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Abstract:
I present a nonlinear complex dynamic systems model of innovation for China within which both efficiency and equity can be addressed. For the fourth industrial revolution(IR4), digital technologies based on semiconductor material foundation and AI are analyzed for China within such a system which can be called an *Augmented National innovation system* or ANIS. There are at least two dimensions along which China's NIS can be augmented. One is to include the AI and semiconductor base for high technology for IR4, and the other is to move towards a more egalitarian innovation system in accordance with the goal of creating a harmonious moderately prosperous economy and society. The Chinese ANIS that is being built for the 21st century has important regional and geoeconomic implications for the future.

Keywords: China, 4th industrial revolution, Innovation, AI, semiconductors, Geoeconomics,, ANIS, complex dynamic nonlinear model

Introduction:

China's march towards a modern/postmodern innovation system was recognized by scholars from early 2000s onwards (Khan, 2004a, 2004b; Gabriele and Khan, 2010; Liu et. al., 2011). We can look at various quantitative measures ranging from rapidly rising expenditure on research and development (R&D) and a larger and higher-quality talent pool to impressive growth in output of scientific publications and patents. Taken together, these metrics all indicate that China is well on its way in the 2020s towards becoming a formidable player in innovation marching towards the fourth industrial revolution technological systems led by Artificial Intelligence and Deep Machine learning (Khan, 2021a, 2021b). Clearly, what we can call the visible entrepreneurial hand of the Chinese state has been active in all these ventures. In our earlier work we noted that since the late 1970s, the government has issued several S&T policies announcements. Furthermore, since joining the WTO, the PRC has responded positively to global issues in innovation with appropriate innovation policies. These new policies have been designed to reform the S&T system, to increase investment in S&T and R&D, to expand the number of scientists and engineers, to establish high-tech parks, to encourage venture capital investment, to better protect intellectual property rights (IPRs) (Khan, 2004a, 2012, 2021a, 2021b). Particularly, since 2006-7 China has been working to build a more innovation-oriented nation. In the meantime, the government has introduced industrial policies that support the development of high-tech sectors, aimed at strengthening industrial competitiveness, encouraging larger investment in innovation, and promoting high-tech trade. We should recognize that innovation financing, preferential tax treatment, and better management of S&T, R&D, and innovation funds also have become more important systemic forces in China that can be modelled as a dynamic nonlinear model of innovation during the 4th industrial revolution. Thus, all these packages--- S&T, industrial, financial, tax, and fiscal policies--- have been combined systemically to form in the last two decades a coherent, integrated package of innovation policies. There is little doubt that China is well on its way to the technical frontiers of the fourth industrial revolution. Here I will focus on two important aspects---the high-grade semiconductor industry as a foundation for high technology of this era, and the rapid progress in AI in China. AI requires both high grade semiconductor base and appropriately innovative software.

AI as a field dates back from the 1950s with a program of constructing "thinking machines" - that is to say, computer systems with human-like general intelligence. We may think of humanoid robots that act and think with intelligence equal to and ultimately greater than that of human beings. But the field has drifted far from its roots in a practical manner generating feasible scenarios of our techno-future. Faced with such a feasible array of AI technologies, one has to become cautious and humble. Therefore, this paper is modestly a preliminary exploration within a new nonlinear model of innovation system developed by Khan (2002, 2004a, 2004b, 2012, 2021a, 2021b) with a preliminary examination of PRCs prospects in this area during the ongoing fourth industrial revolution. The framework I use a can be called an Augmented National Innovation System where both efficiency and equity of innovation systems can be examined.

1. Fourth Industrial Revolution and China: Complex Innovation Systems in an Uneven World

China's technological advancement and dedication to innovative Artificial Intelligence (AI) systems are growing rapidly & robustly. What impact can we foresee AI may have on China's development of sophisticated ICT and other related technology systems? Where is China headed when it comes to Digital Innovation? Counterfactual or anticipatory questions like these can be posed precisely in an approximately appropriate model of innovation and answered with sufficient empirical data.One thing is certain: China's advancement in the AI sector will impact not only its social, economic, and political structure, but also will have global effects.

It should be noted that the 4th industrial-technological revolution will fundamentally alter the scale, scope, and complexity of human societies. To reap the benefits and avoid possible catastrophe, the global response including China must be integrated and comprehensive. To briefly recapitulate the historical trajectory of these revolutions so far, we can begin with the First Industrial Revolution which used water and steam power to mechanize production. The Second used chemical industries, hydrocarbons, and electric power to create mass production and distribution as well as a huge military-industrial complex in the bigger economies. Following on its heels, the Third Industrial Revolution used mainly electronics and information technology to automate production. It also promoted biotechnology and began the path to nanotechnology (Khan, 2005). More recently, a Fourth Industrial Revolution is building on the Third along the lines predicted by Khan in 2005. This is integrating the digital revolution with other technology systems to create a grand synthesis or super convergence of advanced technology systems through AI, Robotics, biotechnology, and nanotechnology.

Three features of these transformations are particularly to be noted: velocity, scope, and systems impact. The Fourth Industrial Revolution is evolving at an exponential rate, and this evolution is disrupting almost every industry and institution in every major country in our planet. In fact, beyond the advanced countries, billions of people connected by mobile devices, storage capacity, and access to knowledge guided by AI will present challenges for new forms innovation systems. If the challenge is taken up by PRC and other advanced countries, possibilities for human and planetary well-being will be multiplied by emerging technology breakthroughs in fields such as artificial intelligence, robotics, the Internet of Things, autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing. This will indeed present a new prospect for global prosperity. PRC can play a leading role in this endeavor. But we need a new integrated political economy model to analyze the prospects and ensure that optimal good can be extracted from the latest scientific-technological revolution. I present such a framework below. A nonlinear mathematical model on relevant functional spaces is presented in the appendix.

Fourth Industrial Revolution and An Augmented National Innovation System(ANIS) emphasizing people's capabilities enhancement as a basic theoretical framework: From NIS (National Innovation System) to ANIS

In a national context, treating innovations in specific sectors---e.g., the ICT sectors--- as part of the techno-economic paradigm embedded in the nation state requires viewing the innovation process as a complex network within a National Innovation System (NIS) and Sectoral Innovation Sub-systems (SISS). The key to understanding the systemic economics of Chinese innovation, particularly in the dynamic semiconductor, AI, biotechnology, nanotechnology, and other knowledge-intensive sectors is to realize that a policy-driven disequilibrium process has set in within PRCs economy of which SSISs are parts. The COVID-19 crisis has put in bold relief the contrast between China's economic system and the US system in particular. During this process, unfortunately but consistent with the complex systems uneven development approach followed here, the gap between the advanced countries of the world and most of the rest is widening while Chinese efforts are leading to reducing the gap in high technology. Unfortunately, unlike China, for countries trapped by neoliberalism under US hegemony, this disequilibrium process is leading to rapid economic changes in the direction of even a greater unevenness in the Global Political Economy (GPE). These changes include intersectoral shifts toward the ICT, other high technology, and knowledge sectors including the AI subsectors, changing skill requirements, high volatility of wages, profits and financial variables and consequent increase in uncertainty about the future states of the national economies and GPE as a system. The dynamics of this disequilibrium process must be studied through methods of understanding complexity. Clearly, our knowledge of such dynamic systems is still in its infancy; but much can be learned by studying some known features. In the last few decades, the frontiers of economics have moved far beyond the standard models of decreasing or constant returns where costs cannot be decreased beyond a certain point, unless factor markets behave in a peculiarly decreasing marginal cost fashion. Leaving the perfectly competitive world behind, economists at the frontiers have been focusing on increasing returns to scale, economies of scope and network externalities. The world of high technology in general and the ICT and knowledge sectors, are characterized much better through these approaches than the old perfectly competitive models. Many models of imperfect competition have also been developed to study interesting and relevant phenomena such as R&D rivalry and R&D expenditures. The upshot of these developments is that economists at the frontiers of their discipline are much closer to understanding many aspects of the digital economy than they were ten years ago. In this paper I want to illustrate this point by discussing a recently developed theoretical approach within the context of NIS and SISS in an uneven world economy. The policy implications for the development of new technologies, particularly Semiconductors, AI, Biotechnology, Nanotechnology, Robotics etc. are quite striking.

National Innovation Systems (NIS), ANIS, Social Learning and Complexity

The National Innovation System--- also abbreviated as NSI or National System of Innovation---- can be broadly defined as the intersectoral flow of technology and information in the economy including households and individuals, productive enterprises and various institutions including both public and private educational and R& D institutions. All these can form a network which under appropriate circumstances can generate a self-sustaining innovative process on the national level. (Nelson, 1990, 1993a, 1993b; Kim and Nelson, 2015; Lee, 2006; Khan, 1983, 1997, 1998, 2002, 2004a, 2004b, 2005; Khan and Thorbecke, 1988, 1989). According to this approach, which I generally follow with some modifications described later, technological development requires a system of well-functioning institutional networks and such development when it occurs results from this complex system of relationships among different groups of actors who respond to appropriate policies in the socio-economic system. Most advanced countries are already societies with highly evolved NIS. Some economies in the Asia-Pacific region like Japan, China, India, Korea, and Taiwan have developed such NIS with various degrees of success. Many poor countries are far behind. This is an example of what I mean by the unevenness of the global economy and globalization . My previous work on NIS(Khan 1998, 2002, 2004a, 2004b) of the requirements of technical progress shows that we need both a deeper understanding of the disequilibrium processes at work leading towards multiple equilibria and complex dynamics, and the economic implications of the complexities of the production and distribution aspects of new technologies. It is with a view towards capturing these complexities leading towards multiple equilibria that an alternative conceptualization of technology systems transition in terms of an Augmented NIS (ANIS) has been formulated by some economists (Khan, 1983, 1985, 1998, 2002, 2003a, 2003b, 2004a, 2004b; James and Khan, 1997; Gabriele and Khan, 2010). In addition to capturing both equilibrium and disequilibrium features of technological transitions, this broad approach can illuminate distributional issues as well. Since poverty reduction remains on the agenda of the national governments of many Asian developing countries and the international development agencies, it can be argued that from this perspective at least the new approach has relevance for the developing countries. But such distributional considerations are of importance in all advanced countries as well. From here on, I wish to highlight the fact that my framework can be viewed as simply a variety of Augmented NIS (ANIS) and its various subsystems and therefore, I will be using the more general term from now on which also has the virtue of maintaining intellectual continuity with NIS and at the same time augmenting the range of the concept. One important extension captured in my formulation is the explicit consideration of both factorial and household income distributions which interact in a causally reciprocal way with the technology systems.

