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The Potential Impacts of the Made in China 2025 Roadmap on the Integrated Circuit Industries in the U.S., EU and Japan

Dan Kim and John VerWey

Abstract

The purpose of this working paper is to estimate the potential impact of the Made in China 2025 Green Paper on Technological Innovation in Key Areas: Technology Roadmap (2017) on integrated circuit (IC) producers in the United States (US), the European Union (EU), and Japan.[1] We attempt to clearly fill in the gaps of projection and consumption data in the scenario presented by the 2017 Roadmap and using the Green Paper's definition of consumption and production. In the first part of the analysis, we assume that the market growth, market share, and projections presented in the Green Paper as the baselines and compare them with other industry data. In part 2, we estimate integrated circuit (IC) production market shares for the U.S., EU, and Japan in both China and globally based on the assumptions made in part 1. In part 3, we estimate IC consumption shares in the US, EU, and Japan. We find that the goals imply a significant decrease in the competitiveness of the integrated circuit industries in the U.S., EU, and Japan, though this conclusion must take into account that the assumptions and logic of the Green Paper do not accurately reflect industry dynamics. Finally, we offer suggestions for future analysis.

[1] Note that an initial technology roadmap was released in 2015. An updated version was completed in 2017 and published in 2018. National Manufacturing Strategy Advisory Committee, Made in China 2025 Key Area Technology Roadmap, October 2015. Translation. http://www.cae.cn/cae/html/files/2015-10/29/20151029105822561730637.pdf; National Manufacturing Strategy Advisory Committee and China Academy of Engineering Strategic Consulting Center, Made in China 2025 Key Area Technology Roadmap (2017), Publishing House of the Electronics Industry, February 2018. Translation. http://www.cm2025.org/uploadfile/2018/0307/2018030814131234.pdf .

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Introduction

China has announced ambitious plans for the development of its semiconductor industry.[2] A recent report by the U.S. Trade Representative (USTR) found that "China's strategy calls for creating a closed-loop semiconductor manufacturing ecosystem with self-sufficiency at every stage of the manufacturing process – from IC design and manufacturing to packaging and testing, and the production of related materials and equipment."[3] The U.S. industry has also voiced concerns about the potential negative impact of China's plan on a globalized industry. The Semiconductor Industry Association (SIA) warned that some of these policy goals can: "(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."[4]

China's goals and implementing guidelines are articulated in three policy documents released in 2014 and 2015: The Guidelines to Promote a National Integrated Circuit Industry (the National IC Plan), Made in China 2025 (MIC 2025), and the Made in China 2025 Technical Area Roadmap. The National IC Plan, released in June 2014, specified a strategy of support for "national champion" firms to catch up with leading international competitors, leveraging investments by national and provincial entities under the auspices of a National Integrated Circuit Investment Fund to acquire critical technologies and construct advanced fabrication facilities.

Made in China 2025, which was released under one year after the National IC Plan, identified next generation information technology (and integrated circuits specifically) as one of ten sectors that China should endeavor to promote, with the goal being a commercially viable domestic manufacturing sector capable of producing products at cost and quality comparable to leading international firms.[5] In October 2015 a Technical Area Roadmap was released by a think tank operating under China's State Council that established non-binding goals for the next generation information technology sector to "develop the IC design industry, speed up the development of the IC manufacturing industry, upgrade the advanced packaging and testing industry, and facilitate breakthroughs in the key equipment and materials of integrated circuits."[6]

The Roadmap suggests that by 2020 China's semiconductor design and manufacturing capabilities should be one to two generations behind industry leaders and supported by a viable domestic supply

[2] For an overview of the globalized supply chain of the semiconductor industry, see: SIA and Nathan's Associates, Beyond Borders, 2016.
[3] USTR, *Section 301 Report*, 2017, 113.
[4] Goodrich, "China's 13th Five Year Plan," 2016, 6.
[5] U.S. Chamber of Commerce, *Made in China 2025*, 2017, 10.
[6] State Council, *MIC 2025 Technical Roadmap,* October 2015, 2.

chain of equipment, material and assembly, test and packaging suppliers.[7] By 2030 the roadmap specifies that "the main segments of the IC industry…reach advanced international levels."[8] In support of these projections, the Roadmap provides information about the size of the global IC market, the Chinese IC market, trends in production, and goals for industrial development by product.[9] In 2017 an updated Technical Area Roadmap was presented with new production and self sufficiency targets, all of which were revised upward (Table 1.).

Table 1. Semiconductor Production and Self Sufficiency Targets in 2015 vs 2017 Roadmaps

	2015 Roadmap Target	2017 Revised Roadmap Target
Domestic Industry Size by 2020	$85 billion	$140 billion
Domestic Consumption Supplied by Local Producers by 2020	49 percent	58 percent
Domestic Industry Size by 2030	$183 billion	$305 billion
Domestic Consumption Supplied by Local Producers by 2030	75 percent	80 percent

Source: USCC, "Economics and Trade Bulletin: January 2019."

Our analysis focuses specifically on the Made in China 2025 Green Paper (hereafter "the Green Paper") on Technological Innovation in Key Areas: Technology Roadmap (2017), particularly on its market assumptions and projections on IC production and consumption. We note that it is not the purpose of this paper to analyze the motivations or the likelihood of success of these broad goals, nor suggest government policies to respond to such goals. Industry analysts have highlighted the potential difficulties of achieving these goals, and the potential disruptions such efforts may have on the global industry.[10] While China's goals may significantly impact the industry's future, responses to these goals by other governments will also undoubtedly matter.

The object of this paper is quite simple: to put China's stated goals into context, by projecting their implications, *as if* these forecasted scenarios are realized. In so doing, we present a clearer picture of China's stated goals for its IC industry and its potential impacts on the global industry. In various parts, we also express criticisms of these goals in the context of industry market realities.

In part 1, we present China's stated goals as outlined in the Green Paper, using their benchmarks as a guide, and filling in the gaps with the latest available industry data. In part 2 we present the implications of these goals on the U.S., EU, and Japanese IC producing industries, both globally and in the Chinese market. In part 3, we present the implications for IC consumption in the U.S., EU, and Japan. We conclude by suggesting alternative methods and definitions to better analyze these goals.

[7] While China has seen some success in narrowing the gap between leading international firms and Chinese-headquartered companies (notably in integrated circuit design with Huawei's subsidiary HiSilicon and in foundry services with Semiconductor Manufacturing International Corporation (SMIC)), the Chinese semiconductor ecosystem continues to lag several generations behind that of international competitors across nearly all semiconductor sub-markets and industries.
[8] U.S. Chamber of Commerce, *Made in China 2025*, 2017, 65.
[9] State Council, *MIC 2025 Technical Roadmap,* October 2015, 1-4.
[10] IC Insights, for example.

As a guide to our analysis, we note that:

- For the purposes of this working paper, the terms "semiconductor" and "integrated circuit" are sometimes used interchangeably. Technically, integrated circuits are semiconductors that contain more than one transistor, while the term "semiconductor" can also refer to discretes (which contain only one transistor) and optoelectronics (which generate or sense light).
- Defining "production" in the semiconductor industry is complicated. In this analysis, "production" refers to front-end wafer fabrication: the process of depositing film layers that act as conductors, semiconductors, or insulators to create circuit patterns on wafers, removing select portions, repeating these steps, and then performing heat treatment, measurement, and inspection. Estimates from the Semiconductor Industry Association indicate that front-end fabrication contributes about 45 percent of a chips value.[11] It does not include back-end testing, assembly, and packaging, which only contributes about 10 percent of a finished chips value.[12]
- There are different types of integrated circuits (memory, logic, analog), some of which are easier or more complicated to produce. The Green Paper does not distinguish between types of ICs and we have followed its logic in making simplifying assumptions to inform the macro-estimates below. However, it is important to note that even if this maximalist scenario is realized, Chinese-headquartered firm production of certain types of ICs (such as GPUs, where Chinese firms trail industry leaders by 5-10 years) almost certainly would not come to be, because it simply is not possible to cultivate the human capital and develop the intellectual property portfolio necessary to produce (design, manufacture, package/test/assemble) fully "Chinese" chips in the Green Paper's timeline.

Part 1: The Green Paper baseline scenario for the Global and Chinese IC industries

First, we create the baseline for our analysis by assuming that the market growth, market share, and projections presented for the global and Chinese IC industries in the Green Paper will be realized. Note that we are highly skeptical of the presented scenario, particularly in terms of China's production market share in the global and domestic consumption markets, as well as the growth projections.

In terms of the market growth for the global IC market, the Green Paper states that:

(1.1) "From 2016 to 2020, the [global integrated circuits] market will be about USD 336.1-400 billion, with a compound annual growth rate of 3.5%. From 2021 to 2030, the market will be about USD 400-537.5 billion, with a compound annual growth rate of 3%."

This is not an unreasonable assumption for the global IC market if current trends continue. However, subsequent projections that redirect production *and* consumption in the Chinese markets would likely disrupt the global market as a whole, putting such steady growth at risk for the global industry.

[11] SIA, *Beyond Borders*, 2016.
[12] See USITC 2017, Import Constraints special topics chapter for a discussion of these steps.

