focusing on design and contracting out manufacturing or fabrication to foundries and are thus referred to as 'fabless'. Among the major design companies are Broadcom, Qualcomm, Nvidia and MediaTek, while the world's biggest foundry company is Taiwanese Semiconductor Manufacturing Company (TSMC). Firms that perform assembly, testing and packaging are known as Outsourced Assembly and Test (OSAT) companies. The vast majority of semiconductor companies derive most of their value from the technology-intensive design and manufacturing stages, as opposed to the labour-intensive final assembly stages (Stratfor, 2019).

Table 1 disaggregates the semiconductor sector into its key market segments, indicating that memory with 30.7% of market share and logic with almost 25% are the largest segments with micro, analog and OSD constituting smaller market segments.

Table 1 Revenue and market share of semiconductor product segments, 2018

Segment		USDbn	% share	% share
Discrete		22.5	5.14	
Optoelectronics		37.3	8.50	
Sensors		13.4	3.06	
O-S-D				16.7
Analog		55.9	12.79	
Micro		65.3	14.94	
Logic		108.4	24.79	
Memory		134.3	30.72	
Total		437.2	100.00	100

Sources: World Semiconductor Trade Statistics https://www.wsts.org/; The Information Network https://www.theinformationnet.com/.

In addition to identifying the revenue and market share of ten companies that accounted for 72.9% of the total sector in 2018, Table 2 also gives an indication of the involvement of these ten companies together with smaller companies in the key segments of the industry. Table 2 also reveals that for the first quarter of 2018, different market segments have different levels of concentration ranging from the top ten companies in OSD chips accounting for only 38.7% of the total market share, to the top ten analog companies accounting for 58%, the top eight micro companies accounting for 88%, only three companies accounting for 96% of DRAM and only six companies accounting for 99.4% of NAND production.

The growth in the threefold segment of OSD, which consists of integrated circuits (ICs) and optoelectronics, sensor, and discrete components is related to emerging technologies such as microelectromechanical systems (MEMS) for sensors and actuators and high-brightness light-emitting diodes (HB-LEDs) for solid-state lighting applications. Among the top companies, three were from Japan, three from Europe, two from the US and one from China and one from South Korea. It is noteworthy that Omnivision, the lone Chinese company to appear anywhere in Table 2, was previously a US company acquired in 2016 before the current restrictions were imposed.

Apart from NXP from the Netherlands and Toshiba from Japan, the US and South Korea are headquarters to the dominant companies, with US companies dominating semiconductor design and South Korea dominating memory chip production. TSMC is included as the world's largest foundry, accounting for more than 50% of global market share.

When we turn to product segments, the data availability in Table 2 is somewhat partial. Intel, which dominates chips for PCs and servers is almost in a category of its own, while Qualcomm make most of its revenue from designing wifi chips, with a significant proportion of that revenue coming from license fees. In 2018, Broadcom was responsible for 80% of global production of Ethernet switch chips on which major smartphone makers are dependent. The specialisation and almost monopolistic position of these companies in the market make them critical in the global value chain.

Table 2 Revenue and market share (%) of top 10 companies plus market share (%) of additional companies in selected segments 2018

							OSD	Micro	Analog	Nand Q41	DRAM Q41
Company	HQ		USDbn	%			%	%	%	%	%
Intel	US		70.8	14.72						7.8	
Samsung	Sth Korea		74.6	15.51			3.4	12		30.4	41.3
TSMC	Taiwan		32.4	6.74							
Qualcomn	US		22.7	4.72							
Broadcom	US		20.8	4.32			2.1				
SK Hynix	Sth Korea		35.3	7.34						11.2	31.2
Micron	US		30.4	6.32						15.4	23.5
Texas Inst	US		15.7	3.26				6	18		
Toshiba	Japan		38.7	8.05						19.3	
NXP	Netherlands		9.4	1.95				19	4		
Top 10			350.8	72.9							
Total			481	100							
					Sony	Japan	8.5				
					Sharp	Japan	4.7				
					Infineon	Germany	3.2	7	6		
					On Semi	US	3.9		3		
					ST	Switzerlar	3.5	10	5		
					Nichia	Japan	3.4				
					Osram	Germany	2.3				
					Onmnivision	China	1.9				
					Renesas	Japan		16	1		
					Microchip	US		14	2		
					Cypress	US		4			
					Analog Devices				9		
					Skyworks Solutions	US			6		
					Maxim	US			4		
					WDC					15.3	
Total market share (%)							38.7	88	58	99.4	96

Sources: Macrotrends (www.macrotrends.net/); Evertiq.com (2019) (https://evertiq.com/design/46055); Roos (2017); IC Insights; Anysilicon (2019); Statista (2018)

Note: data for NAND and DRAM refer only to Quarter 4 in 2018.

While some companies and their headquarter regions have become somewhat specialised such as South Korean companies dominating the memory sector, Taiwanese companies dominating foundry and US companies in design, over-specialisation can affect competitiveness since companies need to adjust to changes in the market such as the growth in demand for chips specific to AI and 5G. The need for flexibility is reflected in the 60% growth in memory chips in 2017 related to smartphones and tablets, which then was followed by a downturn in 2018. Partly in response to the risks of over-specialisation, Table 1 reveals some companies have sought to spread their portfolio into a number of areas such as Samsung, which despite its dominant position in memory also features among the key companies in OSD and microprocessors. Samsung, SK Hynix and Micron dominated both memory segments, although Toshiba and WDC also had significant market shares in NAND, revealing one of the strongest oligarchical ownership patterns in the overall sector.

With the centre of gravity of automotive production having shifted to China in recent years, microcontroller chip companies like NXP have a significant involvement in the Chinese market. In 2016, the Chinese anti-monopoly authority prevented Qualcomm, which gets 60% of its global revenue from Greater China from its almost monopolistic position in the mobile wifi chip market from acquiring NXP. Previously, Qualcomm in China had been fined almost USD 1 billion for exploiting its strong position in the market through charging high levels of license fees.

The analog chip segment was dominated by US and European companies, with Texas Instruments gaining 68.7% of its total income from this area. Among the major logic companies were Freescale (became part of NXP in 2015), Fujitsu Semiconductor Inc., ARM Holdings (a UK company now owned by the Japanese conglomerate SoftBank), MediaTek from Taiwan, Texas Instruments, Qualcomm, Broadcom, Marvell Technology Group and Apple (TrendMarket Research, 2019). While being relatively invisible in many data sources, ARM Holdings, only creates and licenses its technology as intellectual property rather than selling its own physical chips and is one of the most critical companies in the semiconductor value chain.