2. Development of ANIS in PRC in the 21st Century: An Augmented NIS and the linkages between industry and science: the Chinese example

As an example of Augmented NIS, we can look at China. The claim is not that China has adopted an innovation system that is totally different, but rather that there is finally some official recognition in China that issues related to distribution and the maintenance of reasonably harmonious social relations cannot be completely neglected in overall development strategy including the strategy for innovation. As of 2022, China has achieved remarkable coherence in the 4^{th} industrial revolution and AI (Khan, 2021a, 2021b; Lundvall and Rikap, 2022) forming new types of platform business groups (Jia and Kenney, 2021).China's Augmented NIS has witnessed remarkable advances because of a series of reforms aimed mainly at improving its effectiveness and closing the excessive gap which traditionally separated university-based research activities from the technology absorption and innovation needs of the enterprises system. The main thrust of reforms has been to diversify the country's Augmented NIS and to strengthen its market-orientation and market-compatibility; but the role of centrally managed large, long-term research programs has also been enhanced. These reforms, along with the ever-expanding availability of financial resources made possible by economic growth and by the strong role of the state, have allowed China to achieve remarkable advances. This has also led to deeper integration with other economies through both international trade, investment, and joint technological and infrastructural projects. Several organizational and institutional structures which proved their validity in the context of developed market economies were studied, experimented with, and in some cases adopted in China, but such a pragmatic approach does not amount to an attempt to ape Western examples. The most visible change in China's Augmented NIS is probably the progressive shift of the bulk of R&D activities away from universities and specialized research centers and towards industrial enterprises. However, universities participate in many of the most ambitious basic research endeavors, and often play a crucial role in their implementation. For instance, universities carry out about 70% of the projects funded by National Natural Science Foundation (NNSF). The Chinese government is earmarking an increasing volume of funds to elite universities, mainly through the relevant ministries. Elite universities are expected to lead in national R&D programs and projects, facilitate technology diffusion and pullovers, promote spin-off companies, incubation centers, and open laboratories for R&D sharing, to bridge-in foreign technology and partners. This emphasis on the role of universities in engaging directly in the development, production, and commercialization stages of their research results has been dubbed "forward engineering " by Lee. According to him, forward engineering is a peculiarly Chinese component of the "Beijing Consensus", a comprehensive and proactive catch-up strategy very different from the "Washington Consensus" and partly, but not fully like that followed before by other successful Asian latecomers such as Korea and Taiwan. A pioneering one was project 211, aimed at funding the construction of campuses and developing new academic programs in key scientific areas all over the country. Other programs continue to promote university-industry links. The first one of this kind was launched jointly in 2001 by the State Economic and Trade Commission (SETC). The goal of this program was to set up state technology transfer centers in six universities, to promote the commercialization of technological achievements. Research and technological innovations are now seen as crucial channels through which universities contribute to national and local economies. As mentioned above, however, the bulk of China's R&D is presently being carried out by enterprises, many of which are large SOEs. SOEs reforms were carried out in the framework of a complex, ever-changing institutional environment. The behavior of Chinese SOEs is also becoming more modern and effective in several areas, including their ability to attract top executive talents. In China as elsewhere, R&D expenditure is positive and significantly correlated with firm productivity. The contribution of government R&D to firm productivity works mainly through an indirect channel, via the promotion of firms' own R&D, which appears to be a more effective policy tool than direct R&D grants. Other key sources of production improvement and innovation growth are each firm's absorptive capacity, the production network, openness, and managers' education. Market-oriented, competition-enhancing innovation system reforms and corporate governance with clear performance indicators in reformed SOEs have been improving the effectiveness of the incentive structure and fostering S&T linkage activities. As a result, SOEs and private firms in high technology sectors including semiconductors and AI now perform as highly innovative firms. In many SOEs, managers apply the technical innovation audit tool for benchmarking, thereby improving their ability to choose among different types of innovation mechanisms. Due to the influence of the two main stakeholders (government and end-users), firms with a higher degree of government involvement and a correspondently lower degree of openness to the market exhibit a more widespread use of innovation mechanisms, thereby apparently contradicting the positive relationship between market focus and innovativeness traditionally posited by “Western” innovation management theories. This phenomenon is due largely to strong government intervention and strategic planning in SOEs' behavior. The government puts paramount emphasis on long-term investments to promote technological innovations, targeting them as important indicators of SOE performance and awarding resources to SOEs accordingly. SOEs, rely more on government-allocated resources, and therefore tend to perform better in areas that are encouraged by the government, such as new product development. As new product output is an important indicator of SOE performance, SOEs are incentivized to operate at the frontier of new product development. There are dynamic advantages in terms of innovative capacity and technological progress, with major spillovers benefiting the national economy. One also needs to consider the existence of virtuous synergies with the non-state-owned sector. (Lin, 2012)

Notwithstanding China's Augmented NIS's remarkable strengths, remaining challenges are formidable. For instance, there is still a dualistic pattern in China's of technological development, with the export-oriented segments of the economy being relatively isolated from those producing mainly for the domestic market. There could be more synergy technological cooperation between universities and industry, and the inadequate integration of the country's Augmented NIS into the global innovation networks. Without being exhaustive, one last feature of the still evolving Chinese Augmented NIS can be mentioned. Since the beginning of the new regime in the 21st century the increasing social and political tensions which inevitably accompany worsening income distribution have been noted carefully. The worsening distributional situation sets China apart from the other East Asian latecomer innovators. The Xi regime seems committed to changing the distributional picture and managing social and political tensions effectively. The overall macroeconomic and innovation policies are influenced by these goals. Apart from the already developed ANIS of Japan, the region's other players with strong capabilities for developing ANIS are India, Korea, Taiwan, Singapore, Malaysia, Thailand, the Philippines, and Indonesia. Viet Nam is at a lower stage of development but can potentially develop its ANIS integrated with the Asia-Pacific . The present author has carried out studies on a number of these countries and several are ongoing. What can we conclude from the Chinese case study and these other Asian examples?

Since the late 1990s, the Chinese Government has approved a number of crucial strategic decisions to build up a world-class National Innovation System. In 1998 the government instructed the Chinese Academy of Sciences (CAS) - a vast network of research institutes that are presently undergoing feverish expansion and reorganization – to initiate the Pilot Project of Knowledge Innovation Program (KIP). An action plan was carried out for rejuvenating education in the 21st century, in addition to a national meeting on technology innovation and a working conference on basic science research, to further enhance the reform of the scientific research system. Plans are also drawn to open a second-board stock exchange in the securities market, like the American Nasdaq. The KIP piloted at CAS has been a major component of the National Innovation System. In January 2006 China launched the "National Medium- and Long-Term Program for Scientific and Technological Development" (2006-2020), commonly known as the 15-year Plan for science and technology. The Plan's long-term goal is to allow China to become a pre-eminent global economic and technological power, relying on "independent, indigenous innovation":31 "By the end of 2020, we should establish an improved scientific and technological innovation system. . . We will strive to leapfrog the development of China's information science and technology and to acquire core technologies with proprietary intellectual property rights in the IT sector."

According to American Electronics Association (AeA) China has a leadership mainly composed by engineers, who are in a favorable position to understand the nature and the strategic centrality of research and technology. It is notable that by 2010, China had already built-up remarkable elements of strength in the S&T and R&D area. For instance, it had been pouring huge societal investments into higher education and research (state financing for higher education more than doubled in 1998-2003, reaching over USD10 bn by the end of that period, China's number of researchers increased by almost 80% in 1995-2004, and is now second only to the US). Large SOEs are now investing heavily in technological upgrading and human capital formation, and there are several start-up innovative firms, some of them already established in international markets (such as Lenovo, Haier, and Huawei), and others active in crucial areas such as the provision of Internet services for the domestic market.

It is important to locate China's S&T Plan in the framework of the worldwide scenario shaped by the converging trends of key frontier technologies. As the APEC (2005) workshop on this topic has made clear, the convergence of information technology, biotechnology, and nanotechnology called by Khan *super convergence*) might be the most significant technological event of the 21st century (Khan, 2005). The process of convergence is already underway. All the major national and regional players including USA, EU and Japan have already taken significant steps to maintain and gain further advantage in these technologies. China was a latecomer; but in the last two decades catch up has accelerated. In 2022, it has formidable momentum.

China's National Development and Reform Commission (NDRC) started the process of national capacity building and regional cooperation by supporting key strategic ventures which is now accelerating. Increasing the number of competent staff in the areas of planning for high technology development is a cornerstone. In Khan (1998, 2002, 2004a,b, 2008a) the overall planning framework is presented as part of a system-wide effort to create positive feedback loop for innovation, which is at the same time *progressive, equitable, and ecologically sustainable*. I show that of such a wholistic model is a nonlinear complex innovation system. The ANIS framework can be applied through quantitative economy-wide modeling techniques, to analyze the challenges for transition from now to 2020 and then from 2020 to 2050.

The ANIS approach is based on a somewhat novel theory of innovation in the economy wide setting. Its first and most important feature is that the analysis of an ANIS can be thought of as part of the institutional turn in economic theory. However, in contrast with much institutional literature, its propositions can also be expressed in a formal language, through models that can be estimated quantitatively for both rigorous, empirical scientific testing and for policy making purposes. The starting point of the ANIS theory is the creative destruction process at the firm and industry level. However, an extension to an economy-wide setting requires the explicit theorization of the role of the state as well as an interacting nonlinear market process. The direction in which the theory leads is a complex interaction between state policies and market processes that influence the decisions taken by specific firms areas of innovative activities. The key concept that is developed in this context can be called a Managed Creative Destruction (MCD) process. In a national (Or regional) MCD, the creative destruction process characterizing innovation is structured more consciously by the state (or the states in a particular region). It can be argued that China is now going through this process. Following Schumpeter, we assume that innovation in specific firms can have economy-wide effects. As models based on this approach have multiple equilibria, the concept of a Complex sustainable ANIS is formalized by picking an appropriate sequence of equilibria over time. It can be also shown that ANIS has empirical relevance by applying the formal model to an actual economy. Ultimately, technological transformation — in particular the creation of am ANIS - is what makes the difference between sustained growth and gradual or sudden decline.

In addition to the system wide approach to innovation over time, the ANIS theory offers two other distinct advantages. One is the linkage between micro and meso or macro levels. One can start with firm level data on innovation activities and link these to sectoral and intersectoral information flows. In this way, what happens at the firm level can be seen from a larger, economy wide perspective. At the same time, the impact of firm level activities on overall level and pace of innovation can also be ascertained qualitatively and quantitatively.