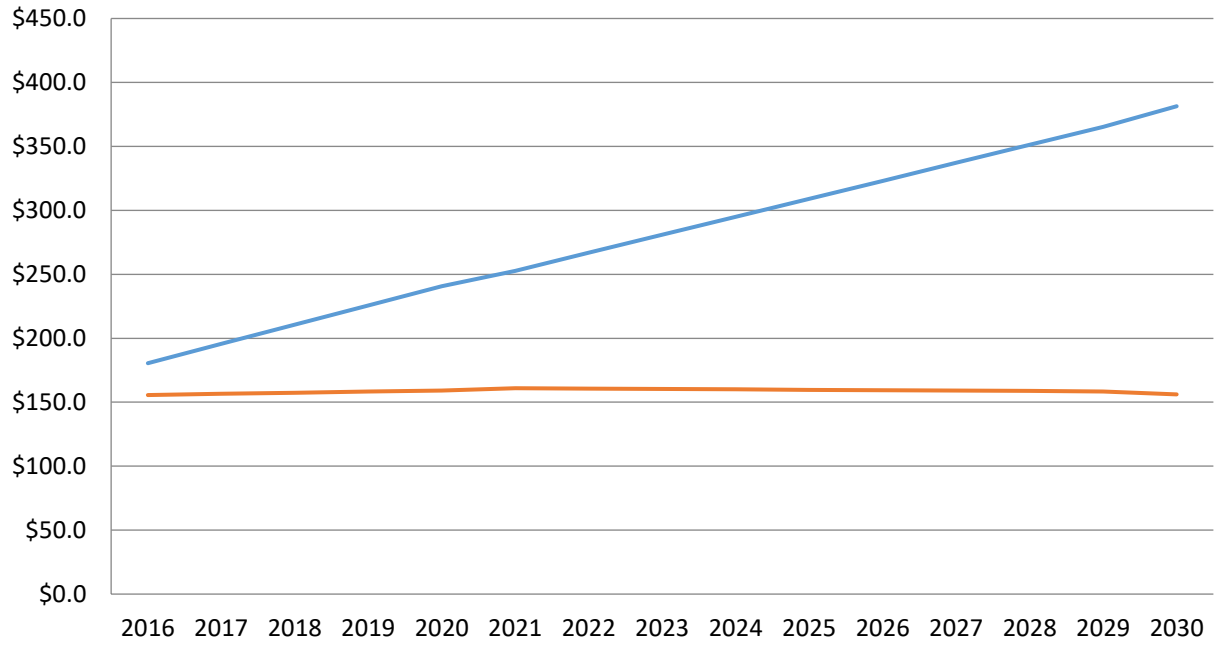
Furthermore, the Green Paper implies a linear growth by providing compound annual growth rates and does not take into account the cyclical nature of the IC market.[13]

For the China's IC market, the Green Paper states:

(1.2) "China's integrated circuit market from 2011 to 2015 was about USD 121.5-166 billion, with a compound annual growth rate of 6.4%. From 2016 to 2020, the market will be about USD 180.5-240.8 billion, with a compound annual growth rate of 5.9%. From 2021 to 2030, the market will be about USD 252.8-381.4 billion, with a compound annual growth rate of 4.2%."

This projection implies that China's domestic consumption market accounted for 53.7 percent of the global IC market in 2016, with the rest of the world accounting for the remaining 46.3 percent. Figure 1 captures this scenario and the growth projections.

Figure 1. The Green Paper's IC Market Growth Projection for China and the World



Source: Author calculations based on Green Paper projections

This baseline of 53.7 percent global IC consumption in China for 2016 is relatively high. Based on industry data, this baseline estimation *must* count IC sales in China for every purpose, including for intermediate consumption (consumer electronics assembly, for example) as part of export processing. This inclusion is consistent with some external industry estimates.[14] Such estimates include purchasing of intermediate goods for purposes of final goods assembly, for example, assembling smartphones or

[13] For example, the IC market is projected to decline in 2019 after a high growth year in 2018. The wide fluctuations of memory-related ICs is just one factor that contributes to IC market swings.

[14] PWC estimated China's semiconductor consumption to be at 58.5 percent of the world's total consumption. See PWC, "China's Semiconductor Market," 2017, https://www.pwc.com/gx/en/industries/technology/chinas-impact-on-semiconductor-industry/china-semiconductor-market.html.

computers in China, whether by Chinese firms (e.g. ZTE or Huawei) or foreign headquartered firms with facilities in China (e.g. Foxxconn, Samsung).[15] To be clear, this baseline estimation would be *much lower* if strictly domestic IC consumption is counted (i.e. consumption of ICs as part of final goods to be consumed within China).[16]

Building on this baseline, the Green Paper projects further growth of China's IC consumption:

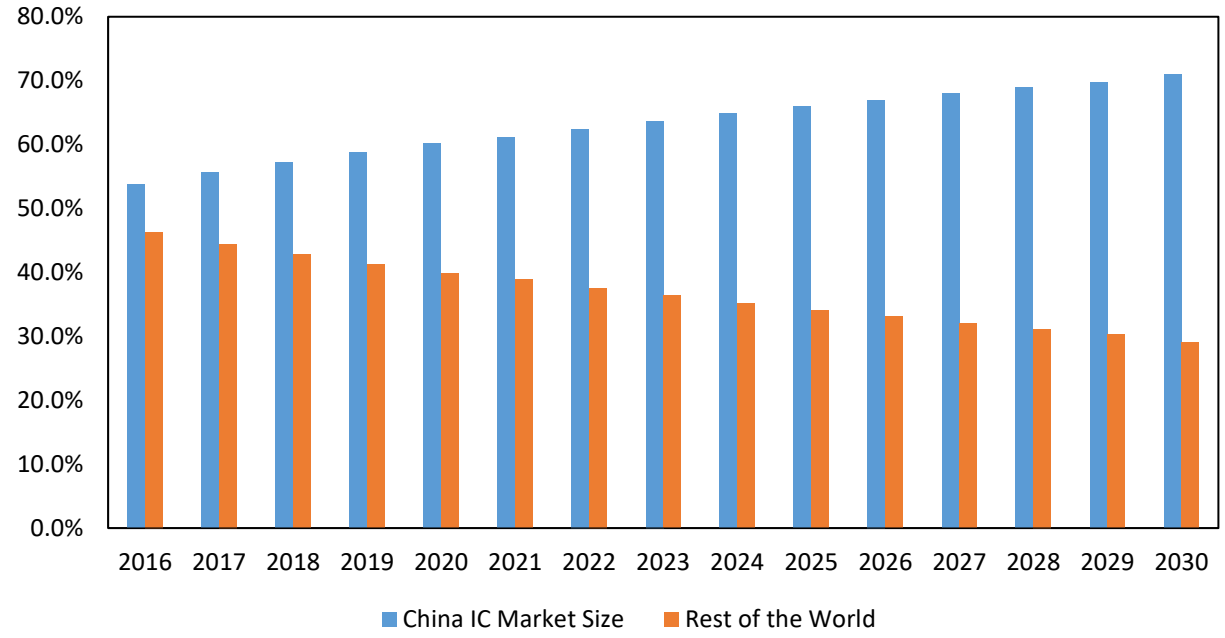
(1.3) "China' integrated circuit market in 2016 will account for 53% of the global market, becoming the world's largest integrated circuit market. It is expected to rise to 60% in 2020, and by 2030 will account for 70% of the global market."

This growth projection is highly enthusiastic and likely overvalued (Figure 2). Again, this *must* include purchases of intermediate goods for final assembly (otherwise, the rest of the world must have essentially stopped consuming electronics altogether). This growth projection therefore assumes that China's global competitiveness in final goods assembly containing ICs will increase until 2030, and/or domestic consumption of ICs in China is sufficient to offset any loss in electronic assembly competitiveness.

This is a highly enthusiastic forecasting. As labor and other costs in China rise, electronics assembly tasks are likely to be diversified to other locations, particularly in Southeast Asia.[17] It would take Herculean localization efforts, including through government policies, to force such increases to remain steady through 2030.

[15] McKinsey estimates that a majority of this consumption is by non-Chinese multinational firms.
[16] For an explanation, see appendix A, where two methods for estimating domestic IC consumption suggests Chinese domestic consumption share after correcting for export processing effects is about 20 percent of the world's IC market.
[17] This trend is already observable among intermediate good electronic manufacturers. See Torsekar and VerWey 2019 for more information.