Having identified the major companies in terms of revenue for the semiconductor sector overall and its key segments, the sector will now be disaggregated according to key business models (Table 3). The most valuable sectors include Integrated Design Manufacturers (USD232 billion) and Fabless companies (USD103 billion) which together accounted for 74.6% of total revenue in 2018 with the IDM having the largest share of any sector at 51.7%. Next comes the foundry sector with 11.1% of revenue, followed by Equipment at 8.2% and the OSAT (assembly and testing) at 6.0%. Most of the foundry activity is located in Taiwan and China with the largest company accounting for more than 50% of global revenue being the Taiwanese TSMC. Although the equipment sector is relatively small, apart from one European company, all others are US-based and these companies form a critical component of the global value chain.

Table 3 Semiconductor sector by revenue and market share, 2018

Sector	$bn	%
IDM	232	51.7
OSAT	27	6.0
Fabless	103	22.9
Foundry	50	11.1
Equipmen	37	8.2
Total	449	100

Source: Adapted from Duhalde and Liu (2018)

Since semiconductor design companies, which include both fabless and IDMs account for 74.6% of the total revenue of the sector, and are obviously the most important group of companies Table 4 identifies the key companies. The top ten IC design companies accounted for USD69.8 billion in 2018 and Broadcom and Qualcomm were the only two listed among the top global semiconductor companies in the same year. Apart from one UK company, Dialog Semiconductor, six of the top companies were from the US and three from Taiwan, indicating how the US continues to have significant controlling role in this most valuable segment.

Table 4 Revenue of top IC design companies 2018

Company	HQ	USDbn
Broadcom	US	18.9
Qualcomm	US	16.3
Nvidia	US	11.1
MediaTek	Taiwan	7.9
AMD	US	5.2
Xilinx	US	2.9
Marvell Technology	US	2.8
Novatek	Taiwan	1.8
Realtek Semicond	Taiwan	1.5
Dialog Semcond	UK	1.4
Top 10 total		69.8

Source: Statista (2018) https://www.statista.com/statistics/546477/worldwide-fabless-integrated-circuit-design-top-companies/

Table 5 % of total revenue for value chain segments by location, 2018

	US	Sth Korea	Japan	Europe	Taiwan	China	Singapore	Others	
IDM	51	28	11	7	2			1	100
Fabless	62		1	2	18	10		7	100
Foundry	10	6	2		73	7		2	100
OSAT	17		5		54	12	12		100

Source: Adapted from Duhalde and Liu (2018)

Table 5 illustrates the geography (company headquarter locations) of the semiconductor GVC in relation to the revenue distribution of four key sectors. Having already identified the key companies in the different semiconductor segments, it's not surprising to discover that the US accounts for 51% of the IDM sector (51% of the total GVC revenue), with 28% from South Korea, 11% from Japan and 7.0% from Europe. The US is also the dominant headquarter location for the fabless sector (23% of GVC revenue), accounting for 62% of the total, with 18% headquartered in Taiwan and 10% in China. Taiwan has the greatest concentration of foundry companies (11% of GVC revenue), accounting for 73% of the total, with the US having 10% and China 7%. In fact, Taiwan's TSMC alone accounts for 56% of global foundry revenue. Again the OSAT segment of assembly and testing (6.0% of the GVC revenue) is dominated by Taiwan with 54% of the total revenue, the US with 17% and China and Singapore both at 12%. In addition to the dominant role of companies from the US and South Korea in the semiconductor GVC, Taiwanese companies clearly play an important role in both the foundry and OSAT segments, while China is also growing in importance in both the fabless and foundry segments.

China's role in the GVC

Even if China's plans to replace foreign sources of semiconductor imports are very ambitious, our examination of the semiconductor GVC shows that China's contribution at present is relatively modest. IC Insights estimates that worldwide integrated circuit (IC) demand was USD430.8 billion in 2018. In the same year, China imported USD312 billion worth of semiconductors and had a trade deficit of USD227.4 billion. When China's local IC manufactured industry's production of USD23.7 billion is included, China's total demand for semiconductors in 2018 was USD251.1 billion or 58.3% of global semiconductor production, making China the most important market for semiconductors but one which has a significant gap between production and consumption (Hwang, 2019). This gap, together with growing concerns about the role of semiconductors in national security are major drivers for China's recent push for greater autonomy in semiconductor production, even if some of that production is carried out by foreign firms in China.

Regarding China's USD155 billion semiconductor demand in 2018, Hwang (2019) notes that 62% came from local companies and 38% from non-Chinese companies. Four major China-based smartphone companies, Huawei, Lenovo, Xiaomi and BBK accounted for USD60 billion of that demand, while demand from Taiwan and from non-China ICT companies, which included Foxconn, Pegatron, Wistron, Quanta Computer, Inventec, Sony, Samsung and LG accounted for USD96.1 billion of the demand. This reflects an ongoing high level of interdependence between Chinese and non-Chinese companies in China's semiconductor market.

Although China has been the largest consumer of semiconductors since 2005, IC production in China represented only 15.3% (USD23.8 billion) of its USD155 billion market in 2018, and IC Insights forecast this figure rising to 20.5% in 2023, which falls well short of China's "Made in China 2025" targets of 40% self-sufficiency by 2020 and 70% by 2025 (Solid State Technology, 2019). In 2018, SK Hynix, Samsung, Intel and TSMC were the major foreign manufacturers that had significant IC production in China. Even with production by China-based startups such as Yangtze Memory Technologies (YMTC) and ChangXin Memory Technologies (CXMT, formerly Innotron), IC Insights forecasts that foreign companies will account for at least 50% of overall production by 2023. This, however, is a big improvement on the 90% figure in 2013 when buying decisions for advanced ICs consumed in China were made mainly in Taiwan, Korea, the US, Japan and Singapore (Ernst, 2013).

Thus, while there is a growing gap between China's capacity to produce chips and its demand, particularly for advanced chips, its capabilities are mainly in low-end chips. By 2013, it was already approaching self-sufficiency in Optical (LED) sensors and discrete devices, making it a co-shaper of markets and standards for global mobile communications (Ernst, 2013). While Chinese firms have traditionally focused on packaging and testing of semiconductors, the design work sector grew at 20% annually between 2005 and 2015, making it the fastest growing sector.

