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China's bold strategy for semiconductors
– Zero-Sum Game or Catalyst for Cooperation?[1]

by

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Abstract

This paper explores whether China's bold strategy for semiconductors will give rise to a zero-sum game or whether it will enhance cooperation that will benefit from increased innovation in China.

As the world's largest producer and exporter of electronic products, China is by far the top market for integrated circuits (ICs), accounting for nearly a third of global demand. Yet its ability to design and produce this critical input remains seriously constrained. Despite decades and many billions of dollars of state-led investment, China's domestic production of semiconductors covers less than 13% of the country's demand.

As a result, China's IC trade deficit has more than doubled since 2005, and now has surpassed crude oil to become China's biggest import item. To correct this unsustainable imbalance, China seeks to move from catching up to forging ahead in semiconductors through progressive import substitution. The **"National Semiconductor Industry Development Guidelines (Guidelines)"** and the **"Made in China 2025" (MIC 2025) plan** were published by China's State Council in June 2014 and May 2015, respectively. Both plans are backed by huge investments and a range of support policies covering intellectual property, cybersecurity, procurement, standards, rules of competition (through the "Anti-Monopoly Law"), and the negotiation of trade agreements, like the Information Technology Agreement. The objective is to strengthen simultaneously advanced manufacturing, product development and innovation capabilities in China's semiconductor industry as well as in strategic industries that are heavy consumers of semiconductors.

Until recently, China has focused primarily on logic semiconductors and mixed-signal integrated circuits for mobile communication equipment (including smart phones), and on the assembly, testing and packaging of chips. Since the start of the 13th FYP, China's semiconductor industry strategy now covers a much broader range of products and value chain stages, while at the same time increasing the depth and sophistication of its industrial upgrading efforts. This important new development is at the center of this paper.

Based on a review of policy documents and interviews with China-based industry experts, I will describe key policy initiatives and stakeholders involved in the current strategy; highlight important recent adjustments in the strategy to broaden China's semiconductor product mix; and assess the potential for success of China's ambitious efforts to diversify into memory semiconductors, analog semiconductors, and new semiconductor materials (compound semiconductors). The chances for success are real, giving rise to widespread worries in the US and across Asia that China's bold strategy for semiconductors may result in a zero-sum game with disruptive effects on markets and value chains. However, Chinese semiconductor firms still have a long way to go to catch up with global industry leaders. Hence, global cooperation to integrate China into the semiconductor value chain makes more sense than ever, both for the incumbents and for China.

Keywords

China, innovation policy, industrial policy, semiconductors, impact on global semiconductor industry, zero-sum game, international cooperation

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[1] A substantially revised version of this study will be published as part of the Center's project on *Trade and Innovation within Global Networks*. Developments until late 2015 are examined in Ernst, D., 2015, *From Catching Up to Forging Ahead: China's Policies for Semiconductors,* East-West Center Special Study, September. See also Ernst, D., 2016, "From Catching Up to Forging Ahead? China's New Role in the Semiconductor Industry", *Solid State Technology*, May.

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About the author

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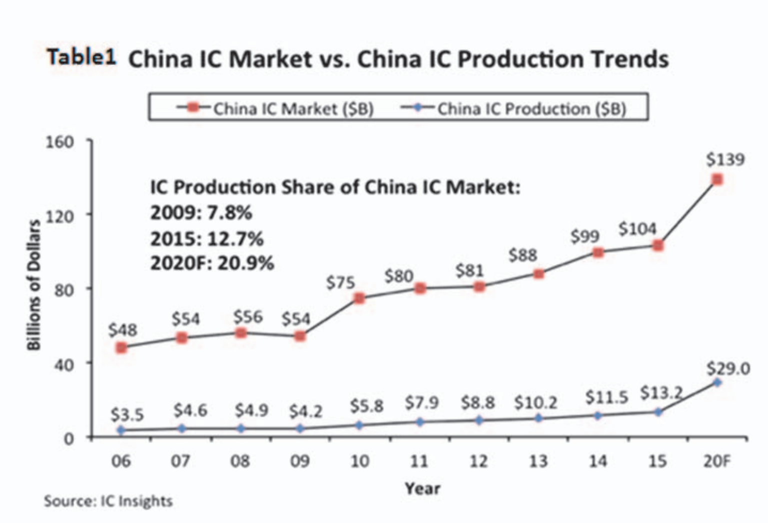
China's challenge
As the world's largest producer and exporter of electronic products, China is by far the top market for integrated circuits (ICs), accounting for nearly a third of global demand[2].Yet its ability to design and produce this critical input remains seriously constrained. Despite decades and many billions of dollars of state-led investment, China's domestic production of semiconductors covers less than 13% of the country's demand[3] (Table 1).



As a result, China's IC trade deficit has more than doubled since 2005, and now has surpassed crude oil to become China's biggest import item. This disturbing import dependence explains why the Chinese government is so concerned about the fate of its semiconductor industry, and why the Chinese leadership at the highest levels has made it a priority to catch up and forge ahead in this strategic industry.

For China's leaders, reducing this import dependence is a matter of national pride. Like in the US, national security needs play an important role. However, all these motivations are dwarfed by economic considerations. Semiconductors are critical for sustaining Chinese exports. In 2015, the *UN Comtrade database* reports China exported nearly $600 billion in information and communication technology (ICT) products (not including IT services and software) that are powered by semiconductors, representing nearly a third of all Chinese exports. Other industries, like IT services and software, automobiles, high speed trains and aerospace (both civil and defense) are also large consumers of semiconductors. Hence, the share of semiconductors in China's exports may well exceed 50%. Semiconductors thus are an essential input of a large share of the products China exports.

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[2] Estimates of China's share in global semiconductor sales differ, reflecting the tricky issue of how to account for double counting within complex global value chains. Realistic estimates range from 29.4% (as reported in the *World Semiconductor Trade Statistics, Blue Book 2/2016*, December 2015) to 36% (as reported in Chinese official data, as reported in Wei Shaojun, 2016, "Is China's IC development a threat to the world?", *China (Shenzhen) IC Innovative Application Summit*, Shenzhen, June 23. Wei Shaojun (Chairman of China Semiconductor Industry Association (CSIA) IC Design Subcommittee and Professor at Tsinghua University Micro- and Nano-Electronics Department), is one of the key players in China's semiconductor industry plan.
[3] IC Insights, the McClean Report 2016 mid-year update, July 7, 2016 http://www.icinsights.com/news/bulletins/IC-Insights-Lowers-Its-2016-Semiconductor-Market-Forecast-To-1/.

China however remains heavily dependent on imports of semiconductors and related technology, primarily from the US, but also from Japan, Korea, Taiwan and Europe. At least 80 percent of the semiconductors used in China's electronics manufacturing are imported and virtually all leading-edge devices like multi-component semiconductors (MCOs). For instance, 43% of the inputs for handsets and networking equipment of China's second largest telecom company, ZTE, are supplied by US companies (Avnet, Qualcomm, Broadcom, Jabil, Intel, Microsoft, Micron, Xilinx, Nvidia and Finisar)[4]. China-based firms supply less than 17% of ZTE' s most recent quarterly procurement value.