The third aspect of ANIS is distributional. The complex system dynamics of ANIS integrates production with distribution. Thus, the distribution of value added in production at both the factorial and household levels can be formulated as part of a general equilibrium (or, under circumstances of internal or external shocks, disequilibrium) framework. Given the levels and distribution of income among households, the consumption patterns and effective demand feedback mechanisms complete the formulation of a system wide model.

China has been earmarking towards research and the broader S&T sector an increasing share of GDP. As a result, China has now achieved a substantial critical mass in the area of research and innovation, second only (according to some estimates) to that of the US, and growing four times faster than that of any of the major world technological leaders, among which there are signs that the enthusiasm for ever-increasing investment in R&D might be declining, both in the public and the private sectors. There is by now plenty of evidence showing that the over the last decade China has witnessed major efficiency-enhancing institutional and organizational changes, a massive accumulation of human capital, and a sustained rate of scientific and technical progress. Labor productivity has been rising fast, and a major part of the improvement is likely to be due to the aforementioned factors, even considering China's extraordinary rate of non-human capital accumulation. R&D input indicators and output indicators such as patents and scientific papers have been rising fast. Although China is doing an excellent job at absorbing, adapting and developing existing technologies, but is still lagging significantly behind world technological leaders in terms of capability to generate state-of-the-art, world-class innovation proper, as is shown for instance by data on basic research and inventions patents.

With respect to state industry, the assessment of available evidence on SOEs' performance is more complex. Most sources indicate that, until the end of the past century, SOEs had been absorbing a major share of investment funds while exhibiting efficiency and profitability levels lower than enterprises belonging to other forms of ownership. Yet, their propensity to innovate (not always in an effective way) was high, and their productivity climbed dramatically, especially during the late 1990s. Latest available evidence appears to show that, during the present decade, the policy of concentrating huge resources on a small number of large and advanced SOEs, while letting smaller and less efficient state enterprises to fend for themselves (recurring increasingly to extreme measures such as closures or ownership changes) has begun to bring significant qualitative fruit, as testified by core SOEs' increasing profitability and international competitiveness and by the embryonic emergence of some world-class state-owned TNCs. Both SOEs and large industrial enterprises operating in China under different forms of ownership - such as joint ventures and private (national and foreign) firms - manifest a very strong willingness to innovate.

The challenge, at the present stage, is to engineer in a relative short period (10-15 years) a decisive qualitative leap in China's NIS, developing a systemic ability to generate world-class indigenous innovations. In addition to generating technical progress, China's development strategy must also address the challenge of establishing a model of innovation compatible with an equitable pattern of income distribution and environmental sustainability, thereby paving the way to the eventual evolution towards a higher and more developed form of socialism. This is the expressed aim of the Chinese leadership, and enjoys considerable popular support.

This strategy aims at embodying world-class best practices from technological world leaders and successful late industrializers but is also uniquely Chinese in at least two crucial aspects. The first is China's sheer size, which allowed her to leapfrog to rank 2 worldwide in terms of the absolute quantitative magnitude of its NIS, at a stage when it still lagged far behind all technological leaders. The second aspect has to do with China’s still unsettled internal politics of distribution. A move away from ignoring distributional and related well-being issues is being attempted. Within the CPC, there is a lively and serious debate about the distributional and well-being aspects for the Chinese people. This is the more positive part of the so-called "China Dream". More broadly, this is part of the complex debates surrounding the 4^{th} Industrial Revolution.

3. An illustrative model of the ANIS complexity approach during the fourth industrial innovation with AI sectors with a material basis in advanced semiconductors

3.A. Technological Systems as Complex Structures

During the fourth industrial revolution, the key strategic question for China on technological innovation concerns the prospects for long-term economic growth with equity. Ultimately, it is the ecologically sustainable growth that will determine the wealth that can be distributed among personal consumption, investment, government spending on infrastructure and public services, etc.

Therefore, it is the creation of an ANIS that will determine the viability of Chinese economy. This process of building an innovation system is very much an evolutionary and path-dependent process. The central idea is that the provision of appropriate types of capital, labor and forms of organization for high value-added industries will lead to rapid productivity increases. However, to sustain such an increase, this innovation system must create a positive feedback loop or a virtuous cycle of innovations. For China's semiconductor industry and AI sectors these positive feedback loops will generate both increasing returns to scale and further innovation capabilities.

The formal technical problem is the existence of multiple equilibria in complex economies. A positive feedback loop leading to a virtuous cycle of growth and technology development is one particular sequence of equilibria in this context. In general, such a sequence also involves increasing returns. In the remainder of this section a theoretical exploration of innovation with increasing returns and multiple equilibria will be undertaken.

Technically, economic processes exhibit non-convexities -- violating the generic assumption of competitive equilibrium economics. In PRC, we find that the process has been a complex state-market interaction. Furthermore, distributional concerns can also be better analyzed in a model of a complex and adaptive social and political economy.

3.B. A 'Simple' Non-linear Model of Complexity

At any single point in time, the model can be presented as a Social Accounting Matrix (SAM) representation of the socio-economic system. The key distinction here is the explicitly non-linear nature of the economy-wide functional relationships. The key theorem shows the existence of multiple equilibria. Some further considerations of complexity and increasing returns show that multiple equilibria are indeed the natural outcomes in such models. Thus, there would seem to be some role for domestic policy in guiding the economy to a particular equilibrium among many.

The virtue of an economy-wide approach to technology systems is the embodiment of various inter-sectoral linkages. In a SAM, such linkages are mappings from one set of accounts to another. In terms of technology systems, the production activities can be broken down into a production (sub-) system and a set of innovative activities thus both separating and linking the AI sectors as a network with all the economic activities in the complex economic-technical system.

One major component of the entire innovation system is, of course, the expenditures on R&D. In the SAM for China for example, this can appear either as an aggregate expenditure along the column labeled R&D, or as a set of disaggregated expenditures. In the latter case these may be specified according to productive activities (e.g., construction, electrical equipment, etc.) or by institutions (e.g., private R&D expenditures, government R&D expenditures, etc.). It should be emphasized that the dynamic effects of R&D on the economy can be captured only in a series of such SAMs over time. This approach is still at the conceptual stage, but appears to be quite appealing. One can contrast the possible policy experiments that can be undertaken within such a framework with the apparently ad hoc science and technology policies in many developing countries. In particular, the impact over time of a ANIS can be traced by building and maintaining such SAMs.

Choice of new technology in China is affected by research and development in at least three different ways. Such a country can attempt to develop new technology through R&D, as mentioned previously. This ultimately requires a positive feedback loop innovation system in order to be self-sustaining. Another alternative is to adapt existing technology. This too requires a production system geared towards innovation in a limited way. A third alternative is to import technology or to acquire it through attracting foreign direct investment. In practice, all these different forms may be combined. The abstract model embodies all these different possibilities. However, the first option requires, among other things, a presence of multiple equilibria. In a unique equilibrium world, the competitive equilibrium (under the assumption of complete markets) will always be the most efficient one. The presence of increasing returns usually destroys such competitive conditions.

We begin with a number of productive activities reflecting the existing technological structure with high technology sectors including AI sectors marked off by specific superscripts with subscripts giving nonlinear *technological coefficients functional* on a function space. Thus these activities are defined on the input-output subspace of the general and abstract mathematical space X along with all other economic activities. In addition to the values of inputs and outputs, points in this space could also represent household and other institutional income and expenditure accounts. We also incorporate the possibility of R&D as a separate productive activity. Formally, it is always possible to break R&D down into as many finite components as we want. The key relationship in this context is that between the endogenous accounts (usually, production activities and technologies, factors and households) and the exogenous ones. It is this relationship that is posited to be *non-linear* and this together with some assumptions on the relevant mathematical space can lead to the existence of multiple equilibria.

Although the existence theorems for these multisectoral models provide some structure for the equilibria as sequences of fixed points in the socio-economic structure with evolving technology systems, it is not specified a priori which equilibrium will be reached. The idea behind a ANIS can now be stated somewhat more formally. It is to reach a sequence of equilibria so that in the non-linear models of the entire economy the maximal fixed points that are attainable are in fact reached through a combination of market forces and policy maneuvers over time. It is also to be understood that path-dependence of technology would rule out certain equilibria in the future. Thus, initial choices of technologies can matter crucially at times.

3. C. The Model on a Lattice

Define X as a vector lattice over a subring M of the real field R .Let $x_+ = \{x \mid x \in X, x \geq 0\}$

A non-linear mapping N is defined such that $N : X_+ \rightarrow X_+, N_0 = 0$. Given a vector of exogenous variables d , the following non-linear mapping describes a simultaneous non-linear equations model of an economy, E:

$$x = Nx + d \qquad (1)$$

for a given $d \in X_+$.

This non-linear system represents a socio-economic system of the type described previously. In order to specify the model further, the following assumptions are necessary.

1. X is order complete
2. N is an isotone mapping

3. $\exists \hat{x} \in$ such that $\hat{x} \geq N\hat{x} + d$

In terms of the economics of the model, the non-linear mapping from the space of inputs to the space of the outputs allows for non-constant returns to scale and technical progress over time. The 3 assumptions are minimally necessary for the existence of equilibrium. Assumption 3 in particular ensures that there is some level of output vector which can be produced given the technical production conditions and demand structure.

Existence of Multiple Equilibria:

Theorem: Under the assumptions 1 - 3, there exists $x^* \in X_+$ so that x^* is a solution of

$x = Nx + d$

Proof: Consider the interval $[0, x] = \{\hat{x} \mid \hat{x} \in X_+, 0 \leq \hat{x} \leq x\}$ where $\hat{x}$ is defined as in assumption 3. Take a mapping F.

$F : x \in X_+ \to Nx + d$

F is isotone and maps $[0, x]$ into itself.

Define a set $D \equiv \{x | x \in [0, x], x \geq Fx\}$.

By assumption 3, D is non-empty.

We now show $x^* \equiv \inf D$ is a solution to $x = Nx + d$. $x^* \equiv \inf D$; therefore $x^* \leq x, \forall x \in D$. F is isotone; therefore $Fx^* \leq Fx \leq x$ for each $x \in D$ implying.

$$Fx^* \leq x^*$$

From (2) we have $F(Fx^*) \leq Fx^*$. Thus $Fx^* \in D$; hence $x^* \equiv \inf D \leq Fx^*$ so, $Fx^* \leq x^* \leq Fx^*$. Therefore $x^* = Fx^*$.

This is an application of Tarski's and Birkhoff's theorem. The key feature to note here is that the equilibrium is not necessarily unique. It should also be noted that under additional assumptions on space X and the mapping N the computation of a fixed point can be done by standard methods (e.g. Ortega and Rheinboldt).