Many Chinese IC producers are foundries that sell their ICs to companies that re-sell these products to the electronic system producers. At an earlier stage in policy development, Ernst

(2013) expressed concern that the push for indigenous innovation ignored the extent to which China was already deeply embedded in the semiconductor global value chain which could have a negative effect on China's ability to catch up. While the lack of consistent intellectual property protection (IPR) has been a major deterrent for foreign firms to establish state-of-the-art fabrication facilities in China, it also explains why many large fabless companies like Qualcomm and Broadcom have been slow to bring leading-edge designs into China to be manufactured indigenous foundries. Thus, Chinese IC foundries have been unable to offer large amounts of IC production using leading-edge feature sizes (IC Insights, 2013).

Table 6 shows the overall profile of the semiconductor sector in China, with Object Based Storage Devices (O-S-D) forming the largest share at 34.1%, semiconductor design at 25%, packaging and testing at 23.8% and manufacturing at 17.1%., indicating a focus on lower end devices and lower value added functions (pwc, 2017). Recent data indicate that companies operating in China, including non-Chinese companies, currently supply only one-third of its USD180 billion semiconductor consumption, with most functions being in lower value-added segments of assembly, packaging and testing (Wang, 2018). This profile is further confirmed by Orr (2018) who estimated that China accounted for 15% of global fabless production, 8.0% of foundry production, less than 1.0% of integrated design and manufacturing (IDM) and less than 1.0% of semiconductor tool production.

A recent survey by China's Ministry of Industry and Information Technology reported that 30 of China's biggest conglomerates were dependent on imports for 95% of central processing unit and CPU-related chips for computers and servers (Huifeng, 2018). Domestic CPUs are only about 30-50% as efficient as those produced by Intel with many Chinese products being mid- to lower-tier. Despite being the world's biggest market for semiconductors, only 15% of its consumption was produced in China in 2018, with more than half of that produced by non-Chinese companies. While China has made progress in optical devices and has achieved almost self-sufficiency in low-power embedded processors, sensors and discrete devices, it continues to be weak in leading-edge multi-core processors, memory devices, semiconductor equipment and design tool services (Yoshida, 2019). Thus, while China is making progress in the storage market, which is easier to break into, 99% of the USD20 billion microcontroller market is in the hands of non-Chinese companies (Lie, 2019).

Table 6 Semiconductor sector by % revenue share for 2016 (USD99 billion)

O-S-D devices	34.1
IC design	25
Packaging/testing	23.8
Manufacturing	17.1
Total	100

Source pwc (2017)

Despite the traditional dominance of IC Packaging and Testing, the China IC Ecosystem Report revealed that IC design with USD31.9 billion had already overtaking it. This report noted that the IC packaging and testing sector was moving up the value chain through mergers and acquisitions and building advanced capabilities to attract Integrated Design Manufacturing (IDM) companies, and China's IC materials market, which had been dominated by packaging materials was also expanding, driven by the new fab capacity development. Although significant differences in revenue forecasts for Chinese chip production are evident in the major data sources of SEMI and IC Insights (Clarke, 2019), some estimates for China's design sector suggest a revenue of USD42.5 billion for 2019 (Statista, 2019).

Despite the obvious evidence of catch-up in some areas, no Chinese company is among the top ten global semiconductor companies, whose acquisition of many crucial microprocessor patents have helped them to secure a dominant share of global IC markets (Fulco, 2018). Zhang (2018) also reveals that in terms of market capitalisation, Intel, Broadcom and Qualcomm were at least ten times that of Shenzhen Huiding Technology, one of China's biggest chip companies. It is also worth noting that Intel Corp, with sales of USD708 billion in 2018, which has a significance presence in China did not include any Chinese company in its list of top quality suppliers in 2018 (Tao, 2018).

The global foundry production capacity is estimated to be USD70 billion in 2019 and Table 7 lists the top 10 foundry companies for the first quarter of 2019. Taiwan's TSMC and South Korea's Samsung are the top two companies accounting for 67.2% of total revenue, with two Chinese companies accounting for only 6.0% of the total (TrendForce, 2019). In addition to major customers such as Qualcomm, Apple and AMD, however, TSMC also includes Huawei's subsidiary, HiSilicon, and Huawei's continued relationship with TSMC is vital for its access to leading-edge chip production, revealing a critical dependency.

The main progress in China's foundry sector has been building market share in some lagging technologies such as 65 nm and 45 nm semiconductors with applications in end-use consumer electronics. In its efforts to achieve greater self-sufficiency, several new 6-, 8- and 12-inch fabs have been established in China since 2017, but the demand for their product remains low to date, partly because policy rather than the market is driving demand, as greater autonomy is prioritised over profitability (Yang et al., 2019). China's pure-play foundry market increased by 41% in 2018, which resulted in China accounting for 19% of the global market. At the end of 2018, installed foundry capacity in China, which includes both foreign and local company capacity, was 1.3 million wafers per month (wpm) in 200mm equivalents, while worldwide it was seven million wpm, while almost half the announced investment in new wafer capacity is expected to come from foreign multinationals (Lapedus, 2019).

Table 7 Revenue (USDm) and % market share (1Q2019) of top 10 foundries

Rank	Company	HQ	1Q19	% share
1	TSMC	Taiwan	7028	48.1
2	Samsung	Sth Korea	2785	19.1
3	Global Foundries	US	1234	8.4
4	UMC	Taiwan	1058	7.2
5	SMIC	China	654	4.5
6	Tower Semiconductor	US	310	2.1
7	Powerchip	Taiwan	251	1.7
8	VIS	Taiwan	221	1.5
9	Hua Hong	China	220	1.5
10	Dongbu Hi Tek	Sth Korea	131	0.9
	Total		13892	95

Source: Trendforce (2019)

Among the half dozen domestic foundries, SMIC is the most significant and has been struggling with yields in 28nm technology, the most advanced process it has achieved to date. Despite getting USD10 billion funding from the government to build capacity for 14nm, 10nm and 7nm, processes that are becoming more complex, SMIC is struggling to eliminate defects that impact on yields (Lapedus, 2019). Thus, while market leaders like AMD and TSMC have already reached 7 nm, SMIC continues to lag two generations behind (Arkenberg, 2018).