To correct this unsustainable imbalance, China seeks to move from catching up to forging ahead in semiconductors through progressive import substitution. The "**National Semiconductor Industry Development Guidelines (Guidelines)"** and the **"Made in China 2025" (MIC 2025, 中国制造2025) plan** were published by China's State Council in June 2014 and May 2015, respectively[5]. Both plans, together with the more recent **Internet Plus Plan**[6] are backed by huge investments and a range of support policies covering intellectual property, cybersecurity, procurement, standards, rules of competition (through the "Anti-Monopoly Law"), and the negotiation of trade agreements, such as the Information Technology Agreement (ITA)[7]. The objective is to strengthen simultaneously advanced manufacturing, product development and innovation capabilities in China's semiconductor industry as well as in strategic industries that are heavy consumers of semiconductors.

Until recently, China has focused on a narrow range of products, primarily logic semiconductors and mixed-signal integrated circuits for mobile communication equipment (including smart phones)[8]. At the backend, China has made big strides in moving ahead in assembly, testing and packaging of chips, where it is now the global market leader.

Since the start of the 13th FYP, China's semiconductor industry strategy now covers a much broader range of products and value chain stages, while at the same time increasing the depth

[4] Bloomberg Supply Chain data, as reported in http://www.bloomberg.com/gadfly/articles/2016-03-07/a-u-s-ban-on-sales-to-china-s-zte-could-backfire

[5] See USITO, 2014, *Guidelines to Promote National Integrated Circuit Industry Development* (unauthorized translation of document published by the Ministry of Industry and Information Technology, the National Development and Reform Commission, the Ministry of Finance, and the Department of Science and Technology), United States Information Technology Office, Beijing, June 24. For an unofficial translation of the MIC2025 plan, see http://www.usito.org/content/usito-made-china-2025-unofficial-translation-2015-5-29.

[6] The **IP Plan** has apparently not yet moved beyond the "vision stage", as reflected in the broad and vague policy statements. http://www.usito.org/news/state-council-provides-guidance-internet-plus-action-plan.

[7] China's successful approach to the negotiations to expand the ITA's product scope, is analyzed in Ernst, D., 2016, "The Information Technology Agreement, Manufacturing and Innovation – China's and India's Contrasting Experiences", http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2737082

[8] "Logic semiconductors" process digital data to control the operation of electronic systems. The largest segment of the logic market, standard logic devices, includes microprocessors, microcontrollers, digital signal processors (DSPs), graphic chips and chip sets. A "mixed-signal integrated circuit" has both analog circuits and digital circuits on a single semiconductor die.

and sophistication of its industrial upgrading efforts. This important new development is at the center of this paper[9].

I briefly review the history of past efforts and ask why they have failed in their larger aims. Based on a review of policy documents and interviews with China-based industry experts, I will describe key policy initiatives and stakeholders involved in the current strategy; highlight important recent adjustments in the strategy to broaden China's semiconductor product mix; and assess the potential for success of China's ambitious efforts to diversify into memory semiconductors, analog semiconductors, and new semiconductor materials (compound semiconductors). The chances for success are real, giving rise to widespread worries in the US and across Asia that China's bold strategy for semiconductors may result in a zero-sum game with disruptive effects on markets and value chains. However, Chinese semiconductor firms still have a long way to go to catch up with global industry leaders. Global cooperation to integrate China into the semiconductor value chain hence makes more sense than ever, both for the incumbents and for China.

1. Why past efforts have failed in their larger aims

Over the last 60 or so years, China's semiconductor industry has come a long way from being a completely government-owned part of the defense technology production system, with state-owned enterprises (SOEs) as the only players, toward a gradually more market-led development model. The role of SOEs has dramatically declined, and deep integration into international trade and global networks of production and innovation has transformed decisions on pricing and investment allocation, with private firms as the main drivers. Major achievements are the rapid growth of China's IC design industry from practically zero at the turn of the century to $17.05 billion in 2014, with an almost 37% compound annual growth rate since 2003. Other achievements include IC designs developed by Spreadtrum (as part of Tsinghua Unigroup) for lowerend smartphones; IC designs for mid-range tablets developed by Rockchip; and the design of a multicore processor for next-generation communications by HiSilicon (an affiliate of Huawei), for the leading-edge 16-nanometer FinFET process technology.

Despite these developments, China's IC design capabilities overall continue to lag far behind the United States, Japan, Taiwan, and South Korea, in terms of both process technology and design line width. In addition, China lacks strong domestic suppliers of electronic design automation (EDA) tools and software and domestic licensors of IC design-related intellectual property.

As for wafer fabrication, Chinese foundries are lagging two generations (ca. four years) behind in process technology and wafer size, and this is true also for China's industry leader SMIC (Semiconductor Manufacturing International Corporation). Not until 2020 are Chinese foundries likely to catch up with the leading Taiwanese foundries. This describes a fundamental challenge for China's new policy to strengthen its semiconductor industry: While chip design companies have the largest growth potential, China's domestic semiconductor manufacturing technology and capabilities have failed to keep up with the country's chip design needs.

[9] Developments until late 2015 are examined in Ernst, D., 2015, *From Catching Up to Forging Ahead: China's Policies for Semiconductors,* East-West Center Special Study, September. See also Ernst, D., 2016, "From Catching Up to Forging Ahead? China's New Role in the Semiconductor Industry", *Solid State Technology*, May.

In short, China's achievements in semiconductors are overshadowed by persistent weaknesses, despite massive earlier support of the government. China is still playing second fiddle in the industry, because the state's indigenous innovation policy collides with the global technology sourcing needs of Chinese semiconductor firms. China's semiconductor industry is deeply integrated into the global semiconductor value chain through markets, FDI, and investment. In the demand chain, for instance, end users, global brand name companies, and electronic manufacturing service providers define performance and cost. In the supply chain, design tool vendors, design services, materials vendors, equipment vendors, and semiconductors producers (including foundries) are important sources of technology and capabilities[10].

This massive process of slicing and dicing the global semiconductor value chain has substantially reduced entry barriers for newcomers. According to Dr. Leo Li, the chief executive officer (CEO) of Spreadtrum, one of China's leading IC design company, "the availability of IC design tools, semiconductor fab services, and open-source Android smartphone software allows Chinese firms to circumvent their weak spots and develop their strengths in hardware, IC design, and integration."[11]

An important qualitative shortcoming of China's indigenous innovation policy is a failure to adjust its top-down organization to the dramatic changes in markets and technology that have transformed the global semiconductor value chain. As long as the state shapes the overall strategy from above, state and market will not work together well. This is not primarily because market forces may not be allowed to operate freely. In fact, China's indigenous innovation policy arguably relies more on using incentives (such as subsidies or government procurement), rather than restrictions on inputs, to promote local technologies.

An important weakness of China's indigenous innovation policy lies in its top-down implementation. Both domestic and foreign industry participants complain that when push comes to shove, vested interests in government agencies tend to override suggestions from industry experts. As long as this top-down approach to industrial policy prevails, China's leadership may end up having only incomplete knowledge of the real and continuously evolving needs of diverse private firms in terms of global knowledge sourcing.