Figure 2. The Green Paper's Global IC Market Share Forecast



Source: Author calculations based on green paper projections

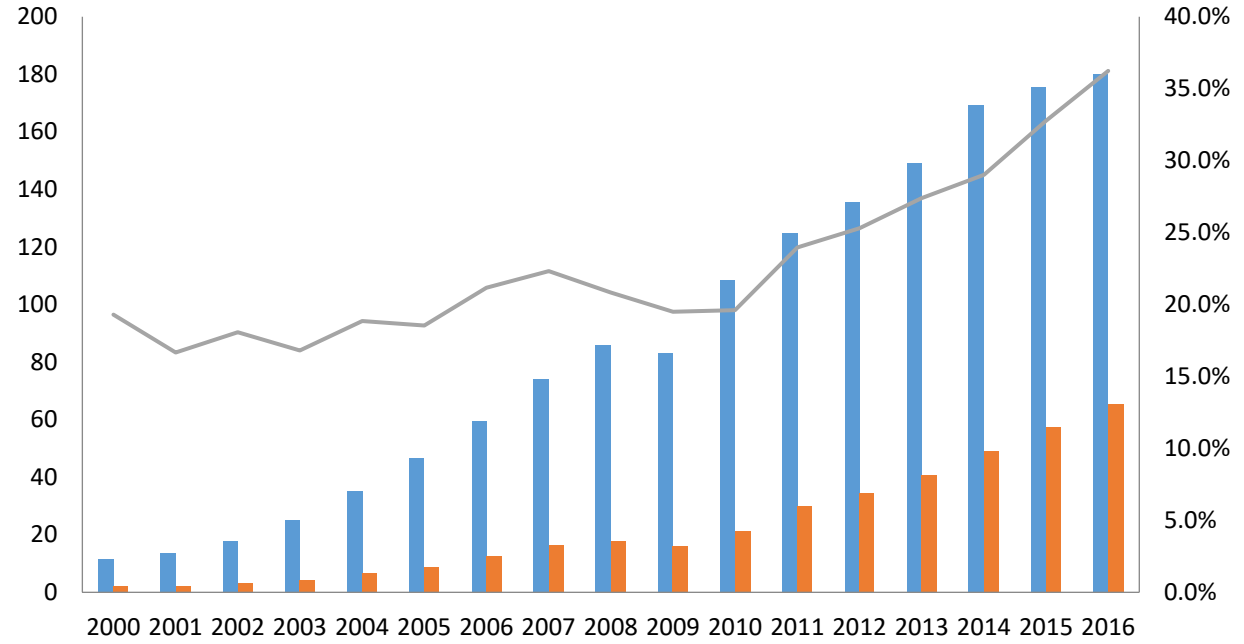
The Green Paper then estimates the baseline for China-based IC production and projections to 2030:

(1.4) "China's integrated circuit output is expected to reach USD 65.3 billion by 2016, meeting 33% of domestic market demand; in 2020 it is expected to reach USD 140 billion and meet 58% of domestic demand; in 2030 it is expected to reach USD 305.1 billion and meet 80% of domestic demand."

These figures are most likely derived from consumption and production figures reported by the China Semiconductor Industry Association (CSIA), but further assumptions must be made. PWC, for example, has also presented data on China's IC consumption and production in which production estimates of $65.3 billion match exactly with that of the Green Paper (Figure 3).[18]

[18] Both are likely derived from China SIA's estimations.

Figure 3. China's IC Consumption and Production ($Billions)



Source: PWC China report, 2017

The grey line in Figure 3 is a simple division between the two figures: (production/consumption). The 35 percent estimation in 2016 by PWC above matches closely with the Green Paper's 33 percent estimation. This may also be an overestimation. Using more recent data, IC Insights estimates that the Chinese IC market in 2018 totaled $155 billion, with China's IC production valued at $23.8 billion, making the production share of China's IC market 15.3 percent.

Taking into account the globalized IC and electronics supply chains, not all ICs produced in China are "consumed" in China.[19] However, the Green Paper asserts that all $65.3 billion ICs produced in China are consumed in China. Therefore, their projections must assume:

(1.5) All ICs produced in China are consumed in China in 2016 through 2030

Furthermore, firms from various countries produce ICs in China. The Green Paper does not distinguish production between Chinese firms and foreign-headquartered firms with facilities in China. If it had, it would show that a majority of ICs made in China are made by non-Chinese firms.[20] In 2018, major foreign producers accounted for at least a majority of China-based IC production, including by SK Hynix (South Korea), Samsung (South Korea), Intel (United States), and TSMC (Taiwan).[21] In fact, though China exported $43 billion in memory chips in 2018, this production was almost entirely done at factories

[19] U.S. International Trade Commission, Import Restraints 9, 2016.
[20] IEK estimates that Chinese firms revenue in 2017 totaled $24.7 billion, which includes more than the just IC production. As an upper bound, Chinese firms would account for about 37.8 percent of Chinese IC production. A more realistic estimate is about 15 percent based on China's total revenues as a share of global revenues (Source: Ting-Fang. China's Upstart Chip Companies Aim to Topple Samsung, Intel and TSMC, 2018.)
[21] IC Insights. "China IC Production Forecast to Show a Strong 15% 2018-2023 CAGR," 2019.

operated by non-Chinese headquartered companies.[22] If only production by China based firms is counted as China-based production, baseline production figures would be much lower.[23]

For the Green Paper figures to sum correctly, it must assume:

(1.6) All IC production in China, including ICs produced by non-Chinese headquartered firms, is counted as "Chinese production."

By not specifically defining domestic production as ICs fabricated by Chinese-headquartered firms, it leaves open the possibility that foreign firms can maintain the majority of IC production in China and China can still claim to meet the goals articulated in the Green Paper. These goals appear primarily about ICs made within a certain geography, regardless of company HQ location.

These goals remain highly optimistic. Practically, these goals could be met by Chinese firms building more IC fabs, and/or major foreign integrated device manufacturers or foundries (Samsung, TSMC, Intel, etc) locating new fabs in mainland China. While China has announced plans to increase their domestic firms' fabrication capacity, particularly among memory chips and the foundry services sub-markets, it is unrealistic to assume foreign firms will build out all or most of their fab capacity in China, particularly their most advanced technology nodes.

Another key assumption related to (1.5) and (1.6) is the following:

(1.7) None of the ICs made in China are consumed in markets outside of China

This assumption must also be true for the Green Paper scenario to be realized. If all China-made ICs are consumed in China, then none would be available for consumption outside of China. This is clearly not the case since non-Chinese firms manufacturing ICs in China are exporting them to other countries. For example, the U.S. Census Department's Related Party Trade database, which tracks U.S. imports from U.S.-headquartered firm's overseas subsidiaries, suggests that almost 60 percent of U.S. imports of semiconductors from China in 2016 were actually from U.S. firm facilities in the country.[24]

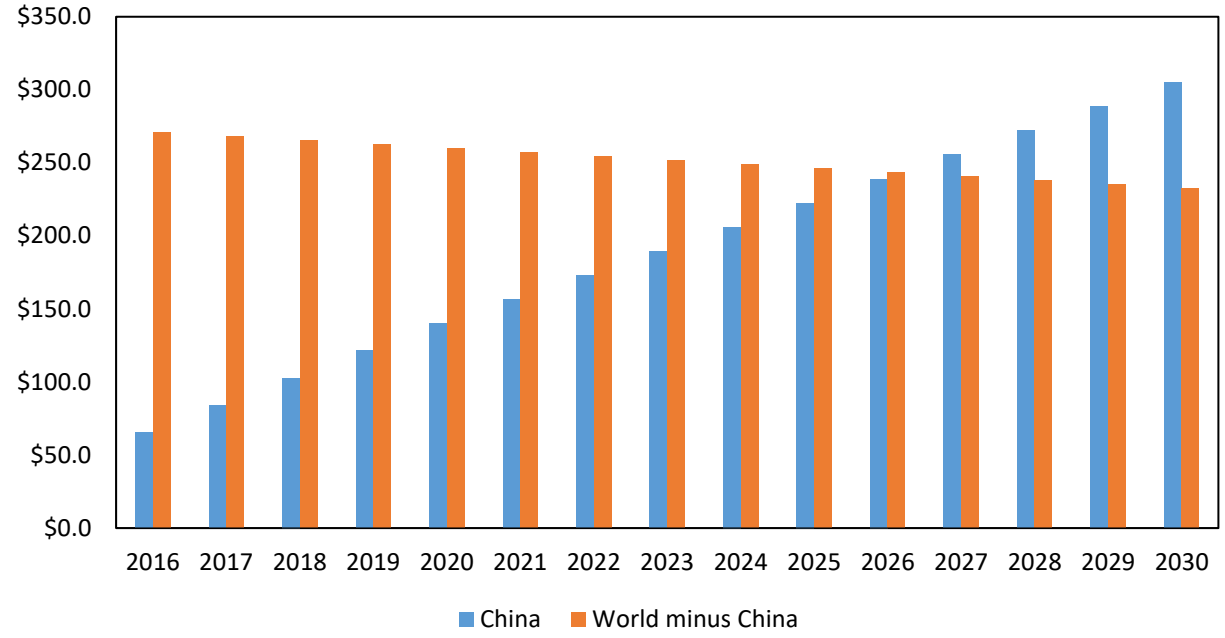
Despite these caveats, the final assumption for this part of our analysis is:

(1.8) The Green Paper's growth scenarios actually happen as portrayed.

The growth scenario that the Green Paper indicates that the majority of global IC production would take place in China by 2027 (Figure 4).