3.D. Multiple Equilibria on Banach Space:

In this section the results for multiple equilibria are extended to functionals on Banach Space. We can define the model again for monotone iterations, this time on a non-empty subset of an ordered Banach space X. The mapping $f : X \to X$ is called compact if it is continuous and if $f(x)$ is relatively compact. The map f is called completely continuous if f is continuous and maps bounded subsets of X into compact sets. Let X be a non-empty subset of some ordered set Y. A fixed point x of a map $N : X \to X$ is called minimal (maximal) if every fixed point y of N in X satisfies

$$x \leq y (y \leq x)$$

Theorem: Let (E, P) be an ordered Banach space and let D be a subset of E.

Suppose that $f : D \to E$ is an increasing map which is compact on every order interval in D. If there exist $y,\ \hat{y} \in D$ with $y \le \hat{y}$ such that $y \le f(y)$ and $f(\hat{y}) \le \hat{y}$, then f has a minimal fixed point x. Moreover, $x \le y$ and $x = \lim F^k(y)$. That is, the minimal fixed point can be computed iteratively by means of the iteration scheme

$$x_0 = y$$

$$x_{k+1} = f(x_k) \qquad k = 0,1,2,....$$

Moreover, the sequence (x_k) is increasing.

Proof: Since f is increasing, the hypotheses imply that f maps the order interval $[\overline{y}, y]$ into itself. Consequently, the sequence (x_k) is well-defined and, since it is contained in $f[\overline{y}, y]$, it is relatively compact. Hence it has at least one limit point. By induction, it is easily seen that the sequence (x_k) is increasing. This implies that it has exactly one limit point $\overline{x}$ and that the whole sequence converges to $\overline{x}$. Since f is continuous, $\overline{x}$ is a fixed point of f. If x is an arbitrary fixed point in D such that $x \ge \overline{y}$, then, by replacing y by x in the above argument, it follows that $\overline{x} \le x$. Hence $\overline{x}$ is the minimal fixed point of f in $(\overline{y} + P) \cap D$. It should be observed that we do not claim that there exists a minimal fixed point of f in D.

We can also show that if $F : x \in X_+ \to Nx + d$ is an intersecting compact map in a non-empty order interval $[x, \hat{x}]$ and $x \le Fx$ and $F\hat{x} \le \hat{x}$ then F has a minimal fixed point x^* and a maximal fixed point x^{**}. Moreover, $x^* = \lim F^k(x)$ and $x^{**} = \lim F^k(\hat{x})$. The first of the above sequences is increasing and the second is decreasing.

Complex Dynamics and Out-of-Equilibrium Behavior:

Complex Adaptive Systems (CAS) are dynamic systems that can evolve with a changing environment. In CAS evolutionary trajectories there is no separation between a system and its environment in the sense that a system does not necessarily passively adapt to a changing environment. On the contrary, we have a system closely linked with all other related systems making up an ecosystem. In this larger ecosystem, change is necessarily that of co-evolution with all other related systems, rather than as adaptation to a separate and distinct environment.

As is well known, nonlinear dynamic systems can display a wide range of dynamic behaviors. Dissipative systems with a big enough perturbation can move to a new basin of attraction with much disorganization during transition. Also, even with bifurcations, we do not know for certain the expected path. Furthermore, catastrophic singularities are also possible.

My argument can now be summarized in terms of, dissipative systems dynamics in a world of multiple equilibria. Instead, a neoliberal global economy may simply go through cycles of instabilities. In China it is possible to set up a new capability enhancing system of production and distribution during the 4th industrial revolution

Technically, the “micro-macro” linkages can also be addressed through agents-based modelling and evolutionary game theory.

4.Partial Progress within the complex systems model: Semiconductor Industry, AI and 4th Industrial Revoluton in China: Data and Analysis

I analyze the semiconductor industry as advanced material foundation for a significant part of the fourth industrial revolution as well as a part of the material foundation for AI in the 21st century. I list in detail the key AI technologies and their applications for China and the world. These are important parts of evolving 21st century geoeconomics. Geoeconomics can be defined as the "geostrategic use of economic power" by states (Wigell, 2016; Khan, 2021a,b; Lundvall and Rikap, 2022). Geoeconomics proposes that an important part of economic and military power derives increasingly from control over markets and advanced technologies. Economic statecraft is analogous to geopolitics with "disposable capital in lieu of firepower, civilian innovation in lieu of military-technical advancement, and market penetration in lieu of garrisons and bases"[1]. In the 21st century power therefore depends largely on "productive efficiency, market control, trade surplus, strong currency, foreign exchange reserves, ownership of foreign companies, factories and technology". Economic interdependence is coterminous with competition, rather "economics is the continuation of war by other means"[2]. According to realist Geoeconomics, states intervene in the market to develop asymmetrical economic interdependence as the stronger and less dependent side in an economic partnership can extract political concessions from the weaker and more dependent side (Hirschman, 1945). Geoeconomics theory therefore expects that the international system gravitates toward a "balance of dependence," the equivalent of a balance of power, as governments seek to reduce excessive reliance on any one state or region (Diesen, 2017). Furthermore. three categories of economic dependency can be defined: (1) strategic industries create dependency due to the human-made scarcity of high technology products or natural resources; (2) transportation corridors are important for economic competitiveness; and (3) financial instruments such as trade/reserve currencies and banks. All these propositions are understood by Chinese high technology policy makers.[3]

Without doubt, the current disruption to the international economic system comes from the spectacular rise of China. Following Deng's wisdom ("hide your strength, bide your time."), Beijing followed initially a strategy of catching up without attracting unwanted attention from great powers. As China's economy in PPP terms surpassed the United States in 2014, the system inevitably entered the early stages of turbulent dynamics (see the model with dissipative dynamics in appendix 3). Clearly, as this paper demonstrates, the PRC has succeeded with its own three-pillared geoeconomics strategy. As Khan (2010, 2018, 2021a, 2021b) and Gabriele and Khan (2010) show, the PRC is asserting control over strategic industries by establishing technological leadership with the China 2025 industrial strategy and through the acquisition of natural resources around the world. Furthermore, since 2013, the PRC has developed the Belt and Road Initiative (BRI) for infrastructure and physical economic connectivity. Finally, though this is in its early stage, financial instruments of power are being established under Chinese control by gradually but

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[1] Huntington, 1993, p. 73

[2] Bell, 2008, p. 330

[3] For the 4th industrial revolution in PRC and AI in particular see Zeng (2021).

strategically internationalizing its currency and building up gold reserves instead of dollar denominated T-bills and US financial assets. As Khan (2015) shows, establishing new development banks such as the Asia Infrastructure Investment Bank, and the China International Payment System (CIPS) as an alternative transaction system to SWIFT are important steps in China's geoeconomic strategy. Perhaps in East Asia, the Chinese-led Regional Comprehensive Economic Partnership (RCEP) will lead eventually to an integrated geoeconomic region.

Chinese semiconductor industry as a key 21st century 4th Industrial Revolution and as hardware support for AI

The Chinese semiconductor industry has expanded dramatically from its small size in the early 2000's. It grew on average by 15.8 percent per annum from 56.2 billion yuan in 2000 to 281.4 billion yuan in 2011, while the global semiconductor output grew on average only by 8.8 percent per annum over the same period. Rapid growth has enabled the share of China's semiconductor output in world output to rise from 4.8 percent in 2002 to 14.5 percent in 2011. The manufacture of discrete semiconductor appliances grew on average by an impressive 22.1 percent per annum over the period 2002-2011. China had nearly 3,000 semiconductor firms with over 600 of them producing integrated circuits by 2013. And yet, even with this strong growth, the Chinese semiconductor industry has faced many challenges over the last 10 years.

Semiconductors, otherwise known as "chips," are an --essential component at the heart of economic growth, security, and technological innovation. Smaller than the size of a postage stamp, thinner than a human hair, and made of nearly 40 billion components, the impact that semiconductors are having on world development exceeds that of the Industrial Revolution. From smartphones, PCs, pacemakers to the internet, electric vehicles, aircrafts, and hypersonic weapons, semiconductors are ubiquitous in electrical devices and the digitization of goods and services such as global e-commerce. And demand is skyrocketing, with the industry facing numerous challenges and opportunities as emerging technologies such as artificial intelligence (AI), quantum computing, Internet of Things (IoT), and advanced wireless communications, notably 5G, all require cutting-edge semiconductor-enabled devices. But the COVID-19 pandemic and international trade disputes are straining the industry's supply and value chains while the battle between the United States and China over tech supremacy risks splintering the supply chain further, contributing to technological fragmentation and significant disruption in international commerce.

Government Promotion

Undoubtedly, Chinese semiconductor industrial development has benefited from strong institutional support. Two distinct stages could be identified, the first before 2000 characterized by specific national programs, while the later stage by overall systemic support. A comprehensive policy framework was established to support development of the semiconductor and supporting industries. Between 2000-2014 witnessed the maturation of the supporting policy, which grew from an abstract national strategy to a concrete policy. Several policy pillars have been set up following issuance by the *State Council of the Software and Integrated Circuit Industries* in June 2000, the *Notification of the Long-term Development Plan for Strategic Emerging Industries* over the 12th Five Year Plan in July 7, 2012. The State Council strengthened policy direction further through further encouraging the Development of the Software and Integrated Circuit Industries in 28 January 2011, which provided further support through financial incentive, preferential investment policies, R&D incentives, import and export subsidies, human resources initiatives and intellectual property rights protection. Human resources initiatives and IPRs protection are both the policy aspects in the document issues in January 2011. Human resources aspect includes detailed policies to support the IC related talents attraction and cultivation through industry academia collaboration, establish the microelectronics institute, reform the educational methods, and talents stimulations policies. The IPR aspect encourages software companies copyright registration, strictly implementing the software and integrated circuit intellectual property protection system. With strong policy support through tax exemptions, subsidies and R&D grants, the government has managed to promote technological capabilities, including in indigenous IC design firms. Through reinforcement of the advantages of the IC sector and upgrading into backward packages, a complete industrial value chain is expected to emerge like a "necklace" of "pearls". The goal of such a scheme is to make China a major player in the global IC industry with domestic brands and national intellectual property rights. This, the government has done through a development roadmap with timeline, development goals, action initiatives and regulations. The sectoral development policy has stimulated industrial upgrading in the semiconductor industry through two ways. Firstly, the shifting of support from particular 3 segments to the entire value chain, with special emphasis on interaction between different industry players in the value chain has benefited upgrading. One example of upgrading is indicated by the Value Added Tax) reform, which has since benefited all companies in the value chain, including design, manufacturing, assembly, testing and special purpose materials and equipment manufacturing. Secondly, the policy encourages cross regional industrial integration, merger and acquisitions.