2. The focus of the current strategy - key policy initiatives, stakeholders involved in implementation

Will China's policy on semiconductors this time around work better than before? Our research finds that China's new semiconductor policy does not represent a radical break with its deeply embedded statist tradition. However, there are some important changes toward a more bottom-up, market-led approach to industrial policy. If sustained, these changes may considerably improve China's chances to succeed in its new push in semiconductors.

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[10] The process of vertical specialization started decades ago, as the semiconductor industry reorganized around so-called "fabless IC design companies," which sent their designs to be made into silicon-based products at "pure-play foundries" (IC contract manufacturers). While a few of the largest integrated device manufacturers, such as Intel and Samsung, continued to combine IC design and fabrication (and thrived), most firms moved to the disaggregated model. For the economics of global vertical specialization in IC design, see D. Ernst, 2005, "Complexity and Internationalization of Innovation: Why Is Chip Design Moving to Asia?" *International Journal of Innovation Management*, Volume 09, Issue 01, March 2005, special issue in honor of Keith Pavitt.

[11] Interview, June 22, 2012.

China's new semiconductor strategy (as defined in the **Guidelines**) relies on two policy initiatives for implementation: (a) the **National IC Industry Leading Small Group,** a State Council-level body currently led by **Vice Premier MA Kai**, to enhance strategy coordination; and (b) "market driven" **IC Industry Equity Investment Funds** to improve investment allocation, and to enhance firm size and capabilities through strategic partnerships, joint ventures, and mergers and acquisitions, involving both foreign firms and domestic firms. The implementation of both policies signals a genuine effort to experiment with new and hybrid approaches to industrial policy that combines top-down decision making with bottom-up approaches, especially for investment funding and for the organization of technical working groups that shape strategy formulation.

The **National IC Industry Leading Small Group** leads and coordinates all other government agencies for China's IC industry development. MIIT plays a key role as the industry regulator and MIIT Minister MIAO Wei is also the Vice Head of that Group. The goal is to speed up government response time and to improve the capacity for flexible response by navigating around entrenched bureaucratic hurdles and rigid regulations. An additional function of the leading group seems to be to mobilize and consolidate public and private resources through public-private partnership.

A consulting commission (the "A-Team") of 12 experts from Academia, Government, Investment Funds and Industry reports to the Leading Group and acts as a think tank to assess policy measures, and to suggest solutions and adjustments in policies[12]. The borderlines between these three groups of experts are fluid, with academicians and government officials also having strong ties to industry.

The A-Team's **Academic Advisors** are *Dr. Ye Tianchun*, President of the China Academy of Sciences Microelectronics Institute, who is the lead on China's megaprojects for semiconductor process technology and equipment, materials, and supply chain-related issues; *Dr. Wei Shaojun,* President, Tsinghua University Microelectronics, who is the lead on China's megaprojects for IC design; and *Dr. Wang Xi,* President of Shanghai Institute of Microsystem and Information Technology, who is the lead on China's semiconductors materials industry. He owns China's largest semiconductor materials firm (上海 simgui)[13] and is the Chairman of the China National Silicon Industries Investment Group (which is seeking to acquire overseas IC materials firms).

The **Government Officials** in the A-Team are *Dr. Huai Jinpeng,* Vice-Minister of MIIT, and a computer engineer who is in charge of coordinating efforts; *Diao Shijing,* Director-General of Electronics, MIIT, who is in charge of coordinating government industrial policy; and *Qi Chengyuan,* Director-General, Hi-Tech Department of NDRC, who is in charge of project approvals for large fabs.

Government Investment Funds are represented in the A-Team by *Ding Wenwu,* who is the General Manager of the National IC Fund, and a former MIIT official; *Lu Jun,* President of SINO IC Capital (representing China Development Bank, the largest shareholder of the National

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[12] Information provided by China-based industry expert who requests anonymity.
[13] http://www.simgui.com.cn/

IC Fund); *Dr. Wu Ping,* President and co-founder of the private equity fund Summitview Capital, with over 20 years of experience as a researcher, entrepreneur and investor in IC design, semiconductor fabrication, and the Mobile internet; and *Wang Xiaobo,* who is the GM of Beijing E-Town, a Fund linked to the Beijing City Government.

The A-Team's **Industry experts** are Xu Xiaotian, Executive-Vice President of the China Semiconductor Industry Assiciation (CSIA) who has close links with SMIC, China's leading semiconductor foundry; Zhao Weiguo, Chairman of Tsinghua Unigroup, and one of the main architects of China's drive to gain access to core technology through mergers, acquisitions and patent licensing[14]; and Zhou Zixue, Chairman of SMIC (and former MIIT chief economist).

According to most foreign industry observers I interviewed, the expertise of participants from industry and research institutes has substantially improved. It is now more common to have experts who have studied and worked abroad and are internationally well-connected. Take the example of Dr. Wei Shaojun, who, as a member of the above A-Team, plays an active role in drafting China's new IC industry policy. As dean of the Microelectronics Institute at Tsinghua University and president of the China IC Design Association, Wei is well-connected within leadership circles. He studied and worked in Belgium, and is internationally recognized and respected as both a frequent speaker at the Global Semiconductor Alliance (GSA) and as a key Chinese delegate to the World Semiconductor Council. Chinese experts like Wei know the international scene well, and are familiar with the intricacies of the global semiconductor industry value chain, which gives them a better understanding of what policies might work in this knowledge-intensive and highly globalized industry.

It is unclear however how the **National IC Industry Leading Small Group** will coordinate with other institutions and political networks. There are widespread rumors for instance that Tsinghua Unigroup is very close to President Xi Jinping, through the former President of Tsinghua University Chen Xi, who himself has close ties to President Xi, given the two were undergraduate classmates. These connections might well offer Tsinghua Unigroup enough leeway to bypass the traditional MIIT and State Council system of approvals.

From the outside, China's semiconductor industry strategy seems to follow the old pattern of top-down government-centered decision-making. However, the above hybrid and ambiguous organizational arrangements may add flexibility and speed of decision-making that are both necessary to survive in the fast moving and unpredictable semiconductor industry.

The national and regional **IC Industry Equity Investment Funds** have gained in importance relative to subsidies as the tool of industrial policy. The government participates in equity investment but claims it will do so without intervening in management decisions. This is expected to reduce the cost of investment for a selected group of firms comprising a "national team" in the semiconductor industry. The underlying financial networks are complex and difficult to disentangle. Take **Hua Capital Management Co., Ltd (HCM)**, a Chinese investment management company, which was chosen to manage the chip design and testing fund under the **Beijing government's** 30-billion-yuan (HK$37.8 billion) **Semiconductor Industry Development Fund**.

[14] http://www.bloomberg.com/research/stocks/private/person.asp?personId=46477461&privcapId=225988676

According to industry observers, the real driving force behind HCM is Chen Datong, who is HCM's chairman as well as co-founder and managing partner of WestSummit Capital, a leading China-based global equity firm focused on helping high-growth technology companies access the China market. Dr. Chen has more than 20 years of investment and operations experience in the technology and semiconductor industries, and he owns 34 US and European patents[15]. HCM's president, Xisheng (Steven) Zhang, started out in 1994 as a post-doctorate researcher at University of California, Berkeley, worked his way into senior management positions at Agilent Technologies and Silicon Valley start-up IC design companies, and joined Beijing-based private equity investment company WestSummit Capital in 2013. Zhang has over 20 years industry experience in semiconductors, and in managing start-up companies in Silicon Valley and in Beijing.