Table 8 shows the sales for China-based chip production for major foreign and Chinese companies, which amounted to USD23.7 billion in 2018. The two South Korean giants, SK Hynix and Samsung together accounted for 57.4% of total production, two US companies, Intel and Diodes-BCD accounted for a further 12.3%, Taiwan's TSMC accounted for 4.0% and five Chinese companies accounted for 23% of total production in 2018, suggesting a 70/30 split between foreign and local production capacity in China, and 5.5% market share for Chinese companies in the global market. Despite significant investment in fabrications plants, IC Insights forecasts suggest that China-based fabs will account for only 8.2% of global IC manufacturing value in 2023 and that at least 50% of IC production will still come from foreign companies such as SK Hynix, Samsung, Intel, TSMC, UMC, GlobalFoundries and Foxconn (Clarke, 2019).

Table 8 Sales and market share of major semiconductor companies in China, 2018

Rank	Company	HQ	USDm	% share	Products
1	SKHynix	Sth Korea	9075	38.2	DRAM
2	Samsung	Sth Korea	4560	19.2	3D NAND Flash
3	SMIC	China	3195	13.4	Foundry
4	Intel	US	2675	11.3	3D NAND Flash
5	Hua Hong Semi	China	1542	6.5	Foundry
6	TSMC	Taiwan	950	4.0	Foundry
7	XMC/YMTC	China	300	1.3	Foundry/3D NAND
8	CR Micro	China	245	1.0	Foundry/Std Ics
9	Diodes-BCD	US	240	1.0	Foundry/Std Ics
10	ASMC	China	180	0.8	Foundry
	Others		810	3.4	
	Total Chinese production		23772	100	
	Global market (bn)		430.8		
	Chinese companies share			5.5	

Source: IC Insights; Lapedus (2019)

Table 9 shows the top Chinese fabless companies in 2016 having sales USD10.1 billion, or 42% of USD24.1 billion total sales, with the remainder accounted for by non-Chinese companies. Apart from Huawei's subsidiary HiSilicon and Unigroup, most Chinese fabless companies lag two generations behind major US companies like Qualcomm (Lewis, 2019). Like many other global fabless companies, HiSilicon relies on CPU design licenses from Arm Holdings, a UK company now owned by Japan's Softbank, which has a 99% market share for its family of RISC architecture for computing processors. Arm's facility in Austin, Texas could place this supplier relationship at risk.

Table 9 Sales of major Chinese fabless companies 2016

Company	USD		Product
HiSilicon	3.87bn	Huawei subsid	chip design
Tsinghua Unigroup	1.86bn	acquired Spreadtrum, RDA	
Omnivision	1.39bn	US company sold	image sensors
ZTE Microelectronics	892.57 m	ZTE subsid	chip design
CEC Huada Semiconductor	505.79m	SOE subsid	sim cards
Nari Smart Chip	478.27m	SOE subsid	smart meters
Shenzen FocalTech	446.28m	was US company	Fingerprint sensors
Silan Microelectronics	342.15m	Hanzhou	Microcontrollers
Beijing ISSI	342.15 m	US company sold	DRAM
Datang Semiconductor	342.15m	Subsd of Datang	wireless chips
		and JV with Qualcomm	
Total	10.12bn		

Source: Adapted from Morra (2017)

Three of the top companies, Omnivision, Shenzhen FocalTech and Beijing ISSI, were former US companies acquired by Chinese investors before the US government began blocking the acquisition of US technology companies. In addition to its efforts to acquire technology through foreign acquisitions, China's semiconductor sector is also dominated by state involvement, both centrally and at provincial level. Tsinghua Unigroup is a significant holding company connected with Tsinghua University and one of the main vehicles for channelling state funds to various companies that are part of China's new push for greater semiconductor self-sufficiency. Other examples include CEC Huada which is a Government-controlled enterprise; Nari Smart Chip is the main supplier to State Grid, the state-owned electric utility monopoly of China, and ZTE is a State-Owned Enterprise (SOE) that is privately managed. By 2018, China accounted for 13% of the global market share of fabless companies, compared with the US with 68%, Taiwan with 16%, Europe with 2% and Japan with 1% (EPS News (2019).

In addition to gaining access to key equipment and materials for producing chips, which may be more difficult because of US sanctions, some commentators highlight the scarcity of expertise and tacit knowledge required for optimising and improving the production process (Lewis, 2019). The need to innovate on a continuous basis in order to compete with global leaders in semiconductor production requires access to experienced personnel (Wang, 2018). A reflection of the dearth of such experience on the mainland was the team of 300 engineers from Taiwan's UMC working with China's JHICC in its joint venture until US sanctions against both firms stalled development of the fab (Hille, 2019).

Thus, the dominant position of foreign companies throughout the semiconductor value chain is explained by the fact that they own most of the intellectual property. US companies like Applied Materials dominate manufacturing equipment, while Intel, Nvidia and Qualcomm control key parts of integrated chip design for microprocessors and thus capture the highest share of revenues in the value chain. Non-Chinese companies such as Samsung, Intel and SK Hynix dominate front-end manufacturing and foreign companies also capture the highest share of design revenues, while the main segments where Chinese companies do well are in back-end manufacturing and assembly and test (Kaza et al., 2011). So, while Huawei's HiSilicon subsidiary has been an important part of China's effort to achieve greater autonomy in semiconductors, it depends on foundries, especially TSMC for producing chips that it designs, and while Huawei has built up a strong portfolio of 5G patents, it depends on US companies like Xilinx, Texas Instruments and Analog Devices for parts to build 5G base stations (Feng, 2019).

5.1 NAND and DRAM in China

With the decline in demand for semiconductors from the mobile device sector, Chinese policymakers broadened the product mix to include 3D NAND flash memory, power, analog and compound semiconductors. While questioning the wisdom of making huge investments in both flash and DRAM memory when Taiwanese firms, despite significant investment, had failed in these areas, Ernst (2016) acknowledged that China's rapidly growing market in automotive, data centres and mobile platforms requiring 3D NAND memory had helped to make China an important memory cluster through attracting significant investment such as Samsung's 3D NAND fab in Xi'an, SK Hynix's DRAM fab in Wuxi and Intel's 3D NAND fab in Dalian and its packaging and test unit in Chengdu. In fact, in 2018 while NAND flash memory accounted for USD57 billion of the total USD150 billion semiconductor market, China accounted for 32% of global capacity (Elinfor, 2019).