[22] GTA/GTIS. HS 854232, (accessed May 29, 2019); VerWey, "Chinese Semiconductor Industrial Policy – Prospects for Future Success," 2019 (forthcoming).
[23] China-based IC producing firms do not have significant production facilities outside of China.
[24] U.S. Census Bureau, NAICS Related Party Database (accessed October 30, 2018).

Figure 4. The Green Paper's Global IC Production Projection



Source: Author calculations based on Green Paper projections.

This is a wildly optimistic growth projection, where by 2030, China-based IC production would supply 80 percent of domestic consumption, and 57 percent of global consumption. Comparatively, IC Insights projects that even if China's current domestic investments were successful in their production, China-based IC production would represent about 23 percent of China's IC consumption and 10 percent of the global IC market in 2023.[25]

Part 2: Implied market impacts for IC production in the U.S., EU, and Japan

In this section, we use the baseline consumption and production market shares outlined by the Green Paper in part 1 to estimate their impact on production in the U.S., the EU, Japan, and the rest of the world.[26] While the scenarios in part 1 were based on the Green Paper projections, for this section we use available industry production data to fill in the data gaps, primarily regarding production in countries and regions outside of China, for which the Green Paper does not comment.

Part 1 makes clear that the Green Paper forecasts an accelerated increase of China's IC production competitiveness compared to the rest of the world between 2016 and 2030. The IC production changes shown in Figure 4 (above) captures this scenario for China and the rest of the world. Because the Green Paper does not make any projections for IC production or consumption in individual countries or regions outside of China, we make the following assumption to simplify the relevant projections:

[25] IC Insights. "China IC Production Forecast to Show a Strong 15% 2018-2023 CAGR," 2019.
[26] The rest of the world mainly consists of Korea and Taiwan, both of which have major IC fabrication capacity.

(2.1) The relative regional production shares outside of China stay consistent from 2016 to 2030, as China meets its targeted production goals.

To be clear, this assumption means that the relative production competitiveness of supplying regions outside of China *among each other* stays the same between 2016 and 2030, even as they collectively and individually lose competitiveness to China. That is, as China's domestic IC production and consumption increase, production and consumption outside of China decrease proportionally relative to their market shares (see Appendix B for an explanation of calculations). This projection is simplified by assumptions (1.5) and (1.7), where all China-based IC production is consumed in China and none is exported for external consumption. In our estimation, this assumption is not entirely unrealistic. There have been 97 integrated circuit wafer fabs closed or repurposed in the past 10 years and of that total 85 of these fab closures occurred in Japan, North America or Europe at a time when China's wafer production capacity growth has been the fastest in the world.[27]

The following assumptions are made to keep these projections consistent with the definitions outlined in the Green Paper (as explained in part 1):

(2.2) IC production within a region or country includes all IC production regardless of the producing firms' headquarter location.

(2.3) IC production value does not take into account the value of IC design or other fabless activities that may take place outside of the producing country/region

(2.4) IC production value is captured at wafer capacity level (200mm equivalents in our case), rather than the value of the ICs at individual wafer or fab levels.

These assumptions, which are necessary to make the projections in this section consistent with the Green Paper, can significantly overestimate the added value of IC production within a specific region. An IC designed in the U.S. by a fabless firm (e.g. NVidia), for example, can be produced outside of the U.S. by a foundry (e.g. TSMC). The design firm would capture a significant portion of the value of the IC, but by the Green Paper's logic, the geographical location of the foundry would capture all the added value.

Similarly, these assumptions can underestimate the added value of IC design and production by firms headquartered in a specific country by ignoring the globalized nature of the IC supply chain. This explains the difference between the market share of semiconductor industry revenue of U.S. based firms (about 50 percent of the global market in 2016) and the share of IC production capacity within the U.S. (about 13 percent of the global share in 2016).

It is important to stress that for the IC industry, production capacity within a geographic location is not necessarily a true reflection of country/regional level industry competitiveness. With that crucial caveat

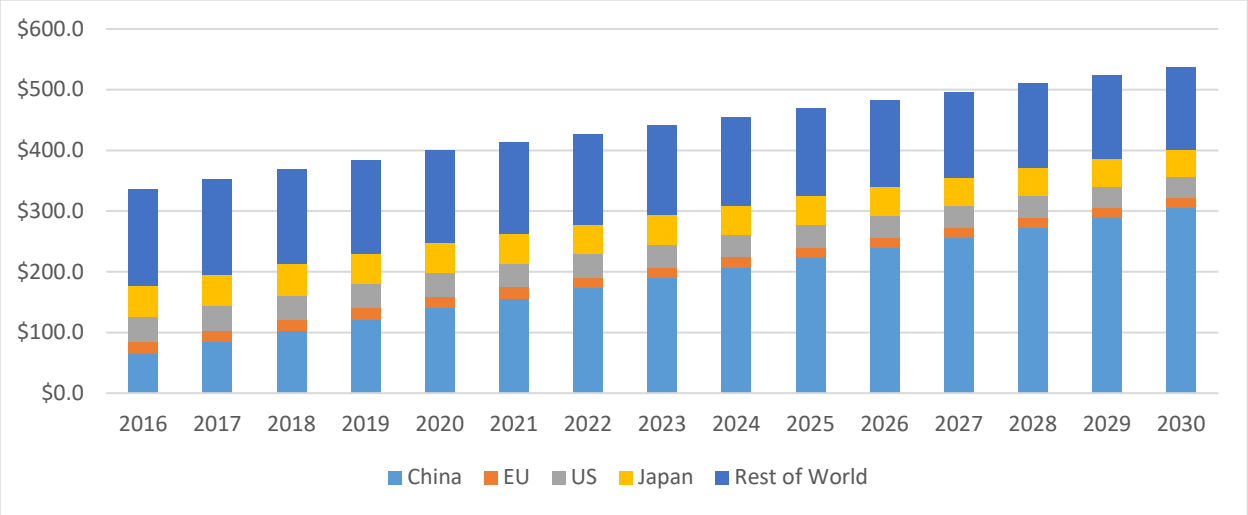
[27] IC Insights. "97 IC Wafer Fabs Closed or Repurposed During Past 10 Years," 2019; SEMI. "China Wafer Production Capacity Growth Fastest in World," 2019.

in mind, the following projections based on the Green Paper are presented in the remaining portion of this section: global IC market, IC market in China, IC market outside of China.[28]

The Global IC Market

For the global market, the Green Paper's scenario implies that IC production value in the U.S., the E.U, and Japan would each decrease at a compound annual rate of about 1.1 percent (Figure 5).

Figure 5. Forecast of Global IC Production by Location



Source: Author calculations based on Green Paper projections

The Green Paper projections imply that between 2016 and 2030:

- IC production in the U.S. would decrease from $40.7 billion to $34.9 billion;
- IC production in the EU would decrease from $19.4 billion to $16.7 billion;
- IC production in Japan would decrease from $51.9 billion to $44.6 billion.
- In contrast, IC production in China would increase from $65.3 billion to $305.1 billion.

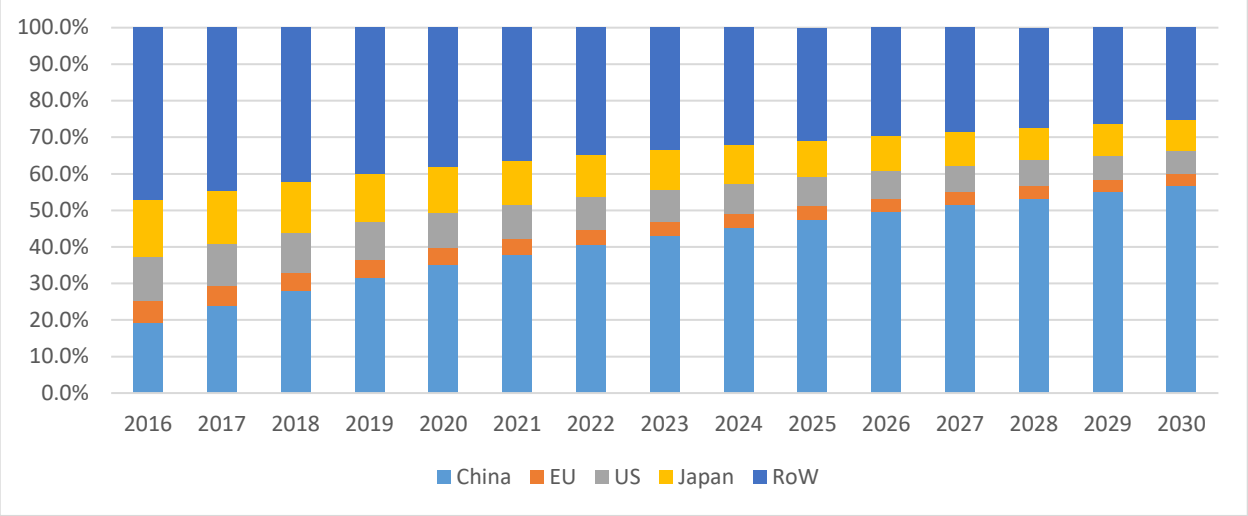
These projections have implications for the market shares of IC production by region (Figure 6).While China would increase its global IC production market share from 19.4 percent in 2016 to 56.8 percent in 2030, production market share from other countries and regions would decline significantly in the same time period:

- the production share for the U.S. would decrease from 12.1 percent to 6.5 percent;
- the production share for the EU would decrease from 5.8 percent to 3.1 percent; and

[28] Also note that the baseline market shares for the U.S., EU, and Japan do not align exactly with industry data, as they were re-sized to fit with the Green Paper's baseline. See Appendix B for more details.