HCM thus would seem to qualify as a professional fund manager with considerable knowledge of key aspects of the semiconductor industry value chain, especially related to IC design. It remains unclear, however, how private equity fund managers, who are supposed to maximize the return to capital, can nevertheless serve as proxies for the government and support its policy to strengthen indigenous innovation.

An additional complicating factor is the rise of **RMB-based equity investment funds**. The Chinese government (both central and local) now encourages domestic PE and VC firms to raise money in Renminbi (RMB) from investors, often with government connections, in China. These RMB funds can move faster than dollar-based funds as they do not need official government approval to convert currency. Earning money from investing is, at best, only part of their purpose. The primary objective of RMB funds is to support the growth of private sector companies by filling a serious financing gap. At the same time, however, Chinese government departments at all levels – local, provincial and national – now play a particularly active role, both in committing money and establishing PE and VC funds under their general control.

It is unclear at this stage, whether the growing importance of RMB Equity Funds might signal a shift towards gradually more market-driven allocation of investment funds. A final assessment thus has to wait until more information is available on how these funds will ultimately be deployed.

3. Adjustments in strategy and the potential for success

China's semiconductor industry strategy has singled out the large and growing gap between semiconductor consumption and production as the critical roadblock to catching up and forging ahead across a broad range of China's leading industries. Semiconductors thus are placed at the center of an integrated industrial upgrading strategy.

In order to implement this integrated strategy, the **Guidelines** seek to raise the share of domestic semiconductor production in China's semiconductor consumption (both measured in value

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[15] Another major player is Liu Yue, the deputy chairwoman of HCM, who also has a wealth of experience in China's IC industry. Of particular interest is her role as an early investor in China's leading foundry SMIC through Walden Capital, and her continuous involvement with SMIC.

terms) to 50% by 2020. Such an ambitious target may not be realistic[16]. But that is probably beside the point. What really matters is the message that this demanding target will convey to all stakeholders within this industry as well as along its value chain:

- No effort will be spared to implement a massive increase of the production/consumption ratio of semiconductors.
- Markets will play a "decisive" role (i.e. a greater role than before, to put it plainly) in determining the range of products, markets and value chain stages. In turn, this will require flexible adjustments in China's semiconductor strategy and support policies.
- Firms that participate in this contest will profit and grow, while firms that stay on the sidelines will lose out.
- Benefits include preferential tax treatment, land and monetary subsidies, R&D and labor incentives, and access to RMB equity funds.
- And these benefits apply to both domestic and foreign players - at least for now.

It seems that this systemic and more market-driven approach to industrial planning has captured the attention of both domestic and foreign firms.

In what follows, I will review the targets stated both in the **Guidelines** and in the **MIC 2025 plan**; highlight important recent adjustments in the strategy with a new focus on broadening China's semiconductor product mix (highlighting analog and compound semiconductors; and assess the potential for success of China's new push into memory semiconductors.

a. The overall targets
The **Guidelines** describe fairly concrete targets for 2015, 2020, and 2030, while the **MIC 2025 Plan** translates these targets into specific support policies for analog and memory semiconductors needed to upgrade industrial end markets. In the fast-moving semiconductor industry, projections that extend beyond a few years should, of course, be treated with a grain of salt. Nevertheless, it is useful to document the expectations of China's leadership.

For 2015, the focus has been on strengthening the nexus between IC design and fabrication. By leveraging the demand pull from mobile devices (especially budget smartphones) to strengthen the IC design industry, the goal is to turn IC design into an engine of growth for China's IC foundry industry. In turn, the target for IC fabrication is to enable Chinese providers of IC foundry services to upgrade from 40-nanometer down to 32-nanometer and 28-nanometer process technology. For IC assembly, packaging, and testing (APT), the 2015 target is that at least 30 percent of APT revenue should come from mid- to high end packaging and testing technology. A recent survey of March 2016 finds that the three leading semiconductor package subcontractors in China (Jiangsu Changjiang Electronics Technology [JCET], Nantong Fujitsu [NFME], and Tianshui Huatian [Huatian]) are all developing advanced processes and increasing their respective capabilities to serve both China and overseas companies[17].

[16] As shown in in Figure 1, the widely quoted *McClean Report 2016 Mid-Year Update* projects a much lower 20.9% share of Domestic IC production in China's IC market.
[17] http://www.semi.org/en/china-strong-market-growth-and-innovation-packaging-0

The target for 2020 is to gradually increase China's local value added and to upgrade its position in the global semiconductor value chain. In addition, China should join global industry leaders in IC design for mobile devices, cloud computing, the Internet of Things (IoT), and Big Data. Finally, by 2030, Chinese firms are expected to compete with global industry leaders across key sectors of the IC industry supply chain and create disruptive technological breakthroughs.

b. Adjustments in the strategy with a new focus on broadening China's semiconductor product mix

Drastic adjustments in China's semiconductor strategy are necessary to achieve these targets, and the leadership seems to be committed to make these changes. Policy documents emphasize that, in order to raise the share of domestic production in China's semiconductor consumption to 50%, a massive import substitution would be required. The only way to make this happen is to broaden the product range of semiconductors.

When the strategy codified in the **Guidelines** was conceived, it was assumed that the demand pull from mobile devices could be used as a powerful catalyst for upgrading China's chip design. In 2014, MIIT's vice minister Miao Wei argued that, as China now is the world's largest smart phone market, and as demand for low-end budget smartphones is driving volume growth, this should provide "favorable conditions for China to leapfrog ahead of others."[18]

However, as demand growth for mobile devices is losing steam as a primary carrier of semiconductor demand in China, Chinese planners decided that it was time to broaden the semiconductor product mix to include *memory semiconductors* (especially sophisticated 3D NAND flash memory*), power and analog semiconductors* for industrial end markets (in line with the MIC 2025 plan), and *compound semiconductors* (i.e. non-silicon semiconductor materials or Wide Band-Gap Materials, such as Gallium arsenide [GaAs] and Gallium nitride [GaN]).

Since the start of the 13th FYP, China's semiconductor industry strategy has been adjusted with remarkable flexibility and speed. The strategy now covers a much broader range of products and value chain stages, while at the same time increasing the depth and sophistication of its industrial upgrading efforts. Reflecting an increasing sophistication of China's industrial planning techniques, a new *two-pronged strategy* is emerging that seeks to strengthen the position of China's semiconductor industry *simultaneously* both in *established applications* (such as computers, multimedia, navigation, simulation, consumer electronics), but also in *newly emerging applications* with potentially huge future demand pull effects.