Lacking the capabilities to develop sophisticated chips, China followed the example of both Taiwan and South Korea by targeting memory as a point of entry to the market (Lapedus, 2019). While some progress has been made, China is still not capable of competing with international companies in Field Programmable Gate Arrays (FPGPA) chips, in Central Processing Units (CPUs) and in Digital Signal Processors (DSPs) (Zhang, 2017). Despite the opportunity presented by its huge market and the importance of semiconductors in supporting smart manufacturing, China still needs to move from the low- to mid-end of the market it currently occupies to developing central and graphic processing units (Dai, 2018).

Because NAND and DRAM memory chips companies are commodity producers and compete mainly on price, this segment, rather than more complex ones such as logic chips and microprocessors, suits China's track record in gaining market share based on price competition (Wang, 2018). But, because of the decades of high-volume DRAM and NAND production by the major memory suppliers, it will be 'almost impossible' for new producers entering the field not to infringe the numerous patents of these companies (IC Insights, 2017).

Also low margins resulting from competing at the lower end of the value chain would make it difficult to invest at the necessary level to compete with market leaders (Wang, 2018). Current tensions with the US created barriers to acquiring foreign technology companies and the necessary equipment for developing their facilities. For example, the new USD24 billion fabrication plant of Yangtze Memory and Semiconductor Manufacturing International Company, a state-funded national champion, has been seriously impacted by a ban on early-stage equipment from US companies like Applied Materials, KLA-Tenor and Lam Research, which together control more than 55% of the front-end wafer plant equipment market (Ting-Fang, 2018).

Table 10 Major investments (USD bn) in memory fabrication in China

Company	HQ	Segment	Node(nm)	K WPM	USDbn	Productior	Location	Investors
YMTC	China	3D NAND	30	200	24	2018	Wuhan	Wuhan govt, Unigroup, SMIC
Hujian Jin	China	DRAM	32	60	24	2018	Fujian	Fujian govt
Tsinghua U	China	NAND/DRAM	TBD	100	30	2018	Nanjing	Nanjing govt.
Giga Devic	China	DRAM	TBD	TBD	TBD	2018	Hefei	Hefei govt.
Intel	US	3D NAND	30	30	5.5	2016	Dalian	Dalian govt.
SK Hynix	Sth Korea	DRAM	20	130	5.5 + 800m expansio	2005	Wuxi	N/A
Samsung	Sth Korea	3D NAND	30	100	7.5 + 7.0 expanion	2014	Xian	N/A

Source: Credit Suisse (Castellano, 2019)

Bearing in mind that SK Hynix and Samsung and Intel accounted for 68.7% of China's top ten semiconductor company total production in the first quarter of 2019, it is not surprising to see major their investments in Table 10. SK Hynix was the first foreign investor to invest more than US10 billion in Wuxi and had a revenue of USD6.4 billion in 2017. In 2018, SK Hynix was working with Wuxi Industrial Development Group on relocating its 200mm M8 equipment from its fab in Cheongju (Korea) to a new foundry in Wuxi by 2021 (Lee Jae-cheol and Kim Hyo-jin , 2018). More recently, however, SK Hynix halted developments in

Wuxi and is now planning to invest USD107 billion over 10 years in four DRAM factories in Yongin in South Korea. While this investment is happening at a time when DRAM prices have fallen steeply, it is part of SK Hynix's long-term plan to retain its competitive edge in DRAM from which it obtains 80% of its revenue.

Until recently, Samsung was the only company capable of mass producing 3D NAND flash. In 2018, it announced a USD7 billion investment at its Xi'an plan to double output to 220,000 300mm 3D flash memory by 2020. In addition to the fact that China is the biggest importer of NAND and Samsung is the biggest supplier, Samsung also wanted to reduce the risk associated with over-concentrating production in South Korea (Ravenlord, 2018). After a price spike in 2017, Samsung agreed to moderate DRAM prices, reflecting China's ability to use its market size as a leverage over market leaders (Wang, 2018).

China's own efforts to develop memory chip production has been badly impacted by US sanctions. US companies have been banned from supplying Fujian Jinhua Integrated Circuit Co. (JHICC), a major DRAM facility, with components or materials after both JHICC and its Taiwanese research and development partner United Microelectronics Corp (UMC) were accused of stealing IP from US company Micron Technology. Previously, Tsinghua/XMC, another major Chinese investment, failed to develop a licensing partnership with Micron and later, a USD23 billion acquisition bid also failed. Like other global semiconductor companies which rely on US suppliers, UMC has currently stalled its partnership with JHICC, forcing it to close down its DRAM programme. The dilemma for companies like Micron, however, arising from the current tensions is revealed by the fact that 51% of its total sales of USD20.3 billion in 2017 were to China, (Castellano, 2019).

In 2017, Samsung announced a USD26 billion expansion plan in order to safeguard its market leader position in NAND memory. Because of this increased capacity and the absence of joint ventures between Chinese companies and market leaders, some commentators pointing to the poor track record of SMIC, China's largest foundry, which has been in business for about 15 years, but still lags significantly behind market leaders are not optimistic about China's ability to catch up (Roos, 2017). Among those expressing scepticism about China's ability to catch up in a short period is Zhao Yuanfu, vice director of the Science and Technology Committee at the Ninth Academy of China Aerospace Science and Technology Corporation (CASC), who identifies China's culture of imitation as a major inhibitor to being able to compete with leaders in the field (Wang, 2019).

5.2 Interdependency

Considering the problem of technology lagging by Chinese companies, it is not surprising to discover that a recent survey by China's Ministry of Industry and Information Technology reported that 30 of China's biggest conglomerates were dependent on imports for 95% of central processing unit and CPU-related chips for computers and servers (Huifeng, 2018). Domestic CPUs are only about 30-50% as efficient as those produced by Intel with many Chinese products being mid- to lower-tier. While China has made progress in optical devices and has achieved almost self-sufficiency in low-power embedded processors, sensors and discrete devices, it continues to be weak in leading-edge multi-core processors, memory devices, semiconductor equipment and design tool services (Yoshida, 2019). Thus, while China is making progress in the storage market, which is easier to break into, 99% of the USD20 billion microcontroller market is in the hands of non-Chinese companies (Lie, 2019).