- the production share for Japan would decrease from 15.4 percent to 8.3 percent.

Figure 6. Forecast of Share of the Global IC Market by Supplying Region/Country

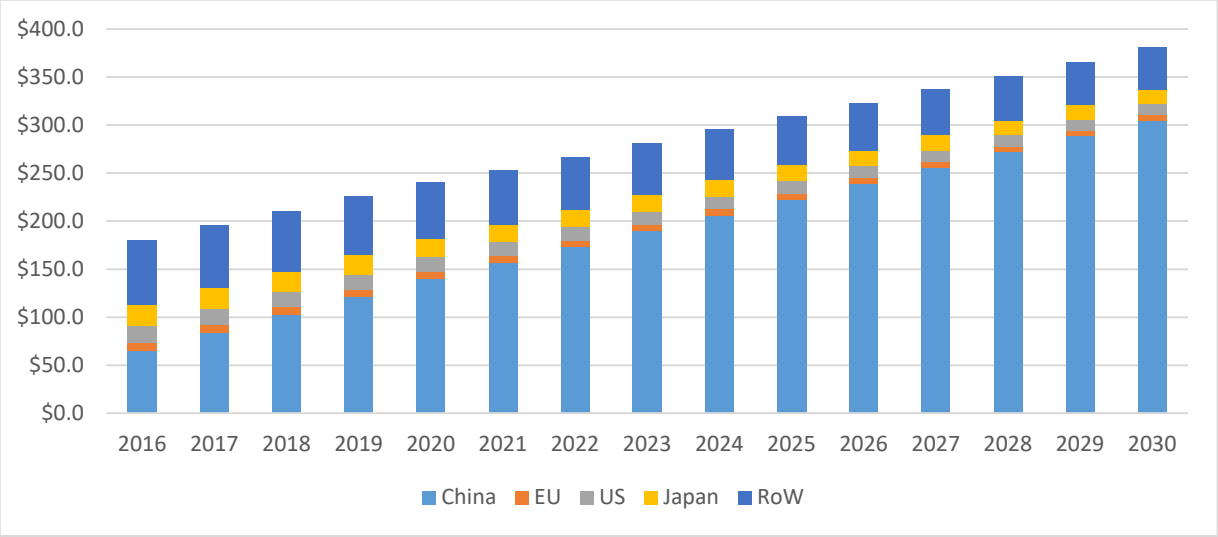


Source: Author calculations based on green paper projections

The IC Market in China

For the Chinese IC market, the Green Paper scenario implies that the value of ICs produced in the U.S., the EU, and Japan would each decrease at an annual rate of 2.9 percent (Figure 7).

Figure 7. Forecast of China's IC Market by Supplying Location



Source: Author calculations based on green paper projections

The Green Paper projections imply that from 2016 and 2030:

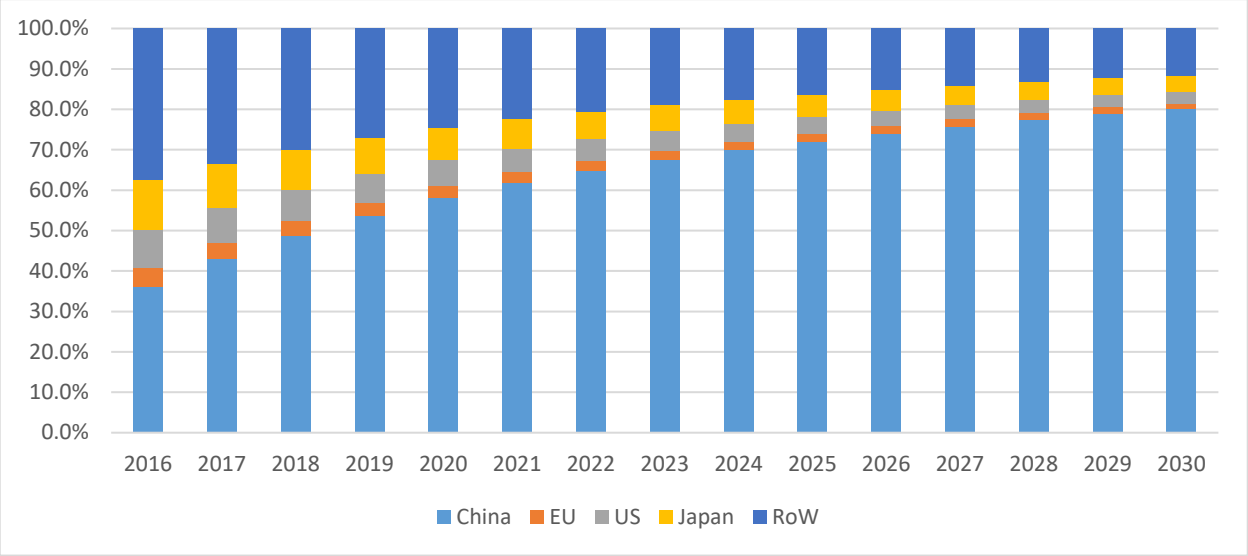
- the value of ICs produced in the U.S. and sold in China would decrease from $17.3 billion to $11.5 billion;

- the value of ICs produced in the EU and sold in China would decrease from $8.3 billion $5.5 billion;
- the value of ICs produced in Japan sold in China would decrease from $22.1 billion to $14.6 billion.
- In contrast, China-made ICs supplied to the Chinese market would increase from $65.3 billion to $305.1 billion.

These projections imply that ICs produced outside of China would quickly lose competitiveness to China-produced ICs within the Chinese market (figure 8). While China-produced ICs would increase their China IC consumption market share from 36.2 percent in 2016 to 80.0 percent in 2030, market shares for ICs made in other countries and regions decline significantly from 2016 and 2030:

- The market share of U.S. produced ICs for the China's consumption market would decrease from 9.6 percent to 3.0 percent;
- the market share for EU produced ICs would decrease from 4.6 percent to 1.4 percent;
- the market share for Japan produced ICs would decrease from 12.2 percent to 3.8 percent.

Figure 8. Forecast of Share of China's IC Market by Supplying Region

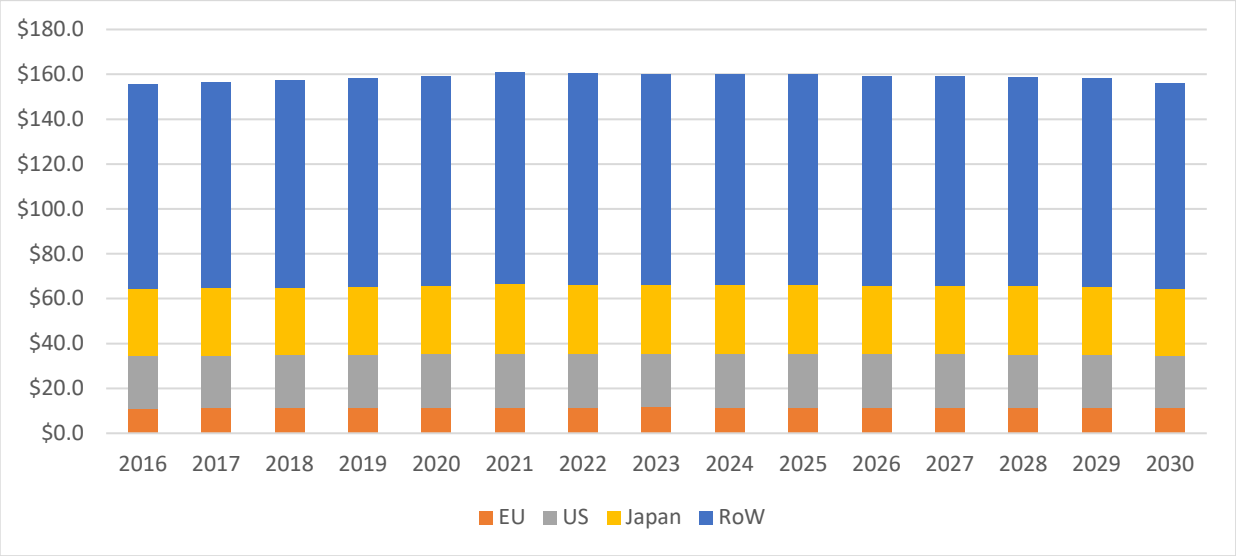


Source: Author calculations based on green paper projections

The Global IC Market outside of China

Meanwhile, for the IC market outside of China, the Green Paper scenario implies that the value of ICs produced in U.S., EU, and Japan would stay relatively constant (a compound annual growth rate of 0.023 percent, Figure 9). This implies that there would be almost no growth in the IC market outside of China.