Among the latter, the following sectors are expected to provide strong demand pull effects for innovation in both IC design and fabrication (not necessarily in order or priority): car-related information technology and electronics; environment-related IT; health-related IT; avionics and other defense-related IT (including drones); new network-based mobile communications; advanced manufacturing technologies (robots; 3D Printing; and the Industrial Internet)); high-performance computing; powerful servers for Big Data centers; LED and other new lighting technologies; and power electronics. A quick email survey, conducted in July and August 2016 among China-based industry experts, resulted in fairly similar assessments of application sectors that are expected to provide strong demand pull effects for innovation in semiconductor design

[18] USITO, 2014 interview with MIIT's vice minister Miao Wei, page 3.

and fabrication. This indicates that China's adjusted priorities for its semiconductor industry might well be on target.[19]

New policy documents, issued by MIIT, to implement the MIC 2025 plan, are laying out important roadmaps for diversifying China's semiconductor industry. For instance, on April 12, 2016, MIIT issued the **Implementation Plan for the 2016 Industry Strong Base Special Project,** which spells out detailed targets for the development of China's design and fabrication of power and analog semiconductors. One focus is on semiconductors needed as key components for robots, high-end sensors, high-end medical device components, super capacitors, high-speed optical communication devices. The plan also mentions encouraging involvement of bank credit, venture capital and RMB-equity funds, to support companies in these sectors, as well as researching the development of an insurance compensation mechanism to act as a warranty for basic components[20].

Why analog semiconductors are attractive

Analog semiconductors offer substantial comparative advantages for China. On the demand side, China's well-funded programs to develop both electric vehicles and smart autonomous buses and cars will create a huge demand for analog semiconductors that are needed for sensors, power management and signal processors. An equally important demand pull will come from the development of Smart Grids, and from the relentless push into alternative energy technologies that are all big users of analog semiconductors. In the medium term, the rise of applications around the Internet of Things (IoT) will further push demand for analog devices.

On the supply side, analog semiconductors also offer substantial advantages - they use mature process technologies, and thus are much more cost effective than digital fabs. While the digital fab may cost billions of dollars in just the setup costs, not to mention the millions to be spent in operational expenses each year, an analog fab can be set up in the cost range of hundreds of millions of dollars. In addition, analog chip design requires close coordination with the chip manufacturer. Having domestic analog fabs thus can be of great help in growing the capabilities of China's analog chip design industry.

Towards an integrated compound semiconductor value chain?

Of particular interest will be China's push into compound semiconductors[21]. While still at an early stage, there are serious efforts under way to develop an integrated compound semiconductor value chain, drawing on the demand pull from China's huge market for lighting/LED and power electronics.[22]

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[19] Interviewees emphasized that Chinese experts involved in China's semiconductor strategy are well-informed professionals and that their roadmaps are consistent with technology planning exercises in global industry leaders.

[20] Information provided by China-based industry expert who has requested anonymity.

[21] According to Wikipedia, a *compound semiconductor* is composed of elements of at least two different species, such as from group 13 (boron, aluminium, gallium, indium) and from group 15 (nitrogen, phosphorus, arsenic, antimony, bismuth). The range of possible formulae is quite broad because these elements can form binary (two elements, e.g. gallium(III) arsenide (GaAs)), ternary (three elements, e.g. indium gallium arsenide (InGaAs)) and quaternary (four elements, e.g. aluminium gallium indium phosphide (AlInGaP)) alloys. https://en.wikipedia.org/wiki/List_of_semiconductor_materials#Compound_semiconductors

[22] A detailed analysis of China's serious efforts to forge ahead in compound semiconductors is beyond the scope of this article, but will be addressed in a separate paper.

As for China's investment into compound semiconductors for the LED industry, a primary catalyst is the **National IC Fund**'s multi-billion USD investment into Fujian province headquartered **Sanan Optoelectronics** (a subsidiary of China's largest LED company)[23] to develop a GaN/GaS semiconductor foundry[24]. As the largest China-based maker of LED epitaxial wafers and semionductors, Sanan is rapidly expanding its fabrication capacity, by ordering a record 100 leading-edge MOCVD[25] sets of production equipment (50 from Veeco, the leading US producer; and 50 from Germany's Aixtron[26]). Much of these purchases are subsidized by the city government of Xiamen.

In order to access this critical technology, Sanan has acquired Taiwan GCS, a second-tier GaN foundry, and most importantly, appears to have successfully finalized the acquisition the leading compound semiconductor equipment maker Aixtron Technologies (based in Germany) for $752 million USD.[27]

China's chances for success in compound semiconductors seem to be considerable, given the speed with which China now has assembled talent and other key building blocks of the value chain in this industry, not only in chip design and fabrication (through Sanan IC) but also now in materials and equipment. Recruitment of foreign experts has played an important role. Take Hsu Chen Ke, Sanan's CTO. A frequent speaker at the Compound Semiconductolr International Conference series, Dr. HSU is an expert in GaN products performance, yield and quality improvement technology, and has 49 authorized patents.

As for compound semiconductors for power electronics, the industry association **SEMI (Semiconductor Equipment and Materials International)** has established a **Power and Compound Semiconductors Committee** on July 28, 2015[28].The committee includes leading global power and compound semiconductor companies as well as optoelectronics and electricity firms. Companies include Infineon and NXP, the Chinese Academy of Sciences, PlayNitride, Cham Crystal Semiconductor, Silicon Cenda, CSR Electric, Silver Mao Microelectronics, Huahong Hong force, Tower Jazz, and CNR. Both the international and the domestic firms are eager to exploit the huge market for GaN RF devices and power electronic devices in computers, mobile communications, networking, automotive electronics, power transmission, modern transportation.

c. The potential for success of China's new push into memory semiconductors.

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[23] http://www.sanan-e.com/en/

[24] http://www.researchinchina.com/Htmls/News/201506/38737.html

[25] MOCVD = Metalorganic chemical vapor deposition, a highly complex semiconductor fabrication method used in the manufacture of optoelectronics.

[26] *DigiTimes*, 29 July 2016

[27] http://www.bloomberg.com/news/articles/2016-05-23/chinese-investor-group-to-buy-europe-s-aixtron-for-752-million.   According to industry experts, Aixtron produces deposition process manufacturing equipment for a wide range of compound semiconductors, including on GaN/GaS materials.   Aixtron equipment is found in almost every fab around the world that deals with GaN process technology - they have direct access to all the process technology recipes for leading GaN Device manufacturers.

[28] "SEMI China forms Power and Compound Semiconductor Committee", *Compound Semiconductor*, August 6, 2015, http://www.compoundsemiconductor.net/article/97688-semi-china-forms-power-and-compound-semiconductor-committee.html

China has not followed in the footsteps of Japan and Korea, where knowledge gained from competing in memory semiconductors was used as the *technology driver* behind the development of their increasingly diversified semiconductor industries[29]. Memory semiconductors until now have remained the *Cinderella* of China's rise in the semiconductor industry.

Why is the Chinese government now changing course, initiating a massive push to develop their thus far non-existent domestic memory industry, with reported investments of more than $40 billion in flash memory production, and another $10 - $15 billion in DRAM memory production over the next five years? Why would China want to spend such vast resources to venture into the memory business, the "bleeding-edge" of the semiconductor industry with its enormous entry barriers and technological hurdles? Are China's leaders oblivious to the huge losses of around $ 40 billion of Taiwanese firms which tried and failed to enter the memory business in the late 1990s and early 2000s, when the industry was less concentrated and barriers to entry lower than today?