This asymmetric relationship is well described by Capri (2018) who views foreign companies partnering with Chinese groups in the production of second and third-tier generations of chips as a game in which they hope to continue innovating outside China, keeping the latest generation of IP out of reach of their Chinese partners. He argues however, that foreign companies are likely to be largely supportive of the Trump administration's efforts to curb China's state-centric technology goals, but will need at the same time to invest more to compete with the level of Chinese state investment in the semiconductor sector. While continuing to lag behind foreign companies in relation to intellectual property, China's semiconductor companies will find it difficult to compete.

While many leading global technology companies have been involved in partnerships with Chinese companies in order to ensure access to China's market, a number of Taiwanese companies have been particularly important in transferring technology and expertise to Chinese companies. Among the most important of these is TSMC, which accounted for 56% of the global foundry market in 2018, and is three generations of process technology ahead of China's SMIC. TSMC's technology leadership globally is reflected in the fact that its market capitalisation exceeded that of Intel in 2017. TSMC's major clients work in close cooperation developing new chips and switching foundries would require them to duplicate R&D invested in TSMC (The Economist, 2018).

Table 11 lists a small number of the many partnerships, joint ventures and other collaborations between foreign and Chinese companies. Some cases, such as Intel and Tsinghua, involved significant investment while others were mere technology licensing agreements. To overcome potential 'security threats' a partnership between Tsinghua Unigroup and Intel was established in Dalian, manufacturing chips for Chinese smartphone companies in China rather than importing them, and since they are under the Unigroup brand, they are officially counted as Chinese chips (Moyen, 2018).

Because of the recent tensions with the US most of these partnerships are either affected by uncertainty or have been ended, but in some cases other business-related factors influenced decisions to end the partnerships. Qualcomm, which receives more than 60% of its global revenue from China paid a USD975 million fine to Chinese authorities for alleged monopolistic business practices, and as part of the settlement, it agreed to work with Huaxingtong Semiconductors (HXT), forming a joint venture with the Guizhou provincial government (WeekinChina, 2019).

With major Chinese companies such as Lenovo, Oppo, Vivo and Xiaomi among its key customers, Qualcomm has been working with these Chinese smartphone companies in China's National Development and Reform Commission's (NDRC) 5G project. With the increased tensions with the US, however, companies like Qualcomm seeking to gain greater access to China's market will find themselves squeezed between the geopolitical interests of the US and China's own ambitions to achieve greater autonomy in the semiconductor sector (Yoshida, 2018).

Table 11 Examples of foreign partnerships with Chinese semiconductor companies

Foreign	HQ	Chinese	Project	Status
UMC	Taiwan	Fujian Jinhua	DRAM foundry	stalled
Qualcomm	US	SMIC	28nm, 14nm	
Qualcomm	US	SJSemi	10nm	
Qualcomm	US	Huaxingtong	server chips	ended
Arteris	US	Cambicon	technology licence	
Nvidia	US	Alibaba	cloud chips	
Intel	US	Horizon Robotics	AI chips	
Intel	US	Tsinghua Unigroup	USD 1.5bn	
Intel	US	Unisoc	5G	ended
Arm	UK	Huawei	servers	
Google	US	Huawei	Android	stalled
Cypress/Spansion	US	XMC	NAND	
Nvidia	US	TUSimple	autonomous truck	
AMD	US	THATIC	server CPUs	on US entity list
IBM	US	Suzhou PowerCore	server chips	licensing
NXP	Netherlan	Hawkeye	auto radar	

5. Conclusion

This paper has looked at the implications for China's current integration into the semiconductor global value chain for upgrading its capabilities and moving towards its goal of achieving a greater level of technological autonomy in this global sector. Well before the current trade tensions with the US, China was already embarked on a campaign to achieve greater technological autonomy in sectors that had national security connections, and semiconductors was at the core of its Made in China 2025 programme. The current tensions, however, have highlighted China's exposure to critical dependencies on foreign technology in semiconductor development and the current threat of decoupling of its interconnected supply chains could create significant barriers for the future development of this sector in China.

Latecomer nations face many barriers to technology upgrading particularly in sectors that are highly globalised like semiconductors. Many of the barriers for latecomer companies, specific to semiconductor development, which have already been highlighted in the literature such as the oligopolistic structure of the sector, the high cost of R&D for continuous innovation, particularly for the most leading-edge nodes, the cyclical nature of the sector creating high risks for companies seeking to move up the value chain, are all evident when we examine the empirical state of Chinese company involvement in the global value chain and within China itself.

While there is evidence of upgrading and of some movement up the value chain, such as the emergence of HiSilicon and general growth in the design sector, the reality is that much of the higher value added activity in China continues to be dominated by major global companies. With no Chinese companies present among the top global semiconductor companies and with most Chinese activity focused on lower value added functions and less sophisticated chips, the current tensions and their resulting sanctions have highlighted the continued dependence of Chinese companies on critical foreign suppliers, both in areas like design software and chip manufacturing. Even in the case of HiSilicon, such critical dependencies have created considerable uncertainty about its future development.

While other scholars have emphasised the need for state involvement in managing a latecomer nation's integration into global value chains, the danger of policy tensions between techno-nationalism and techno-globalism has also been highlighted. In China's case, the determination to achieve greater technological autonomy in semiconductors has been backed up with very significant investment, but important elements of its strategy such as acquiring foreign technology companies has been thwarted by the current sanctions. The ability of the US to close down major DRAM fabrication plants in China by imposing bans of critical supplies of equipment also illustrates the particular difficulties facing China's efforts to achieve autonomy.

Because the relationship between China and the more developed regions in the semiconductor GVC has been asymmetric and interdependent, the current tensions have a real likelihood of causing significant disruption to a complex ecosystem of supplier networks that have been constructed over many decades. This disruption will have negative consequences both for China and for those critical supplier companies that have become very reliant on China's market and her plentiful engineering talent. Involvement in China's dynamic technology market has not only helped to fund the on-going innovation of leading semiconductor companies but has also contributed to their involvement in emerging market segments in automotive, artificial intelligence and robotics. The retrenchment of semiconductor development within national boundaries, based on an old-world perspective of international trade is likely to have a hugely negative effect on the pace of innovation in the semiconductor sector globally. Certainly, it will delay considerably China's enormous potential contribution globally and to its own efforts to achieve greater technology autonomy.