Figure 9. Forecast of the Global IC Market (minus China) by Supplying Location

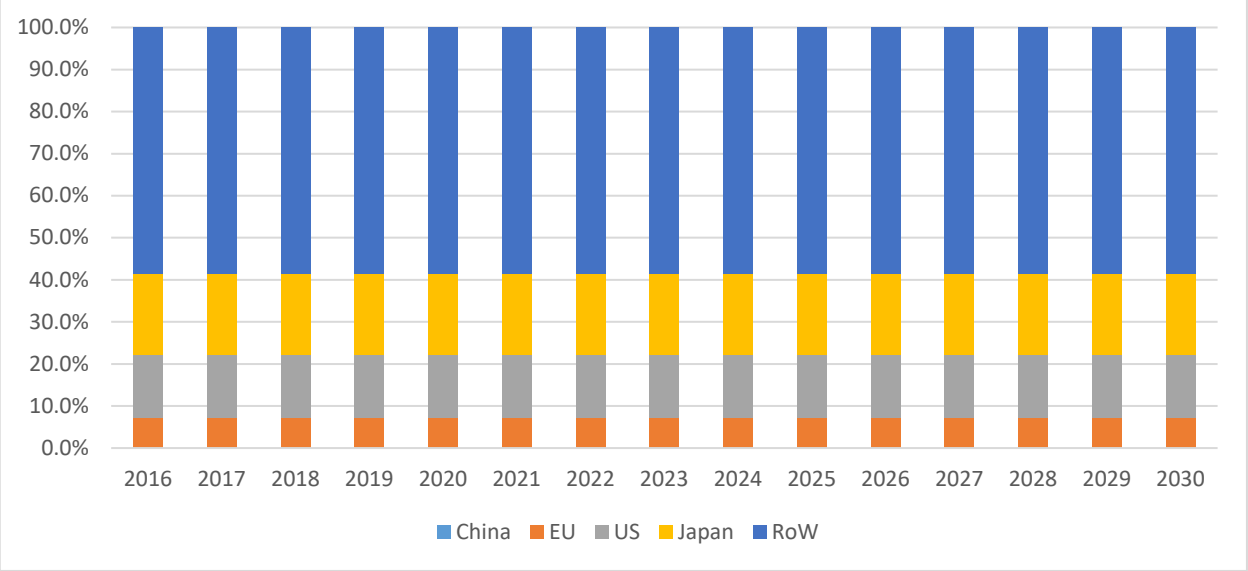


Source: Author calculations based on green paper projections

The value of ICs made in the U.S. and sold in the global market outside of China would be relatively unchanged from $23.4 billion in 2016 to $23.5 billion in 2030; ICs made in the EU sold in the global market outside of China would be relatively unchanged from $11.2 billion 2016 to $11.2 billion in 2030; ICs made in Japan sold in the global market outside of China would decrease from $29.8 billion in 2016 to $29.9 billion in 2030. As outlined in part 1, ICs produced in China would not be sold outside of the Chinese market.

The market share of IC production for the global market outside of China stays the same from 2016 to 2030 due to assumption (2.1). U.S.-produced IC market share is 15.0 percent; EU made IC market share is 7.2 percent; Japan made IC market share is 19.2 percent; and market share of ICs made in the rest of the world is 58.6 percent (Figure 10).

Figure 10. Forecast of the Share of Global IC Market (Outside China) by Supplying Region



Source: Author calculations based on green paper projections

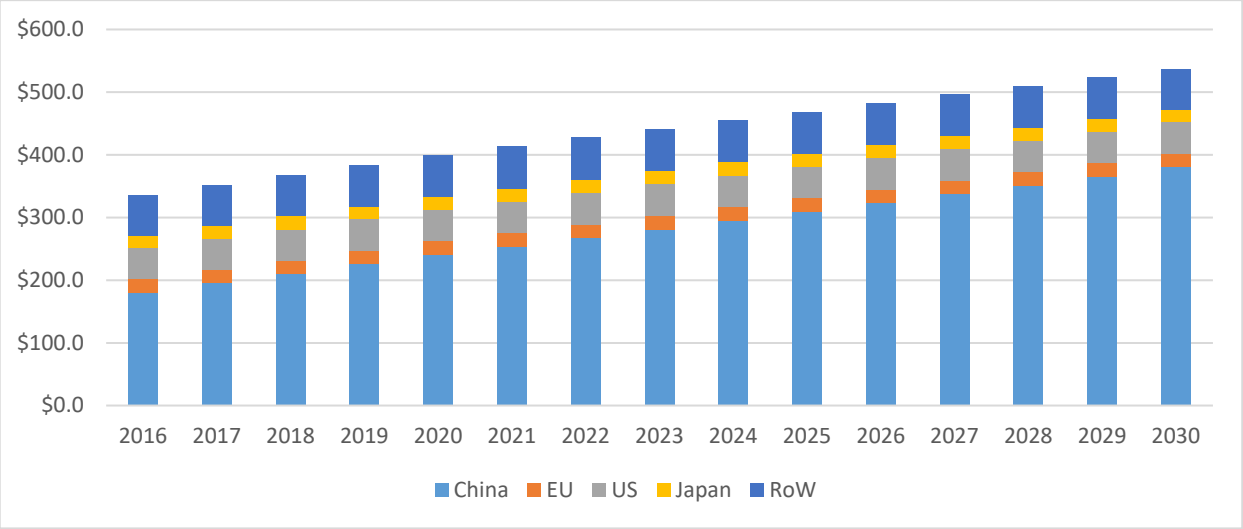
Part 3: Implications for IC consumption in the U.S., EU, and Japan

Increasing China's domestic IC production and domestic IC consumption are key parts of the Green Paper's projections. As explained in part 1, IC consumption in the context of the Green Paper includes purchasing ICs as part of assembly of downstream products, whether consumed domestically or exported abroad. These domestic goals are likely to influence IC consumption patterns outside of China. For this part of the analysis, we use a similar assumption about consumption share patterns as we did with production in part 2 (2.1):

(3.1) the relative regional consumption shares outside of China stay consistent from 2016 to 2030, as China meets its targeted consumption goals.

The Green Paper projects that worldwide IC consumption growth rate remains virtually unchanged from 2016 to 2030 with the exception of China, where consumption growth is projected to increase from $180 billion to $381 billion (Figure 11). We assume that the relative IC consumption shares in regions outside of China stays the same between 2016 and 2030. That is, as China's domestic IC consumption increases, consumption outside of China decreases proportionally relative to their baseline 2016 market shares (see Appendix B for an explanation of calculations).

Figure 11. Forecast of Global IC Consumption by Region ($B)



Source: Author calculations based on green paper projections

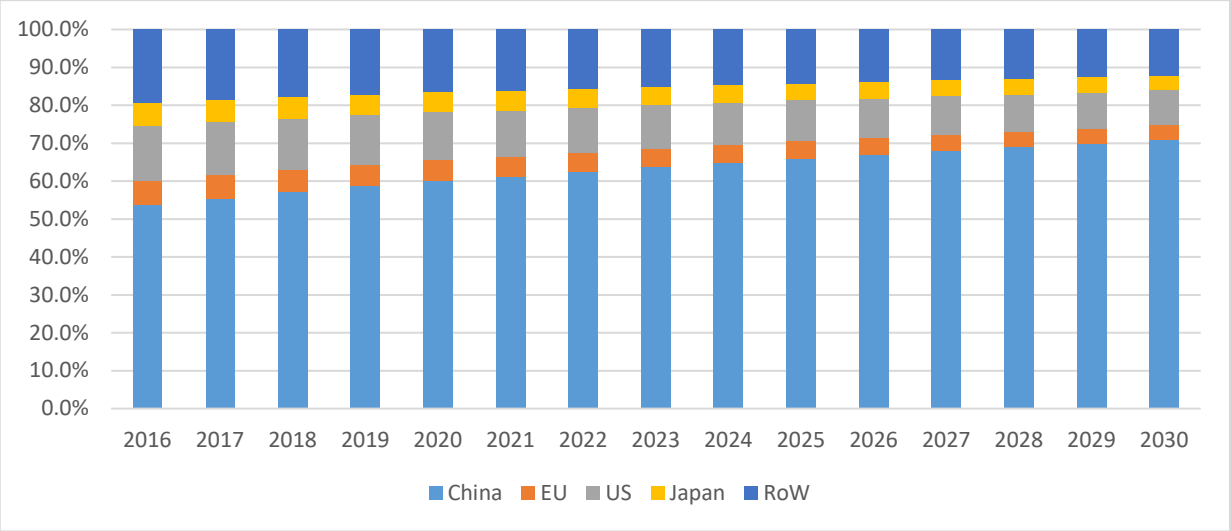
The green paper projections imply that IC consumptions increases slightly for all regions outside of China between 2016 and 2030:

- IC consumption in the U.S. increases slightly from $49.1 billion to $49.2 billion;
- consumption in the EU increases from $21.2 billion to $21.3 billion;
- consumption in Japan increases from $20.3 billion to $20.4 billion;
- consumption in all other regions increases from $65.0 billion to $65.2 billion.