In my view, there is reason to be reasonably optimistic about China's chances of success in memory semiconductors. To explain why, I will explore the economic rationale for China's push into memory, highlighting China's potential latecomer advantages in particular for 3D NAND flash memory; assess China's efforts to obtain core technologies; examine the current status of the Wuhan XMC-Tsinghua Unigroup cluster, with a brief reference to competing projects; and review what we know about the background, qualifications and international connections of the XMC team.

The economic rationale for China's push into memory

The memory market is huge. Memory semiconductors, used in personal computers, smartphones, and servers, are a key semiconductor segment and the second largest semiconductor market globally in terms of sales in between logic and analog semiconductors, totaling nearly $80 billion in 2015[30]. By 2019, the memory market is projected to have reached $ 119bn, or 30% of global semiconductor market.

But this is a market with two very different market segments: DRAM is in secular decline, since prices are falling faster than bit growth. By contrast, bit growth for 3D NAND flash is faster than the price decline. As a result, 3D NAND products are expected to gain market share relative to the current best practice 2D NAND flash memories.

The DRAM market is highly concentrated – the three industry leaders control almost 95% of the market (with Samsung alone commanding more than 40%)[31]. Late entry into such a highly concentrated market will come at a very high cost. By contrast, the current 3D NAND market is

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[29] On Korea, see Kim Linsu, 1997, *Imitation to Innovation. The Dynamics of Korea's Technological Learning*, Harvard Business School Press, Boston/Mass.; and Ernst, D., 1994, *What are the Limits to the Korean Model? The Korean Electronics Industry under Pressure*, The Berkeley Roundtable on the International Economy (BRIE), University of California at Berkeley:129 pages.

[30] http://www.semiconductors.org/news/2016/02/01/global_sales_report_2015/global_semiconductor_sales_top_335_billion_in_2015/

[31] According to J.M. Blair classic analysis (Blair, J.M., 1972, *Economic Concentration*, Harcourt Brace and Jovanovich, New York), the three industry leaders have established a tight oligopoly, while Samsung alone comes close to being a global monopolist.

less settled – while Samsung again dominates with almost 41% of total 3DFlash production, its much smaller competitors (Micron/Intel; Toshiba/Sandisk; Cypress/Spansion; and SK Hynix) have all developed different but attractive 3D-NAND technologies. As we will see, this might facilitate China's access to core technologies.

What might be China's comparative advantage?

China's massive efforts to upgrade its manufacturing industry will create a huge demand for sophisticated servers, where memory, especially 3D NAND flash memory will be critical. Main application markets will include automotive, data centers, and mobile platforms (IoT)[32]. This huge market has already attracted massive foreign investment, with the result that China is emerging as a global memory cluster: Samsung's main 3D NAND fab is in Xi'an; SK-Hynix has a DRAM fab in Wuxi; and Intel is building out its Dalian fab to build 3D NAND and has packaging and test in Chengdu. China's leadership has decided that it wants to participate in this new "memory rush".

Industry experts emphasize that China may well reap latecomer advantages, as it is moving directly into 3D NAND without ever having invested in 2D NAND. In contrast, Samsung and other players in the NAND market face legacy costs, due to their massive investments in earlier 2D NAND technology. In addition, next-generation disruptive memory technologies may well provide additional opportunities for China's catching-up efforts. For instance, MRAM chips built with spin transistors are expected to be faster, more powerful, and may have other novel properties that traditional memory do not have. Or take 3D XPoint, a new memory technology announced by Intel and Micron in July 2015 which is expected to outdo 3D NAND with improved durability and much faster operating speeds.

China's efforts to obtain core technologies

But where would China access the required core technologies for the design and fabrication of 3D NAND memory semiconductors? **Tsinghua Unigroup** tried to make a memory technology arrangement with **SK Hynix** and also with **Toshiba**, neither of which have come to fruition[33]. However, a partnership with Spansion (a former joint venture between AMD and Fujitsu) has brought an important breakthrough[34]. In June 2014, XMC announced its first working chip for Spansion's 32nm memory technology. In May 2015, 32-layer 3D NAND flash memory chips were successfully tested and verified for 40nm process technology[35]. Drawing on a $ 200 million investment, these chips were jointly developed, on the back of multiple licenses and IBM patents. It is unknown, how these investments were shared among the partners, but it is plausible to assume that the Chinese side may have shouldered the larger burden.

[32] The big growth will be in multi-chip modules especially for solid state disk (SDD), but also smartphones, datecenters, IoT. Cloud computing datacenters will still need hard disks (HDD), but they need the higher performance of 3D NAND for big data analytics.

[33] For instance, SK Hynix has rejected an investment offer from Tsinghua Unigroup to buy 20 percent of SK Hynix for about $5.3 billion on condition that the company built a wafer fab in China to make NAND flash memory. http://www.eetimes.com/document.asp?doc_id=1328353

[34] In December 2014, Spansion was merged with Cypress Semiconductors, based in San Jose,CA.

[35] Currently, volume production is in 32-layer NAND flash, with 48-layer starting, and 64-layer expected to reach production in a couple of years.

In the end, what matters is that XMC has been to learn key ingredients of 3D NAND design and process technology. This cooperation culminated in February 2016, when Cypress (the owner of Spansion) signed a 3D NAND development and cross licensing agreement with China's XMC. XMC brings cash and Cypress/Spansion contributes core NAND IP. Industry insiders expect that XMC will have a 48 layer 3D NAND chip qualified by the end of 2017 with volume production expected to start in 2018.[36]

On July 26, 2016, it was announced that Tsinghua Unigroup has acquired control of XMC[37].Tsinghua Unigroup Chairman Zhao Weiguo will be president of a new holding company for XMC called **Yangtze River Storage Technology Co**. Tsinghua Unigroup will own more than 50% of Yangtze River Storage, with other stakes held by the national chip fund and a fund backed by the Wuhan city government. Strengthened by Tsinghua Unigroup's acquisition, the combined group has proposed to license 3D NAND technology from Micron. Under the proposed Tsinghua/XMC-Micron cooperation, Micron would receive licensing fees and a portion of memory production capacity from Tsinghua/XMC. Such a deal would be highly attractive for Micron. Micron needs the money, as its DRAM revenues are falling[38]. Micron also needs more production capacity to compete with rivals including Samsung Electronics, SK Hynix and Toshiba which are all ramping up their 3D NAND flash capacity[39].

The above deal indicates that Tsinghua's acquisition strategies are becoming more sophisticated. It seems that Tsinghua has learnt from earlier failed acquisitions that were blocked by the CFIUS. While Tsinghua claims that financial objectives are at the center, the real purpose is to license critical 3D NAND technology. Tsinghua's strategic motto now seems to be: *"If you can't buy out firms that have the technology, then license their IP."* In short, Tsinghua's approach is now gradually adjusting to international best practice techniques of technology acquisition. While US technology export restrictions still might act as a spoiler, it is unlikely that it will in the future prevent any longer China from acquiring and absorbing key technologies in the memory semiconductor space.