Industrial Expansion

The Chinese IC industry has been gradually moving up along the value chain of the global production network, witnessed by rapid growth of R&D input and output by domestic firms. The combination of inner strength and external forces significantly promoted the overall advancement of semiconductor industry, where reinforce of inner strengths is featured by the growing number of firms and domestic research institutes, and external forces means the foreign firms with cutting-edge technology synchronize domestic firms to learn and upgrade. Meanwhile, strong domestic demand and national supporting policies provide local semiconductor firms a strong favorable external environment to thrive. The size of IC industry has been growing rapidly, with production volume increasing from 3500 million items in 1984 to 71.4 billion items in 2012 (the first three quarters). Table 1 profiles a growing IC industry of China with main economic indicator. The number of employees increases 14.7 percent every year, jumping from 74004 people in 2000 to 293023 people in 2010. The growing number of firms brought an increase in industrial gross output, which increased from 27.23 billion yuan in 2000 to 234.02 billion yuan in 2010 with an average annual growth rate of 24 percent throughout the period. A yearly increase of 22.32 percent in the profits lasted over the period, and exports grew 25.5 percent every year from 15.95 billion yuan in 2000 to 154.57 billion yuan in 2010. During the rapid growth, the Chinese semiconductor industry has become an important part in the global production network. Countries which have developed semiconductor industries have set up industry bases or some research and development centers in China, including the USA, EU, Japan, South Korea, and Taiwan region. So far in China, semiconductor industrial clusters have formed in the Bohai Area, Yangtze River Delta, and Pearl River Delta. The Middle and west region has become the base for IC packaging and testing, for instance LED packaging. Despite its status as a latecomer in the industry, China semiconductor sales grew 29.5 percent every year on average from 12 billion yuan in 2001 to 158 billion in 2011, with its market share in the world increasing from 1.9 percent in 2001 to 9.8 percent in 2011. While the sales shot up to 325 billion yuan in 2008 from 125 billion in 2007, sales fell back to 110 billion in 2009. The share in the world shows a stable rise, suggesting a sudden rise in demand from the international market in 2008. The development of China's IC industry was reflected not only by quantity, but also on its industrial structure to enjoy significant participation in global production activities. The sales of IC design grew 41.2 percent every year from 1.5 billion yuan in 2001 to 47.4 billion yuan in 2011. Throughout the period, the share of packing and testing significantly dropped from 79.3 percent to 38.9, while the share of design increased from 7.3 percent to 30.1 percent. This dramatic structural change indicates the speeding up of industrialization of China's IC industry. The production activities are shifting away from low-value-added exercise, and is gradually upgrading technological capacity in high-value-added product design.

Current state of the Semiconductor Industry in China

Global chip sales from Chinese companies are on the rise, largely due to increasing U.S.-China tensions and a whole-of-nation effort to advance China's chip sector, including government subsidies, procurement preferences, and other preferential policies.

Just five years ago, China's semiconductor device sales were $13 billion, accounting for only 3.8% of global chip sales. In 2020, however, the Chinese semiconductor industry registered an unprecedented annual growth rate of 30.6% to reach $39.8 billion in total annual sales, according to an SIA analysis . The jump in growth helped China capture 9% of the global semiconductor market in 2020, surpassing Taiwan for two consecutive years and closely following Japan and the EU, which each took 10% of market share. Sales data for 2021 are not yet available. If China's semiconductor development continues its strong momentum – maintaining 30% CAGR over the next three years – and assuming growth rates of industries in other countries stay the same, the Chinese semiconductor industry could generate $116 billion in annual revenue by 2024, capturing upwards of 17.4% of global market share . This would place China behind only the United States and South Korea in global market share. Equally startling is the number of new firms in China rushing into the semiconductor industry. Nearly 15,000 Chinese firms registered as semiconductor enterprises in 2020 . A large number of these new firms are fabless start-ups specializing in GPU, EDA, FPGA, AI computing, and other higher-end chip design. Many of these firms are developing advanced chips, designing and taping out devices on bleeding-edge process nodes . Sales of Chinese high-end logic devices are also accelerating, with the combined revenue of China's CPU, GPU, and FPGA sectors growing at an annual rate of 128% to nearly $1 billion in revenue in 2020, up from a meager $60 million in 2015 . Across all four subsegments of the Chinese semiconductor supply chain – fabless, IDM, foundry, and OSAT – Chinese firms recorded rapid increases in revenue last year, representing annual growth rates of 36%, 23%, 32%, 23%, respectively, based on an SIA analysis. Leading Chinese semiconductor firms are on track to expand domestically, and even globally, in several submarkets. SIA analysis further shows that in 2020, China held an impressive 16% market share in the global fabless semiconductor segment, ranking third after the U.S. and Taiwan, and up from 10% in 2015 . Benefiting from China's massive consumer and 5G market, Huawei's HiSilicon, China's largest chip designer, generated nearly $10 billion in revenue in 2020, despite tightened export control restrictions (largely due to significant stockpiling suggested by official Chinese trade data). Other Chinese fabless firms, such as communications chip supplier UNISOC, MCU and NOR flash designer GigaDevice, fingerprint chip firm Goodix, and image sensor designers Galaxycore and OmniVision (a U.S.-headquartered corporation acquired by China), have all reported a 20-40% annual growth rate to become China's top fabless firms. Moreover, in addition to supplying Chinese OMEs, GigaDevice, OmniVision, and Goodix have entered the top 3 global smartphone vendors' supply chains .

Meanwhile, Chinese consumer electronics and home appliance OEMs and leading internet firms have also been ramping up efforts to expand into the semiconductor sector by designing chips in-house and making investments in established semiconductor firms, with notable progress made in designing advanced chips and building domestic supply chains over the past two years . China also maintains robust growth in building out its semiconductor manufacturing supply chain, with 28 additional fab construction projects totaling $26 billion in new planned funding announced in 2021 . SMIC and other Chinese semiconductor leaders have further expanded their partnerships with local governments to construct additional joint venture fabs, with a focus on mature technology nodes . Wafer manufacturing startups are continuing to spring up in the trailing-edge fabrication field, backed by government incentives . On the chip manufacturing front, due to the inclusion of Huawei and SMIC on the U.S. government's Entity List (China's most advanced chip designer and foundry, respectively), the Chinese semiconductor industry has largely suspended advanced logic node manufacturing development and redirected most capital to mature fabrication technology. As a result of this change, from September 2020 to November 2021, Chinese wafer manufacturers have added nearly 500K wafer per month (WPM) capacities in trailing nodes (>=14nm), and only an additional 10K in capacity for advanced nodes. China's wafer capacity increase alone accounted for 26% of the worldwide total . In 2021, China also started commercial shipments of indigenously manufactured mobile 19nm DDR4 DRAM devices, and 64-layer 3D NAND Flash chips and started 128-layer products . While the Chinese memory industry is still at an early stage of development, Chinese memory firms are expected to achieve a compound annual growth rate of 40-50% in output and become highly competitive over the next five years . Regarding backend production, China is a global leader in outsourced assembly, packaging, and testing (OSAT), with its top three OSAT players collectively holding more than 35% of the global market share .

All indications are that China's rapid growth in semiconductor chip sales is likely to continue due in large part to the unwavering commitment from the central government and robust policy support in the face of deteriorating U.S-China relations. While there remains a long way to go for China to catch up with existing industry leaders – especially in advanced node foundry production, equipment, and materials – the gap is expected to narrow over the next decade as Beijing sharpens its focus on semiconductor self-reliance during the current 14th Five-Year Plan

Trump Administration Ban

In September of 2019, the Trump administration placed restrictions on exports to Semiconductor Manufacturing International Corporation, China's most advanced maker of computer chips. Dozens of Chinese companies, including SMIC and drone maker DJI, were added to the Commerce Department's so-called Entity List, which effectively cuts them off from US suppliers and technology. Some industry leaders were not worried about the ban initially as the ban only applies only to those technologies that are “uniquely” capable of producing semiconductors at 10 nanometers in size or below. However, since the ban, China has faced immense pressure on the self-reliability of China's technology industry as a whole. Currently, experts predict that China is at least two generations (four years) behind the chip makers in the US. These US companies include but are not constrained to Apple, Google, Nvidia, Intel and Qualcomm, to note a few.

The following tables and charts summarize the analysis of the evolution of this sector as part of a Chinese ANIS.

1: Operating Models in the Semiconductor Industry, and Leading Firms

Integrated Device Manufacturer (IDM) Model	Intel, Micron, Samsung, Texas Instruments
Fabless-foundry model	
Design (fabless)	AMD, Broadcom, MediaTek, HiSilicon, Qualcomm
Manufacturing (foundries)	GlobalFoundries, SMIC, TSMC, UMC
Assembly, test, and packaging (ATP)	Amkor, ASE, ChipPAC, JCET, J-Devices, Power-tech, SPIL

Source: Adapted from SIA, “Beyond Borders,” May 2016

Table 1 depicts the operating models in the semiconductor industry globally. One can also find the leading firms who utilize said operating models.

Table 2: Worldwide Ranking of the Top-15 Suppliers of Semiconductors in 2018

Company	**Headquarters**	**Operating Model**	**2018 Forecasted Sales (billion)**
Samsung	South Korea	IDM	$65.90
Intel	United States	IDM	$61.70
TSMC	Taiwan	Foundry	$32.20

SK Hynix	South Korea	IDM	$26.70
Micron	United States	IDM	$23.90
Broadcom	United States	Fabless	$17.80
Qualcomm	United States	Fabless	$17.00
Texas Instruments	United States	IDM	$13.90
Toshiba/Toshiba Memory	Japan	IDM	$13.30
Nvidia	United States	Fabless	$9.40
NXP	Europe	IDM	$9.30
STMicroelectronics	Europe	IDM	$8.30
Infineon	Europe	IDM	$8.10
Sony	Japan	IDM	$7.90
Western Digital/Sandisk	United States	IDM	$7.80

Source: IC Insights, "Nine Top-15 2018 Semi Suppliers Forecast to Post Double-Digit Gains," November 12, 2018.

Table 2 shows a worldwide ranking of the top fifteen suppliers of semiconductors in 2018 globally.