The IC consumption share for China increases from 53.7 percent to 71.0 percent. Meanwhile, IC consumption shares fall for all other regions (Figure 12) between 2016 and 2030:

- The IC consumption share for the U.S. decreases from 14.6 percent to 9.2 percent
- the consumption share for the EU decreases from 6.3 percent to 4.0 percent;
- the consumption share in Japan decreases from 6.0 percent to 3.8 percent; and
- the consumption share for other regions decreases from 19.3 percent to 12.1 percent.

Figure 12. Forecast of Global IC Consumption by Region (% share)



Source: Author calculations based on green paper projections

The share of IC consumption is a partial indicator of the regional industry competitiveness of goods production that use ICs as enabling intermediate inputs. Such products could include a wide range of goods from information and communications technology products (smartphones, computers, etc.) and automotive electronics to heavy machinery. While changes projected in the Green Paper are likely to have potential implications for the supply chains of these downstream industries, we do not comment on such implications.[29]

Conclusion: A Caution About Assumptions

We approached this analysis to provide more clarity on the implications of China's efforts to support and increase their domestic IC industry as outlined in the Green Paper. Because the projections in the Green Paper require simplifying assumptions, as explained in part 1, we use comparable assumptions to project implications for the global IC market in parts 2 and 3. The result of this analytical exercise is perhaps obvious: if the Green Paper projections hold true, China would become the majority producer and consumer of ICs in the global market place, while other supplying countries and regions would experience sharp declines in relative industry competitiveness.

We have pointed out the weaknesses of assumptions and definitions presented in the Green Paper along the way to encourage caution in attempting to understand the stated goals of China's IC industry. The same caution must be applied to the conclusions of this analysis. The Green Paper projects major shifts in global IC production and consumption, but under highly questionable assumptions and highly optimistic growth projections. The Green Paper also assumes that firms headquartered in the U.S., EU, and Japan, many of whom are currently world-leading, will passively lose market share. Finally, the

[29] See SIA 2016, Beyond Borders for a potential "Galapagos island effect" of such a scenario.

Green Paper assumes a current level of competitiveness for China's IC industry that is not necessarily a reflection of reality.

Combined, these assumptions and growth projections are not an accurate reflection of current industry dynamics. While we have made efforts to provide more detailed implications of these goals for the U.S., the EU, and Japan, we caution that the analysis provided in this paper should be understood within that context. Just as China's efforts could be highly disruptive to the global market, reaction to their efforts can also prove disruptive. In addition, there are major firms headquartered in Taiwan and South Korea which would be impacted by this scenario which are not part of this analysis.

More nuanced analysis is required to better understand the impacts of China's efforts, which means departing from the assumptions and definitions of the Green Paper – an analysis we will attempt in forthcoming working papers. Specifically, the Green Paper does not capture the globalized nature of the IC supply chain where production location is not necessarily the main driver of industry competitiveness. IC design, fabrication, and assembly take place in discrete locations and the entire process frequently crosses multiple national borders from start to finish, with value added at each stage in production.

There is also some cognitive dissonance between the logic presented in the Green Paper and the overarching goals of Made in China 2025. As we noted, multiple leading international firms such as Intel (US), SK Hynix (South Korea), Samsung (South Korea), and TSMC (Taiwan) have notable operations in China. By considering any production that occurs within China's geographic borders "Chinese" production, the Green Paper's logic allows for a future in which the majority of Chinese IC production is still done by non-Chinese headquartered firms. This would undermine some of the knowledge transfer/industrial development goals articulated by Made in China 2025, allowing leading international firms to produce profitable, relatively low-value, integrated circuits for consumption in the Chinese market and reinvest those profits in their headquartered country to maintain international competitiveness in other regions and sub-markets.

The global IC supply chain is an interdependent ecosystem. Fabless IC firms do not have any production capacity and depend on contracting foundries' ability to invest in, and assume the risks associated with, enormous fixed costs of production. Still, these fabless firms capture a significant portion of the industry's revenue. Foundries with large production capacity (with no IC design capacity) depend on large economies of scale and customers (mostly fabless IC firms) from all regions for sustained survival in the market place. Integrated device manufacturers with capacity in both design and fabrication compete by spreading their supply chain as efficiently as possible to supply to their customers in all parts of the world. It is difficult to imagine fabless IC firms, foundries, or integrated device manufacturers that can survive by solely supplying from or to a particular region while making sufficient investments to keep up with the pace of innovation required to succeed in the industry.

With this in mind, we acknowledge and suggest further analysis to better capture industry characteristics. Specifically, we suggest the following analysis, some of which we will attempt in forthcoming working papers:

- Potential impact of China's IC plan with more industry-aligned definitions of consumption and production, adjusted production/consumption shares, and growth scenarios that better fit current industry dynamics.

- Potential impact of China's current and planned domestic IC investments in specific sectors, particularly the memories sector (NAND and DRAM in particular).
- An assessment of China's recent attempts to compete in the fabless IC design sector.
- Potential impact of China's IC plan on the Korea and Taiwan, two markets with fastest growing shares of IC production capacity.
- Potential impact of China's IC plan on upstream industries (semiconductor manufacturing equipment and materials suppliers) and downstream industries (electronics).

Bibliography

Goodrich, Jimmy. "China's 13th Five-Year Plan Opportunities & Challenges For the U.S. Semiconductor Industry," *U.S. China Economic and Security Review Commission*, April 27, 2016, https://www.uscc.gov/sites/default/files/Jimmy%20Goodrich_Written%20Testimony%20042716.pdf.

IC Insights. "China IC Production Forecast to Show a Strong 15% 2018-2023 CAGR," February 7, 2019, http://www.icinsights.com/news/bulletins/China-IC-Production-Forecast-To-Show-A-Strong-15-20182023-CAGR/.

IC Insights. "97 IC Wafer Fabs Closed or Repurposed During Past 10 Years," February 27, 2019, http://www.icinsights.com/news/bulletins/97-IC-Wafer-Fabs-Closed-Or-Repurposed-During-Past-10-Years/.

PriceWaterhouseCoopers. "China's Semiconductor Market: 2017 Update," 2017, https://www.pwc.com/gx/en/industries/technology/chinas-impact-on-semiconductor-industry/china-semiconductor-market.html.

National Manufacturing Strategy Advisory Committee, Made in China 2025 Key Area Technology Roadmap, October 2015. Translation. http://www.cae.cn/cae/html/files/2015-10/29/20151029105822561730637.pdf;

National Manufacturing Strategy Advisory Committee and China Academy of Engineering Strategic Consulting Center, Made in China 2025 Key Area Technology Roadmap (2017), Publishing House of the Electronics Industry, February 2018. Translation. http://www.cm2025.org/uploadfile/2018/0307/20180308141312234.pdf.

SEMI. "China Wafer Production Capacity Growth Fastest in World," January 7, 2019, http://www1.semi.org/en/china-wafer-production-capacity-growth-fastest-world.

Semiconductor Industry Association. "Beyond Borders: The Global Semiconductor Value Chain," May 2016, https://www.semiconductors.org/document_library_and_resources/trade/beyond_borders_the_global_semiconductor_value_chain/.

State Council of the People's Republic of China. "Notice of the State Council on Printing and Distributing 'Made in China 2025' (Chinese)," May 8, 2015, http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm.

State Council of the People's Republic of China. "The National Outline of the Development of the Integrated Circuit Industry Officially Announced (Chinese)," June 24, 2014, http://www.gov.cn/xinwen/2014-06/24/content_2707360.htm.

Ting-Fang, Cheng. "China's Upstart Chip Companies Aim to Topple Samsung, Intel and TSMC," Nikkei Asian Review, April 25, 2018, https://asia.nikkei.com/Spotlight/Cover-Story/China-s-upstart-chip-companies-aim-to-topple-Samsung-Intel-and-TSMC.

Torsekar, Mihir and John VerWey. "The East Asia-Pacific's Participation in the Global Value Chain for Electronic Products," March 2019, https://www.usitc.gov/publications/332/journals/east_asia-pacifics_participation_in_the_global_value_chain_for_electronic_products.pdf.

U.S. Chamber of Commerce. "Made in China 2025: Global Ambitions Built on Local Protections," March 16, 2017, https://www.uschamber.com/report/made-china-2025-global-ambitions-built-local-protections-0.

U.S.-China Economic and Security Review Commission. "Economics and Trade Bulletin: January 2019," January 11, 2019, https://www.uscc.gov/trade-bulletin/january-2019-trade-bulletin.

United States International Trade Commission. "The Economic Effects of Significant U.S. Import Restraints," September 2017, https://www.usitc.gov/publications/industry_econ_analysis_332/2017/economic_effects_significant_us_import_restraints.htm.