The current status of the Wuhan XMC-Tsinghua Unigroup cluster and competing projects
Wuhan Xinxin Semiconductor Manufacturing Corporation (XMC) has had a bit of a checkered history, originally as a subsidiary of SMIC. Since 2013, XMC has been fully independent.

The selection of the Wuhan XMC fab cluster was primarily political, and demonstrates how difficult it is to give greater prominence to market forces, i.e. opportunity costs and return-on-investment. Wuhan has special connections to MIIT's Miao Wei (who was Wuhan former Mayor). After intense struggles among diverse stakeholders, Wuhan was selected and will be funded with up to $ 24 billion by the **National IC Industry Investment Fund**, the **Hubei IC Investment Fund**, the **China Development Bank's Development Fund** and **Hubei**

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[36] http://blogs.barrons.com/techtraderdaily/2016/05/06/lam-applied-could-enjoy-chinas-booming-fab-spend-but-not-forever-says-citi/

[37] Dou, Eva, 2016, "Tsinghua Unigroup Acquires Control of XMC in Chinese-Chip Deal; Developing capability to produce memory chips is a priority for Beijing's economic planners", WSJ, July 26.

[38] Micron may be facing $ 9billion of net debt, and there are rumors that Intel could provide a much-needed cash injection ("How Micron Tech Could Be Saved by Intel, *Barron's*, May 12, 2016)

[39] http://www.theregister.co.uk/2016/07/11/china_rush_3d_nand_micron/

Technology Investment[40]. In addition to the government-led funds, Semiconductor Manufacturing International (SMIC), and two RMB Equity Investment Funds (Hubei Science & Technology Investment Group and Hua Capital) will also participate in the project.

According to Simon Yang, the CEO of XMC, "XMC asked for $15B, but they were told to take $24B on the basis that if they were going to be serious about being a world leader then they needed to match the world leaders' investment."[41] Yang acknowledges that implementing the $24 billion Wuhan project will come at a high cost. He expects that XMC will lose a huge amount of money for three to five years, before reaching the break-even point. Few other companies, with the possible exception of Samsung, Google or Apple, could afford to burn that much money.

All the physical conditions are in place to enable a rapid capacity expansion. XMC has enough land on its campus for six 300mm wafer fabs. The site has enough space to build two additional 2-line megafabs, each with a capacity of up to 100k wafers per month. XMC at present produces 20,000 wafers of NOR flash per month. Monthly wafer production (mostly of 3D NAND) is projected to reach 300,000 in 2020 and 1 million in 2030. Much of the $24 billion project budget will be spent on equipment, so Applied Materials and Lam Research in the US , but also Europe's ASML will greatly benefit. "Foreign firms are intrigued, concerned and excited, all of it at the same time."[42]

To realize such a massive expansion, XMC will have to increase headcount by a factor of 10. For the extremely capital-intensive foundry business, labor costs are less of an issue. For XMC, labor costs are estimated to account for between 5 and maximum 10% of total costs. According to Yang, XMC's CEO, "perhaps a Chinese workforce can be hired more cheaply than in rival foundry locations, yet it provides but a small advantage when it comes to cost-efficiency. And even that advantage could soon be gone, because Chinese labor today costs three times more than that in many other developing countries."[43]

The real human resource bottleneck is to recruit and retain top talent, in order to be able to establish strong innovation capabilities. XMC has the deep pockets needed to compete in the global market for the best and most experienced 3D NAND specialists. A brief review of the background, qualifications and international connections of the XMC management team shows that, at least in this industry, China's capacity for global knowledge sourcing is alive and well.

For instance, Dr. Simon Yang, President,CEO, is a veteran semiconductor industry executive, with previous senior management positions at SMIC, Chartered Semiconductor （now Global Foundries） and Intel. He received his PhD in Materials Engineering at Rensselaer Polytechnic Institute （RPI), and holds more than 20 patents. Dr. Feng Hong, EVP,COO, has served various engineering and management positions in Intel, GSMC, Chartered and NXP, and has received his PhD in Materials Science and Engineering at North Carolina State University. Dr.

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[40] http://www.theregister.co.uk/2016/04/11/chinese_contract_chip_manufacturer_building_3d_nand_fab/
[41] Simon Yang, CEO of XMC, presentation at CASPA event ",Memory, The Turning Point of China Semiconductor", April 9, 2016: http://www.caspa.com/events/symposium/event-list/56f092b48c14d4e571c8bb53
[42] Phone interview with China-based industry expert, July 20, 2016, who requests anonymity.
[43] XMC CEO Simon Yang's Semicon China 2015 opening keynote, quoted in http://www.techdesignforums.com/blog/2015/03/17/china-foundry-outlook/.

Michael Chen, EVP,CBO, has held senior management positions in multiple NSDQ-listed companies in the U.S, like Pericom and Lattice, and has been Chairman of CASPA (Chinese American Semiconductor Professional Association). He received his MS in Electrical Engineering from The Pennsylvania State University. Finally, Dr. Shaoning Mei, SVP of Strategic Technology and CTO, has held senior management positions Huahong NEC, IBM, Philips and NXP. He received his PhD in Physics at Rensselaer Polytechnic Institute （RPI).

4. Cooperation or Zero-Sum Game? Implications for international firms and the global semiconductor industry

There are widespread concerns both in the US and across Asia that China's ambitious semiconductor industry strategy may disrupt markets and value chains, and challenge incumbents in this important industry. In the US, the **International Trade Administration** for instance argues that "China's opaque policies and unprecedented, state-led investment to develop an indigenous semiconductor industry … create medium and long-term uncertainties for U.S. industry prospects in the Chinese market."[44] For the **U.S. Semiconductor Industry Association**, "…[s]ome of these policies have the potential to: (1) force the creation of market demand for China's indigenous semiconductor products; (2) gradually restrict or block market access for foreign semiconductor products as competing domestic products emerge; (3) force the transfer of technology; and (4) grow non-market based domestic capacity, thereby disrupting the fabric of the global semiconductor value chain."[45]

Unease is also widespread in Japan, Korea, and Taiwan that the new competition from China's semiconductor industry might challenge established strong positions of their leading companies. For instance, Taiwan's IC design industry expects that China will catch up with the likes of MediaTek in less than two years[46]. On the other hand, larger global industry leaders seem to be betting their future on the success of China's policies. Examples include Taiwan's TSMC, the global leader in IC foundry fabrication; and Samsung Electronics, the integrated global industry leader in IC fabrication and mobile devices.

Leading US semiconductor firms seem to acknowledge that China's rise in this industry will continue. Instead of sitting by and playing a reactive game, leading semiconductor companies like Intel or Qualcomm are betting their future on the success of China's policies. Intel, for instance, now depends on China for one-fifth of its revenues, while Qualcomm relies on the China market for nearly half of its income. Examples include Intel's substantial investment in Spreadtrum (one of China's leading IC design firms), and Qualcomm's investment in China's leading IC fabrication company, SMIC.