Table 3: Notable Semiconductor-Related Chinese Industrial Plans

Year	Title	Semiconductor-related provisions
1956	Outline for Science and Technology Development, 1956–1967	Identified semiconductor technology as a "key priority" for China's future.
1983	"Build Two Bases (North and South) and One Point"	Designated a "South Base" (around Shanghai, Jiangsu and Zhejiang) and "North Base" (Beijing, Tianjin, and Shenyang) where firms could share resources and develop semiconductor industry supply chains.
1982	The Strategy for the Development of China's Electronics and Information Industries	6 Strategies Outlined focused on using foreign technology to advance China's technology via joint ventures, creation of a domestic electronics supply chain with an emphasis on quality mass production and large-scale ICs.
1990	Project 908	Advocating Project 908, which sought to establish China's first world-class I.D.M. at Wuxi's #742 Factory.
1991	8th Five-Year National Economic and Social Development Plan	Called the development of the domestic IC industry a "main task" of the state. Articulated "Project 908."
1995	Project 908 Breaks ground	Goal was to establish a 150mm (6-inch) wafer fab run as China Huajing Electronics Group (IDM).
1996	9th Five-Year National Economic and Social Development Plan and 2010 Long-Term Goals	Called for development of next-generation ICs.
2001	10th Five-Year National Economic and Social Development Plan Outline	Called for the focused development of high tech industries and to "vigorously develop the IC… industry."
2005	National Medium- and Long-Term Science and Technology Development Plan Outline (2006-2020)	Articulated China's long-term technology development strategy. Of 13 key projects identified, development of core electronics (including chips) and chip manufacturing are prioritized as numbers one and two.
2006	11th Five-Year National Economic and Social Development Plan Outline	Called for the "vigorous" development of ICs and other industries at the core of the "digitization trend."
2011	12th Five-Year National Economic and Social Development Plan Outline	Inaugurated a "high performance ICs project."
2014	Guidelines for the Development and Promotion of the Integrated Circuit Industry	Called for establishing a National IC Industry Development Leading Small Group to coordinate design of the industry's development and starting a National Integrated Circuit Investment Fund.
2015	Made in China 2025	Strategy calling for accelerated advances in key manufacturing technologies, including chips.
2015	Made in China 2025: Major Technical Area Roadmap	Established specific sales values and market share targets for the IC industry to be met by domestic production.
2016	13th Five-Year National Economic and Social Development Plan Outline	Called for the active promotion of advanced semiconductor technology.

Source: USTR, Section 301, Report, March 2018, pp. 111-113; Lewis, "Learning from the Superior Techniques," 2019, pp. 32-35.

Table 3 describes the notable semiconductor related Chinese industrial plans from 1956 to 2016.

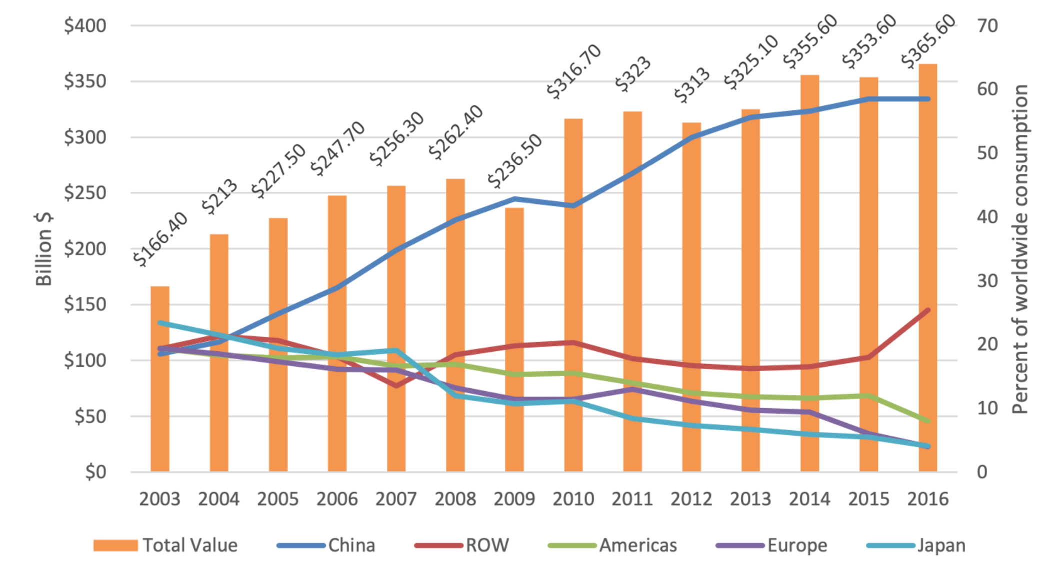
Table 4: Announced Chinese Semiconductor-Related Investment Into the United States

Announced	U.S. target	Chinese investor	Value
Jul-06	LSI Logic- ZSR(R) Digital Signal Unit	VeriSilicon Holdings	$13 million
Jan-08	Quorum Systems	Spreadtrum Communications	$77 million
Nov-10	Creation of US subsidiary	China WLCSP Co. Ltd.	$1 million
Jun-11	MobilePeak Systems stake	Spreadtrum Communications	$27.2 million
Aug-11	Telegent Systems	Spreadtrum Communications	$92 million
Sep-11	MobilePeak Systems stake	Spreadtrum Communications	$3.6 million
Mar-15	Integrated Silicon Solutions Inc.	Hua Capital Management, SummitView Capital, E-Town Memtek	$640 million
Apr-15	FlipChip International	Tianshui Huatian Technology	$41 million
May-15	WiSpry	AAC Technologies Holdings	$10 million
May-15	Static Control Components	Apex Microelectronics	$63 million
Jun-16	Marvell Technology*	Datang Telecom	$2 billion
Jul-15	Bridgelux	China Electronics Corporation, Chongqing Linkong Development Investment	$130 million
Jul-15	Micron Technology*	Tsinghua Holdings	$23 billion
Aug-15	Micrel Technology*	Unnamed Chinese buyer	$839 million
Sep-15	Atmel*	China Electronics Corporation	$3.4 billion
Sep-15	Western Digital*	Tsinghua Unisplendour	$3.8 billion
Sep-15	Pericom Semiconductor	Montage Technology Group (subsidiary of China Electronics Corp.)	$442 million
Dec-15	Xcerra- interface board business	Fastprint	$23 million
Dec-15	Mattson Technology	Beijing E-Town Dragon Semiconductor Industry Investment Center	$300 million
Dec-15	Fairchild Semiconductor*	China Resources, Hua Capital Management	$2.5 billion
Jan-16	OmniVision Technologies	CITIC Capital Holdings, Goldstone Investment, Hua Capital Management	$1.9 billion
Jan-16	Initio	Sage Microelectronics	$40 million
Jan-16	Vivante	VeriSilicon Holdings	Not known
Mar-16	Global Communications Semiconductors	Sanan Optoelectronics	$226 million
Mar-16	GigOptix	Shanghai Pudong Science and Technology	$5 million
Mar-16	Anadigics	Unnamed Chinese buyer	$78.2 million
Apr-16	Lattice Semiconductor	Tsinghua Holdings	$41.6 million
May-16	Marvell Technology Group	Tsinghua Holdings	$78.2 million
Jun-16	Multi-Fineline Electronix	Suzhou Dongshan Precision Manufacturing	$610 million
Jun-16	Integrated Memory Logic	Beijing E-Town Chipone Technology	$136 million
Aug-16	MEMSIC	HC Semitek; China Reform Holdings Corporation	
Sep-16	Analogix	Beijing Shanhai Capital Management & National IC Fund	$500 million
Nov-16	Lattice Semiconductor*	Canyon Bridge Capital Partners	$1.3 billion
Feb-18	Xcerra Corp*	Hubei Xinyan	$580 million

*Note: * = Proposed Transaction Terminated. Source: Rhodium Group.*

Table 4 lists the announced Chinese semiconductor related investment into the United States by the year.

Figure 1: Worldwide Semiconductor Consumption Market by Region, 2003-2016



Source: PwC, "China's Semiconductor Market," 2017

Figure 1 depicts the worldwide semiconductor consumption market by region from 2003 to 2016. The graph shows us that China has come out on top year after year with an all-time high in 2016.

Figure 2: The "Global Market Share" of The Semiconductor Industry (2020)

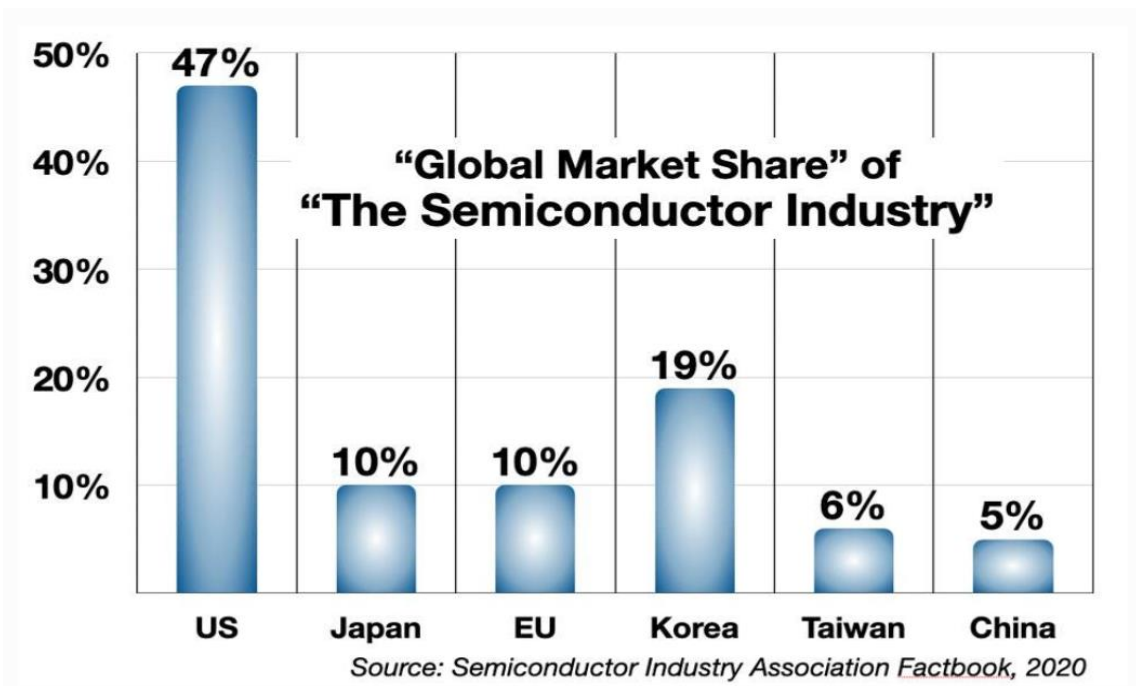


Figure 2 goes further to show us the Global Market Share of the Semiconductor Industry as of 2020. The United States has the largest global market share.