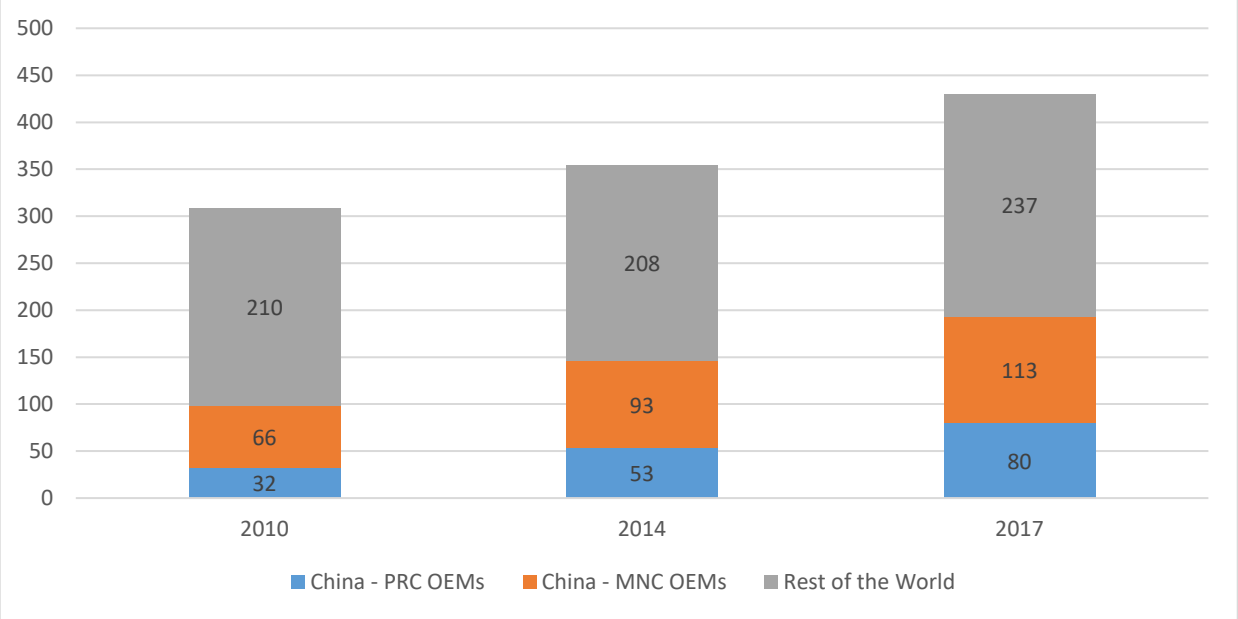
United States Trade Representative. "Section 301 Report into China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation," March 2018, https://ustr.gov/about-us/policy-offices/press-office/press-releases/2018/march/section-301-report-chinas-acts.

Appendix A: Alternative Methods to Calculate the Chinese IC Market Size

There are different ways to define China's IC market. As stated above, the method by the Green Paper defines China's "consumption" of ICs in a way that includes the purchases of ICs that are used as intermediate goods as part of assembly of final electronic goods that are ultimately exported. While most ICs are intermediate goods, this method overstates how many ICs are ultimately consumed within China rather than exported to another location for final use. We offer two methods to this calculation that accounts for this overestimation.

First, the IC market in China can be deconstructed into purchases by China based OEMs (e.g. Huawei), and non-China based OEMs (e.g. Apple). McKinsey provides an estimate based on data from IHS that a majority (59 percent) of ICs consumed in China were consumed by non-Chinese OEMs in 2017, while Chinese OEMs consumed the remaining 41 percent. As a global share, ICs purchased by Chinese OEMs totaled 19 percent of global ICs (Figure A.1).

Figure A.1. Share of Semiconductor Consumption in China and Rest of World



Source: McKinsey & Company and IHS; PRC is People's Republic of China; MNC is multinational corporations; OEMs is original equipment manufacturers.

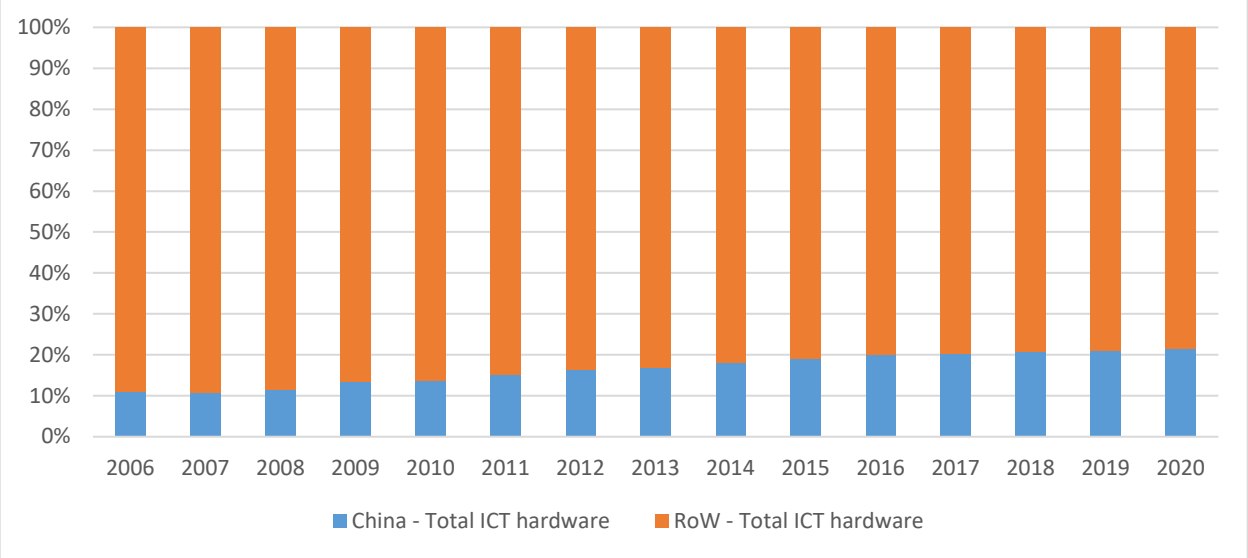
The growth of Chinese OEMs consumption of ICs is an indicator that downstream firms (i.e. firms that consume IC, such as mobile phone or computer producers) have become more competitive in this period. It does not necessarily indicate a strengthening of China's IC producers' competitiveness over this time period.

Electronics made by Chinese OEMs tend to be more competitive in China compared to the rest of the world (i.e., mostly consumed in China, some consumed outside of China), while non-Chinese OEMs are more competitive globally (i.e. mostly consumed outside of China, some consumed within China).

Therefore, the above figure is a useful proxy for how much domestic consumption of ICs occurs within China that excludes intermediate goods consumption as part of final assembly.

Second, because most information and communications technology (ICT) goods use ICs as integral inputs, ICT spending within a geographic location provides a useful proxy for IC consumption for corresponding locations. The international data corporation (IDC) provides this information. In 2017, China accounted for about 20 percent of global ICT hardware spending (Table A.2).

Figure A.2. ICT Hardware Spending Shares



Source: IDC Blackbook, 2016 v3.2; ICT Hardware includes ICT devices (including PCs, tablets, smartphones, etc) and ICT infrastructure (including servers, and telecom equipment); 2017 to 2020 are projections.

Together, these two alternative methods of calculating consumption arrive at relative agreement. China's internal consumption of ICs was about 20 percent of the global share in 2017.

Appendix B: Estimating baseline production and consumption shares for the U.S., EU, and Japan

Because the Green Paper production and consumption market shares for China do not match with industry data, we use the following methodology to estimate the market shares for the U.S., EU, and Japan to fit with the Green Paper's projections.

First, we take China's market share for both production and consumption as given by the Green Paper. Second, we adjust the market sizes based on current industry data. For production, we take the IC wafer fab capacity by region, as provided by IC Insights:

Table B.1: 2016 Wafer Fab Capacity by Region (from IC Insights), percent share of global capacity

China	EU	US	Japan	RoW
10.8	6.4	13.4	17.1	52.3

Source: JC Insights.

To calculate:

(B.1) WorldMKT = ChinaMKT + OtherMKT (where ChinaMKT = .108)

(B.2) OtherMKT = WorldMKT - ChinaMKT

Note that the Green Paper suggests that China as 19.4 percent capacity.

(B.3) WorldMKT' = ChinaMKT' + OtherMKT' (where ChinaMKT' = .194)

We adjust the China share to 19.4, then adjust down other regions' market shares by holding the individual market shares outside of China fixed. For example, for the adjusted U.S. market share:

(B.4) USMKT' = (USMKT/OtherKMT)* (1-ChinaMKT')

Using this method, U.S. market share decreases from 13.4 percent to 12.1 percent in 2016. This logic is applied to all years from 2016 to 2030. Adjusted market shares for 2016 are:

Table B.2: 2016 adjusted IC production shares, percent share of global capacity

China	EU	US	Japan	RoW
19.4	5.8	12.1	15.4	47.2

Source: Author calculations.

The methodology is the same for consumption shares outlined in part 3. The industry data is from SIA's WSTS end-use data.

Table B.3: 2016 IC End-Use by Region (from WSTS), percent share of global

China	EU	US	Japan	RoW
31.9	9.3	21.5	8.9	28.5

Source: SIA and WSTS end-use data.

Note that the Green Paper suggests that China's consumption share is 53.7 percent in 2016. We use the same method above to adjust down the share of other regions to fit with the Green Paper baseline and projections.

Table B.4: 2016 adjusted IC consumption shares, percent of global

China	EU	US	Japan	RoW
53.7%	6.3%	14.6%	6.0%	19.3%

Source: Author calculations.