References

Anysilicon (2019) Top 10 Analog Semiconductor IC Suppliers 2017-2018. Anysilicon, May 09, 2019 https://Robert Castellano.com/top-10-analog-semiconductor-ic-suppliers-2017-2018/

Arkenberg, C. (2018) China inside: Chinese semiconductors will power artificial intelligence TMT Predictions 2019. Deloitte Global, Dec 11, 2018 https://www2.deloitte.com/insights/us/en/industry/technology/technology-media-and-telecom-predictions/chinese-semiconductor-industry.html

Baldwin, R. (2017): The Great Convergence: Information Technology and the New Globalization. Cambridge, Belknap Press.

Capri, A. (2018) Semiconductors -- Beijing versus the West China's push runs into trouble amid trade war and US companies' tech theft fears. Nikkei, Oct 12, 2018. https://asia.nikkei.com/Opinion/Semiconductors-Beijing-versus-the-West

Castellano, R. (2019) Why Memory Chips Won't Be Impacted By A Trade War In One Chart. Seeking Alpha, Apr. 9, 2018 https://seekingalpha.com/article/4161770-memory-chips-impacted-trade-war-one-chart

Clarke, P. (2019) IC Insights, SEMI far apart on significance of Chinese IC production. EENewsanalog, Feb 11, 2019. https://www.eenewsanalog.com/news/ic-insights-semi-far-apart-significance-chinese-ic-production

Dai, S. (2018) China must face its weakness in semiconductors squarely, says head of state-backed fund. SCMP, 4 Octo, 2018 https://www.scmp.com/tech/article/2161178/china-must-face-its-weakness-semiconductors-squarely-says-head-state-backed

Duhalde, M. and Liu, Y. (2018) 'Made in China 2025': How Beijing is boosting its semiconductor industry. SCMP, Sept 25, 2018 https://multimedia.scmp.com/news/china/article/2165504/china-2015-semiconductors/index.html

ELINFOR (2019) NAND Flash industry in 2019 has huge variables, not just price reduction. ELINFOR, 16.02.19 https://www.elinfor.com/market/nand-flash-industry-in-2019-has-huge-variables-not-just-price-reduction-m-25

Ernst, D. (2013) An Advanced Manufacturing Puzzle – Why is China still playing second fiddle in semiconductors? American Association for the Advancement of Science (AAAS) 2013 annual meeting, panel on Advanced Manufacturing: Today, Tomorrow, and Beyond http://aaas.confex.com/aaas/2013/webprogram/Session5981.html

Ernst, D. (2016) China's bold strategy for semiconductors – Zero-Sum Game or Catalyst for Cooperation? East-West Center, Honolulu & Centre for International Governance Innovation, Waterloo.

Feng, E. (2019) U.S. Move To Isolate Huawei Sends Ripples Through Global Supply Chain. NPR, May 16, 2019 https://www.npr.org/2019/05/16/723983055/u-s-move-to-isolate-huawei-sends-ripples-through-global-supply-chain?utm_source=dlvr.it&utm_medium=twitter

Fulco, M. (2018) betting all the chips: China seeks to build a world-class semiconductor industry. CKGSB Knowledge, November 29, 2018. http://knowledge.ckgsb.edu.cn/2018/11/29/technology/china-semiconductor-industry/

Gao, X., and Liu, J. (2012). Catching up through the development of technology standard: The case of TD-SCDMA in China. Journal of Telecommunications Policy, Volume 36 Issue 7, 531-545.

Hille, K. (2019) Trade war forces Chinese chipmaker Fujian Jinhua to halt output. Financial Times, January 28, 2019. https://www.ft.com/content/87b5580c-22bf-11e9-8ce6-5db4543da632

Huifeng, H. (2018) Beijing did a tech reality check on its industrial champions. The results were not amazing. SCMP, 18 Jul, 2018. https://www.scmp.com/news/china/economy/article/2155862/beijing-did-tech-reality-check-its-industrial-champions-results

Hwang, C. (2019) The role of Chinese IC designers in worldwide supply chain. DIGITIMES, Taipei, 14 May 2019. https://www.digitimes.com/news/a20190514VL201.html?chid=9

IC Insights (2013) Foreign IC Companies to Represent 70% of China's IC Production in 2017, Up From 58% in 2012. Research Bulletin, July 23, 2013. http://www.icinsights.com/news/bulletins/Foreign-IC-Companies-To-Represent-70-Of-Chinas-IC-Production-In-2017-Up-From-58-In-2012/

IC Insights (2017) Without Technology, China's "MIC 2025" Results for ICs Likely to Fall Woefully Short of its Goals. IC Insights, Jan, 31, 2017. http://www.icinsights.com/news/bulletins/Without-Technology-Chinas-MIC-2025-Results-For-ICs-Likely-To-Fall-Woefully-Short-Of-Its-Goals/

IC Insights (2019) McClean report – A complete Analysis and Forecast of the Integrated Circuit Industry. IC Insights, January, 2019. http://www.icinsights.com/services/mcclean-report/

Jae-cheol, L. and Hyo-jin, K. (2018) SK Hynix to move foundry to Wuxi, China in JV. PulseNews, 11.7.2018 https://pulsenews.co.kr/view.php?year=2018&no=436831

Kaza, S., Mishra, R., Santhanam, N. and Tandon, S. (2011) The challenge of China. Mckinsey, Autumn 2011. http://www.mckinsey.com/en/Client_Service/Semiconductors/Latest_thinking/The_challenge_of_China.aspx

Lapedus, M. (2019) China's Foundry Biz Takes Big Leap Forward. Semiengineering, Jan 28, 2019 https://semiengineering.com/chinas-foundry-biz-takes-big-leap/

Lee, K. and Lim, C. (2001). Technological regimes, catching-up and leapfrogging, Research Policy, 30: 459–483.

Lee, K., Gao, X. and Li, X. (2017) Industrial catch-up in China: a sectoral systems of innovation perspective, Cambridge Journal of Regions, Economy and Society 2017, 10, 59–76.

Lee, K. (2019) The art of economic catch-up: barriers, detours and leapfrogging in innovation systems. Cambridge University Press.

Lewis, J. A. (2019) Learning the Superior Techniques of the Barbarians. Center for Strategic and International Studies, Jan 2019. https://csis-prod.s3.amazonaws.com/s3fs-public/publication/190115_Lewis_Semiconductor_v6.pdf

Liu, L. (2019) Countdown: How Close is China to 40% Chip Self-Sufficiency? EETimes, 11.4.19 https://www.eetimes.com/document.asp?doc_id=1334555#

Macher , J.T. and Mowery, D.C. (2004) Vertical specialisation and industry structure in high tech industries. Business Strategy Over the Industry Lifecycle Advances in Strategic Management, Volume 21, 317–356.