Figure 3: Semiconductor Manufacturing Capacity (2021)

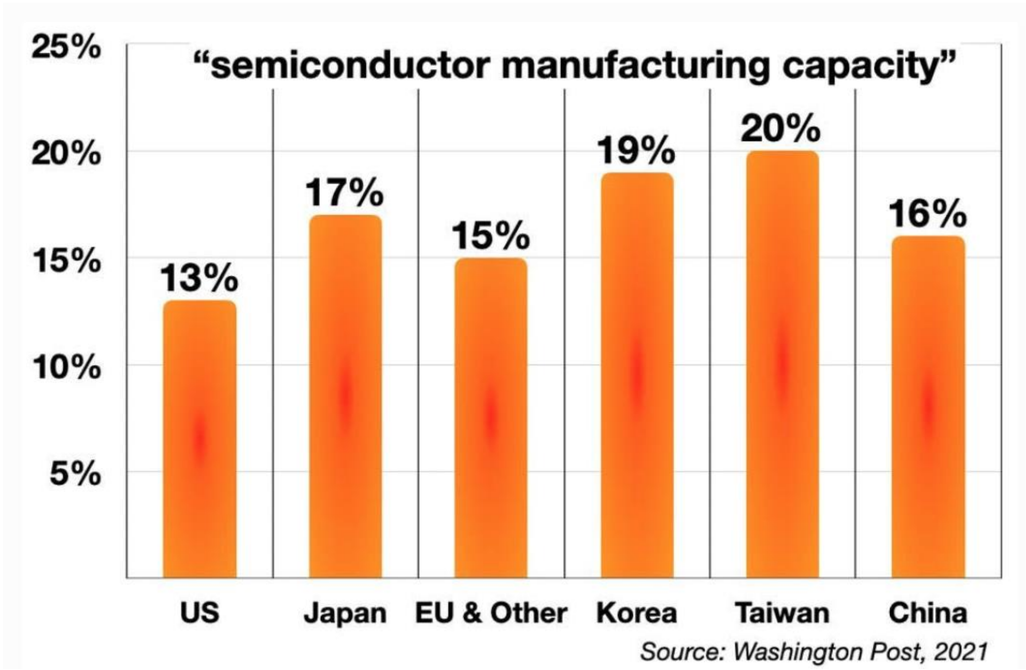


Figure 3 describes the semiconductor manufacturing capacity of 2021 with Taiwan coming out on top.

Figure 4: Where Semiconductors are Manufactured or Assembled (2021)

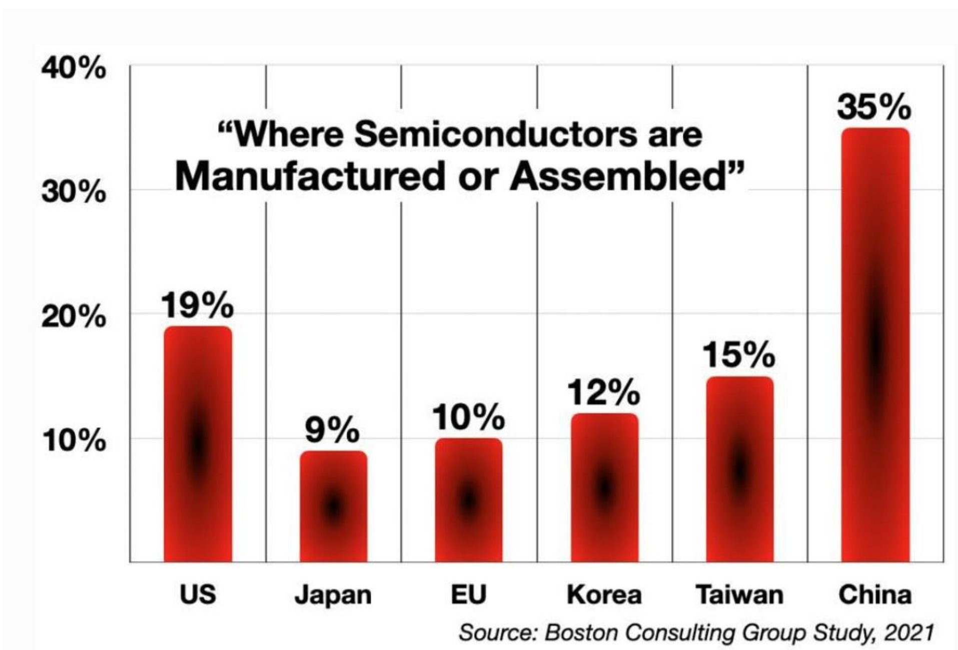
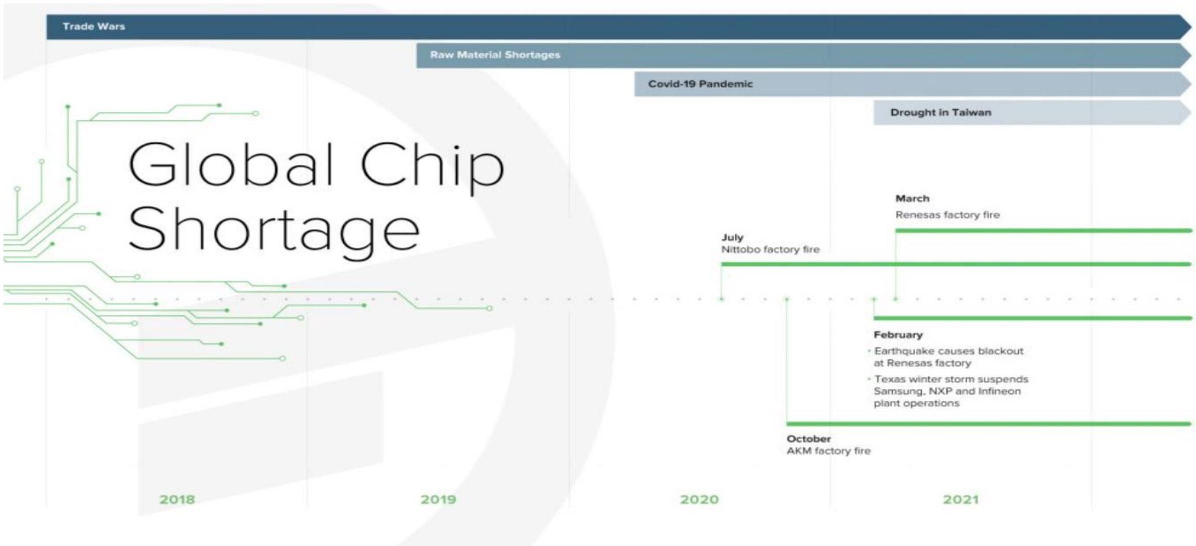


Figure 4 analyzes where semiconductors are manufactured or assembled globally. The graph shows us that most semiconductors are manufactured or assembled in China.

Figure 5: Global Chip Shortage



Source: Fusion Worldwide

Figure 5 analyzes the global chip shortage starting in 2018 to present. It mentions various factory fires.

Figure 6: Global Semiconductor Market Share, by Major Country/Region

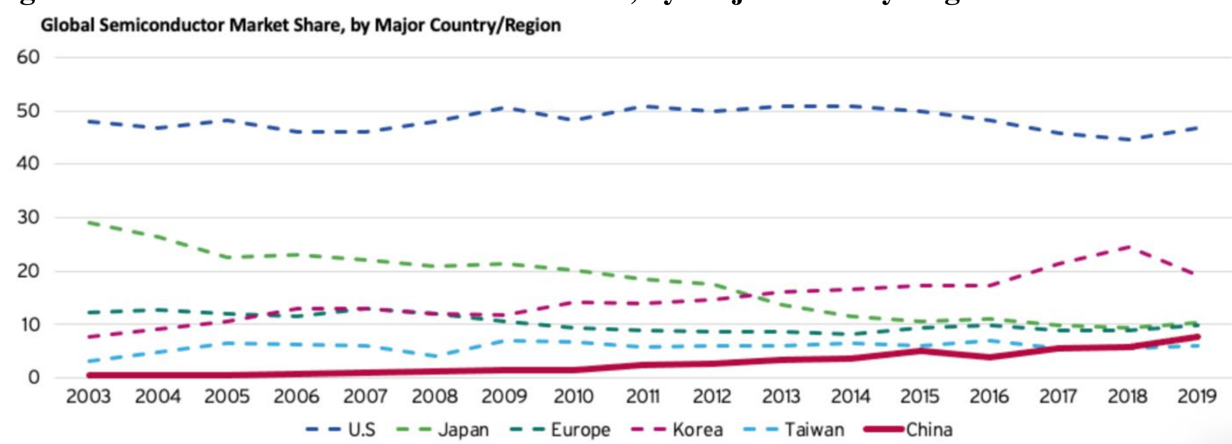


Figure 6 shows the global semiconductor market share by major country and/or region from 2003 to 2019. China remains stagnant throughout.

Figure 7: China-Based Fabs More Cost Competitive Due to Government Support

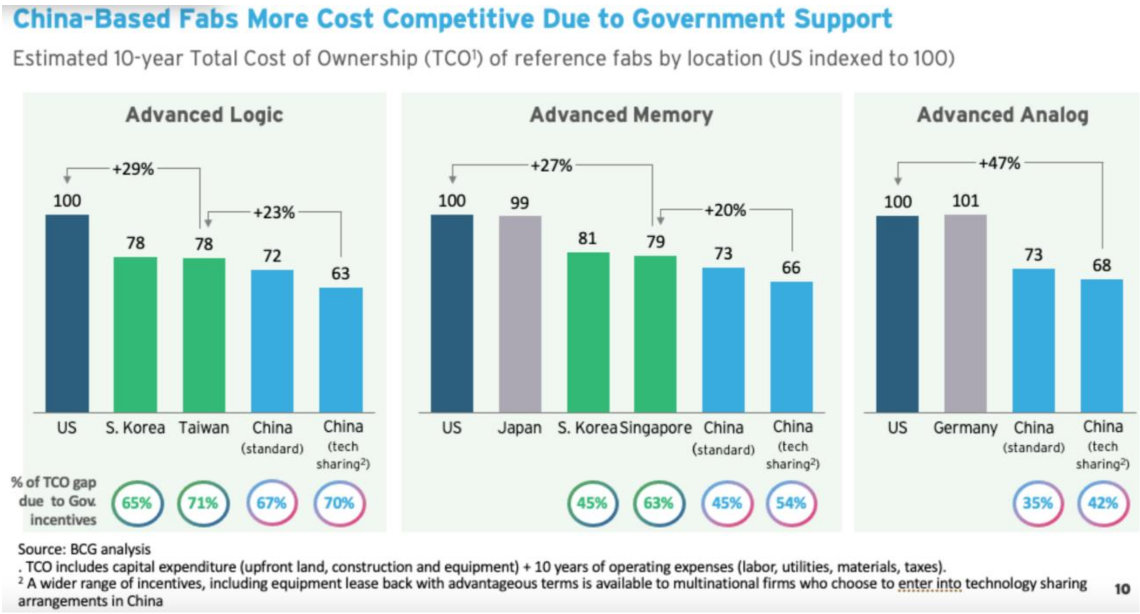


Figure 7 analyzes China-Based Fabs that become more cost competitive due to government support for an estimated 10-year total cost of ownership (TCO) of reference facts by location (US indexed to 100).