In fact, U.S. and other foreign firms are quite explicit that they might accede to Chinese demands to transfer technology and form joint ventures with its firms, if only they could expand or at least

[44] International Trade Administration, *2016 Top Markets Report Semiconductors and Semiconductor Manufacturing Equipment Country Case Study China*, Department of Commerce, Washington, D.C.: page 1.

[45] Goodrich, J., 2016, *China's 13th Five-Year Plan Opportunities & Challenges For the U.S. Semiconductor Industry*,
Written Testimony Prepared for the U.S. – China Economic & Security Review Commission April 27, 2106 Hearing on China's 13 th Five-Year Plan: page 114.

[46] Yen, Patty, 2016, "Taiwan's IC Design Sector. Ready for Chinese Investment?" *CommonWealth Magazine,* Taiwan, *April 08, 2016 (No.594)*, http://english.cw.com.tw/article.do?action=show&id=15075

sustain their share of the China market. Among the most enthusiastic U.S. supporters of China's ambitious semiconductor strategy are leading equipment vendors like Applied Materials and Lam Research who are bound to receive massive orders. The same is true for ASML, the largest supplier in the world of photolithography systems for the semiconductor industry, based in the Netherlands. Equally supportive of China's policies are leading providers of EDA (electronic design automation) tools and software, such as Cadence, who are deeply involved in most stages of China's semiconductor industry strategy.

In short, leading global semiconductor companies have decided to help China grow its own domestic industry in exchange for short-term market access. This raises the question to what degree foreign companies might act as an amplifier of China's policies, and whether foreign firms in some cases may actually provide more effective support than the Beijing government in expanding China's semiconductor industry. Most of the key players in the global semiconductor industry in fact are all actively searching for ways to invest in China and to expand through partnerships and M&A. While their intention may be to keep these collaborative arrangements restricted to older-generation technologies or to market segments where their position is eroding, they often discover that Chinese partners have become more sophisticated in their demands and negotiation techniques.

In the current US election year, however, protectionist policies are regaining support that would seek to roll back China's rise as an economic power. While the focus primarily is on exchange rates and the control of foreign direct investment and technology, there are also those who want to exclude China from the global semiconductor value chain. For instance, during the *U.S. – China Economic & Security Review Commission* April 27, 2106 Hearing on China's 13 th Five-Year Plan, Commissioners repeatedly criticized the **Semiconductor Industry Association's** plea to integrate China into the global semiconductor value chain as detrimental to US interests. Based on the evidence presented in this paper, is difficult to think of a more disastrous strategy.

Cooperation rather than zero-sum game would also be in China's interest. While China's semiconductor policy may gradually improve China's position, the US in particular remains far ahead as a market and technology leader in this industry. In 2015, US firms controlled more than 50% of global sales in semiconductors, and they continue to have a dominant share of the industry's essential patents and intangible innovation capabilities.[47] In the same year, 56.2% of the huge China semiconductor market was held by US firms.

Given such an *asymmetric* industry structure, it is hard to see how a Zero-Sum Game scenario could be a preferred option for China's leadership. At least vis-à-vis the dominant US, China can only move ahead if it retains some form of cooperation. For China, an important objective of such cooperation would be reduce the danger that the US and other incumbents could continue their own earlier zero-sum games, where the world's leading semiconductor firms would benefit from China's large purchases, while China would "stay forever at the bottom of the chain."[48]

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[47] Semiconductor Industry Association, *2016 Factbook,* March 2016, http://blog.semiconductors.org/blog/the-2016-sia-factbook-your-top-source-for-semiconductor-data

[48] Wei Shaojun, "Is China's IC development a threat to the world?", presentation at the *2016 China (Shenzhen) IC Innovative Application Summit*, June 23, 2016, quoted in: Zhao, F., "China's IC Industry: 'Don't Let World Bully Us'", *EETimes*, August 2, 2016.

Unfortunately, there are signs that some stakeholders in China's semiconductor strategy might be trying *to do too much at once*. Rather than carefully selecting strategic priorities, as Japan and Korea have done, there is a tendency to race ahead *simultaneously* in equipment, materials, foundry, IC design, memory, and compound semiconductors. The extraordinary size of China's economy might provide greater space than in Japan and Korea for such a broad brush approach. Yet, in the fast-moving and highly unpredictable semiconductor industry, a *"too much at once"* strategy might well result in a *zero-sum scenario* that could produce more losers than winners, especially among Chinese firms. This might inflict major damage on China's ambitious plans. If China would insist on trying to do almost everything across the semiconductor value chain, this might ultimately lead to diffuse and weaken China's efforts. Chinese semiconductor firms may then end up playing in "just okay" market segments with "me too' products, unable to compete globally.

However, in light of the high costs of such a "trying to do too much at once" approach, there is reason to assume that pragmatism might prevail. After all, an important insight of research on China's economic development is that "…[p]ragmatism has been a hallmark of China's reforms over the past thirty years, as Chinese leaders have not flinched from a realistic view of their challenges. They typically experiment with various approaches before deciding on the best ways to address major concerns."[49]

In short, there seems to be ample scope for enhanced cooperation between the two largest players in the global semiconductor industry. China's persistent innovation gap in a broad range of semiconductors implies that Chinese firms continue to need access to core technology from incumbents, both from the US and Asia, whether in terms of equipment, core components, software, or system integration. This implies that China's semiconductor industry push will create new markets for American firms and other global industry leaders (like Samsung or TSMC), provided they stay ahead on the innovation curve.

Implementing such *cooperation among (almost, but not yet) equals* faces many hurdles, such as finding the right balance between the protection of intellectual property rights and China's interest in technology diffusion. While incumbent industry leaders seek to retain the *status quo*, latecomers like China seek to adjust the old rules to reflect their interests. Progress toward adjusted rules of reciprocity should be possible, once the United States and China accept that while their economic and innovation systems are different, they are deeply interdependent.

China, for example, ought to acknowledge that the United States needs safeguards against forced technology transfer and potential overcapacity as a result of policies such as compulsory licensing, information security standards and certification, and restrictive government procurement policies. The United States, in turn, needs to acknowledge that Chinese firms feel disadvantaged by restrictions on Chinese foreign direct investment and on the export of so-called dual-purpose technologies to China. The United States also needs to address Chinese concerns (which are widely shared by other countries) about the unequal distribution of benefits under

[49]K. Lieberthal, *Managing the China Challenge: How to Achieve Corporate Success in the People's Republic* (Washington, DC: Brookings Institution Press, 2011), 7.

present rules of patent licensing, especially for essential patents in critical interoperability standards.

Institutions like the **World Semiconductor Council (WSC)** might provide a forum for developing a framework for such cooperation. There is no doubt however that the WSC framework needs further strengthening to include in particular concerns of smaller countries, like Taiwan and Korea, who seek to retain a place in the intensely competitive global semiconductor industry.

Hammering out such improved rules of cooperation would lay the foundations for a more dynamic global semiconductor industry that would benefit from increased innovation wherever it takes place, whether in Silicon Valley, Shenzhen or Beijing, Taipeh, Bangalore, Seoul, Tokyo, Moscow, Eindhoven, Louvain, or Cambridge, to name but a few of the many semiconductor innovation clusters.