Morra, J. (2017) Taking the Pulse of China's Semiconductor Industry, Electronic Design, June 29, 2017 http://www.electronicdesign.com/embedded-revolution/taking-pulse-chinas-semiconductor-industry

Moyen, M. (2018) Why Intel Is Happy To Boost China's Domestic Semiconductor Industry. Seeking Alpha, Mar. 2, 2018 https://seekingalpha.com/article/4152860-intel-happy-boost-chinas-domestic-semiconductor-industry

Nellis, S. and Jiang, S. (2019) Tall chip tale? Huawei's backup plans leave experts unconvinced. Reuters, May 17, 2019. https://www.reuters.com/article/us-usa-trade-china-huawei-analysis/tall-chip-tale-huaweis-backup-plans-leave-experts-unconvinced-idUSKCN1SN0YN

Orr, G. (2018) Flipping the Switch on China's Semiconductor Industry. Linkedin, May 25, 2018 https://www.linkedin.com/pulse/flipping-switch-chinas-semiconductor-industry-gordon-orr/

pwc (2017) China's Semiconductor Industry – 2016 update https://www.pwc.com/gx/en/industries/technology/chinas-impact-on-semiconductor-industry/chinas-semiconductor-industry.html

Reuters (2019) Samsung to invest US$b billion in China plants to boost flash memory chip production. Reuters, 13 Dec, 2019. https://www.reuters.com/article/us-samsung-china/samsung-to-invest-an-extra-8-billion-in-china-chip-plant-media-idUSKBN1YG1GM

Rho, S., Lee, K. and Kim, S. H. (2015) Limited Catch-up in China's Semiconductor Industry:A Sectoral Innovation System Perspective, Millennial Asia, 6(2), 1-29

Roos, G. (2017) Will Samsung Dash China's Memory Market Hopes? EPSNews, Nov 16, 2017 https://epsnews.com/2017/11/16/will-samsung-dash-chinas-memory-market-hopes/

Semiconductor Industry Association (2016) Beyond Borders: The global semiconductor value chain. Nathan Associates, May 2016. file:///E:/Interview%20analysis/new%20paper/Semiconductor/Seminductor%20GVC.pdf

Shin-Hyung, L. (2019) Challenges ahead as Samsung leaps into logic chips. Asia Times, May 24, 2019. https://www.asiatimes.com/2019/05/article/challenges-ahead-as-samsung-leaps-into-logic-chips/

Solid State Technology (2019) China IC production forecast to show a strong 15% 2018-2023 CAGR. Solid State Technology February 2019. https://electroiq.com/2019/02/china-ic-production-forecast-to-show-a-strong-15-2018-2023-cagr/

Statista (2019) Revenue from the integrated circuit (IC) design semiconductor sector in China from 2016 to 2019. https://www.statista.com/statistics/976334/china-integrated-circuit-design-revenue/

Stratfor (2019) As the US-China tech war rages on, the electronics industry braces for impact. Stratfor, 29 March, 2019. https://worldview.stratfor.com/article/us-china-tech-war-rages-electronics-industry-braces-impact

Tao, L. (2018) China's call for 'core technology' breakthrough belies its weakness in semiconductors. SCMP, 23 April, 2018. https://www.scmp.com/tech/enterprises/article/2142990/chinas-call-core-technology-breakthrough-belies-its-weakness

The Economist (2018) TSMC is about to become the world's most advanced chipmaker. The Economist, April 5th, 2018. https://www.economist.com/business/2018/04/05/tsmc-is-about-to-become-the-worlds-most-advanced-chipmaker

Ting-Fang, C. (2018) China's rising memory chip leader won't try to 'crash the market'. Nikkei Asian Review, September 20, 2018. https://asia.nikkei.com/Business/Companies/China-s-rising-memory-chip-leader-won-t-try-to-crash-the-market

Transparency Market Research (2019) Logic Semiconductor Market - Global Industry Analysis, Size, Share, Growth, Trends, and Forecast 2018 – 2026. https://www.transparencymarketresearch.com/logic-semiconductor-market.html

TrendForce (2019) Global Top Ten IC Foundries Ranked for 1Q19, with TSMC Expected to Reach 48.1% Market Share, Says TrendForce. TrendForce, 18.3.2019. https://press.trendforce.com/node/view/3222.html

Yoshida, J. (2018) Qualcomm in China: BFF or DOA? EETimes, 26.1.2018. https://www.eetimes.com/author.asp?section_id=36&doc_id=1332899#

Yoshida, J. (2019) U.S.-China Crisis: Fallout for Chip Industry. EE Times Talks to Dieter Ernst. EETimes, 24.2.19. https://www.eetimes.com/document.asp?doc_id=1334360#

Yang, Y., Liu, N. and Wong, S-L. (2019) China pushes self-made chips in response to US threats. Financial Times, 30.5.2019. https://www.ft.com/content/f2695456-7d2c-11e9-81d2-f785092ab560

Vialle, P., Song, J. and Zhang, J.(2012). Competing with dominant global standards in a catching-up context. The case of mobile standards in China, Telecommunications Policy, 36 832-846

Wang, D. (2018) The new challenger in memory chips. Ideas, March 7, 2018. https://research.gavekal.com/user/login?destination=node/13419

Wang, Y. (2019) A state scientist's views on China's microchip industry. Sixth Tone, Feb 8, 2019. https://www.sixthtone.com/news/1003539/a-state-scientists-views-on-chinas-microchip-industry

Week in China (2019) Chips are down - *Qualcomm shutters JV in Guizhou.* Week in China, 450, May 3, 2019. https://www.weekinchina.com/2019/05/chips-are-down/

Zhang, Y. (2017) Heavy live coverage! Professor Wei Shaojun 2018 ICCAD speech compete PPT, EET China, November 16, 2017 (in Chinese). https://www.eet-china.com/news/201711160900.html

Zhang, S. (2018) US semiconductor makers dwarf Chinese peers in market valuation as China's chip dream remains distant. SCMP, 23 April, 2018.

https://www.scmp.com/business/china-business/article/2142929/us-semiconductor-makers-dwarf-chinese-peers-market-valuation