Figure 8: China Share of Worldwide Semiconductor Fabrication Capacities

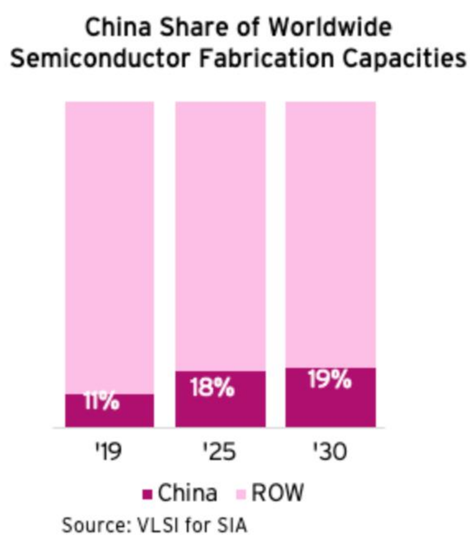
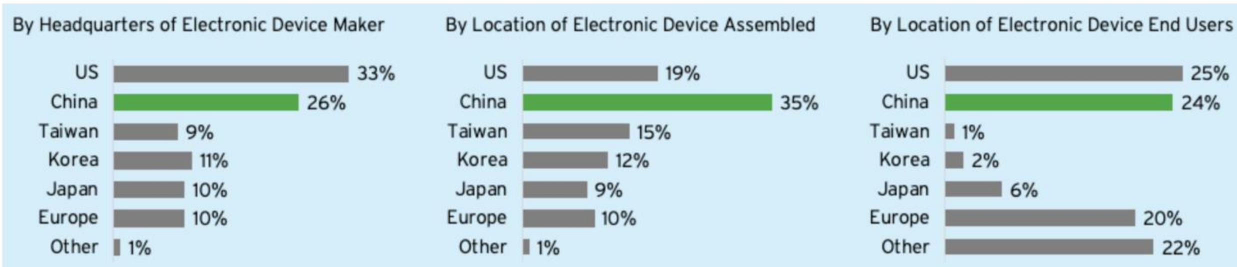


Figure 8 further describes China's share of worldwide semiconductor fabrication capacities.

Figure 9: Global Semiconductor Sales by Geographic Area, 2019 (%)



Source: UN Comtrade; BCG x SIA: Strengthening the Global Semiconductor Supply Chain in an Uncertain Era

Figure 9 depicts the global semiconductor sales by geographic area in 2019 in percentages.

A detailed list of AI-related technologies in China:

Clearly, with an adequate industrial base in high technology, China can catch up and become a leader in many areas of AI. China has made rapid progress in catching up and is either at the frontier or already dominant in the following AI areas:

- Brain models, Brain mapping, Cognitive science
- Natural language processing
- Fuzzy logic and soft computing
- Expert systems
- Decision support systems
- Automated problem solving
- Knowledge discovery
- Knowledge representation
- Knowledge acquisition
- Knowledge-intensive problem solving techniques
- Knowledge networks and management
- Intelligent information systems
- Intelligent web-based business
- Intelligent agents
- AI and evolutionary algorithms
- Distributed AI algorithms and techniques
- Neural networks and variations, including: Deep Learning
- Heuristic searching methods
- Constraint-based reasoning and constraint programming
- Intelligent information fusion
- Learning and adaptive sensor fusion
- Search and meta-heuristics
- Integration of AI with other technologies
- Social intelligence (markets and computational societies)
- Social impact of AI

- Emerging technologies
- Applications (including: computer vision, signal processing, military, surveillance, robotics, medicine, pattern recognition, face recognition, finger print recognition, finance and marketing, stock market, education, emerging applications, ...)

MACHINE LEARNING; MODELS, TECHNOLOGIES & APPLICATIONS:
- Statistical learning theory
- Unsupervised and Supervised Learning
- Multivariate analysis
- Hierarchical learning models
- Relational learning models
- Bayesian methods
- Meta learning
- Stochastic optimization
- Heuristic optimization techniques
- Neural networks and variations (eg. Deep Learning)
- Reinforcement learning
- Multi-criteria reinforcement learning
- General Learning models
- Multiple hypothesis testing
- Markov chain Monte Carlo (MCMC) methods
- Non-parametric methods
- Graphical models
- Bayesian networks
- Cross-Entropy method
- Time series prediction
- Fuzzy logic and learning
- Inductive learning and applications
- Graph kernel and graph distance methods
- Graph-based semi-supervised learning
- Graph clustering
- Graph learning based methods
- Motif search
- Aspects of knowledge structures
- Computational Intelligence
- General Structure-based approaches in information retrieval, web authoring, information extraction, and web content mining
- Latent semantic analysis
- Aspects of natural language processing
- Intelligent linguistics
- Computational Neuroscience

- ALGORITHMS FOR BIG DATA:
  Data and Information Fusion

Algorithms (including Scalable methods)
Signal Processing
Data-Intensive Computing
High-dimensional Big Data
Multilinear Subspace Learning
Sampling Methodologies
Streaming

- BIG DATA FUNDAMENTALS:
Novel Computational Methodologies
Algorithms for Enhancing Data Quality
Models and Frameworks for Big Data
Graph Algorithms and Big Data

- INFRASTRUCTURES FOR BIG DATA:
Cloud Based Infrastructures (storage & resources)
Grid and Stream Computing for Big Data
Autonomic Computing
Programming Models and Environments to Support Big Data
Software and Tools for Big Data
Emerging Architectural Frameworks for Big Data
Paradigms & Models for Big Data

- BIG DATA MANAGEMENT AND FRAMEWORKS:
Database and Web Applications
Federated Database Systems
Distributed Database Systems
Knowledge Management and Engineering
Novel Data Models
Data Preservation and Provenance
Data Protection Methods
Data Integrity and Privacy Standards and Policies
Scientific Data Management

- BIG DATA SEARCH:
Multimedia and Big Data
Social Networks
Web Search and Information Extraction
Scalable Search Architectures
Cleaning Big Data, Acquisition & Integration
Visualization Methods for Search
Graph Based Search and Similar Technologies

- PRIVACY IN THE ERA OF BIG DATA:
Cryptography

Threat Detection Using Big Data Analytics
Privacy Preserving Big Data Collection
Intrusion Detection

- DATA MINING/MACHINE LEARNING TASKS:
  Regression/Classification
  Segmentation/Clustering/Association
  Deviation and outlier detection
  Explorative and visual data mining
  Mining text and semi-structured data
  Temporal and spatial data mining

- DATA MINING ALGORITHMS:
  Artificial Neural Networks / Deep Learning
  Fuzzy logic and rough sets
  Decision trees/rule learners
  Evolutionary computation/meta heuristics
  Statistical methods
  Collaborative filtering
  Case based reasoning
  Ensembles/committee approaches

- DATA MINING INTEGRATION:
  Mining large scale data/big data
  Data and knowledge representation
  Data warehousing and OLAP integration
  Integration of prior domain knowledge
  Metadata and ontologies
  Legal and social aspects of data mining

- APPLICATIONS and Further Research Areas:
  Bioinformatics, Medicine Data Mining, Business/Corporate,
  Industrial Data Mining, Direct Marketing, Database Marketing,
  Engineering Mining, Military Data Mining, Security Data Mining, ...

- Data to Information to Knowledge Mapping
- Knowledge Mining
- Business Intelligence
- Information Retrieval Systems
- Knowledge Management and Cyber-Learning
- Database Engineering and Systems
- Data and Knowledge Processing
- Data Warehousing and Datacenters
- Data Security and Privacy Issues
- Information Reliability and Security
- Information and Knowledge Structures

- Knowledge and Information Extraction and Discovery Techniques
- Knowledge and Information Management Techniques
- Knowledge Extraction from Images
- Knowledge Representation and Acquisition
- Large-scale Information Processing Methods
- Intelligent Knowledge-based Systems
- Decision Support and Expert Systems
- e-Libraries (Digital Libraries) + e-Publishing
- Ontology: Engineering, Sharing and Reuse, Matching and Alignment
- Agent-based Techniques and Systems
- Workflow Management
- Content Management
- Data and Knowledge Fusion
- Global Contextual Processing and Management Implementation
- Data/Information/Knowledge Models
- Managing Copyright Laws
- Interoperability Issues
- Transaction Systems
- Ontologies and Semantics
- Object-oriented Modeling and Systems
- Case-based Reasoning
- Classical Aspects of Information Theory
- Applications (e-Commerce, Multimedia, Business, Banking, ...)
- Natural Language Processing
- Information Integration
- Multi-cultural Information Systems
- Domain Analysis and Modeling
- Metamodeling

Theoretical, mathematical, empirical and experimental aspects of cognitive computing, including:

- Bio Inspired Cognitive Algorithms
- Improving Cognition in machine learning systems
- Modeling Human Brain processing systems
- Multimodal learning systems
- Reinforced learning
- Cognitive evolution
- Cognitive inferential systems
- Cognitive improvement in deep learning networks
- Advancements in Neural Networks
- Multiscale Learning systems
- Fractal based learning and decision support systems
- Application of chaos Engineering in machine intelligence
- Dynamical learning systems
- Application of Information Theory in Machine Intelligence

- Application of linear and nonlinear optimization theory in ML
- Self-Adaptive and Self Organizing Systems
- Manifold and Metric learning
- Cognitive Modeling, Visualization and Analytics of Big Data
- Graph Theoretic approaches in dimensionality reduction
- Information and Knowledge retrieval and searching algorithms
- Big data knowledge mining
- Mathematical modeling of Big Data and Artificial Intelligence
- Cognitive Signal Processing
- Rough Set Theory
- Agent Based Modeling in Machine Learning Systems
- Information Processing and Decision Making Systems
- Big Data Fusion and Information Retrieval
- Time and Space Analysis in Machine Learning
- New application of classical stochastic and statistical analysis for big data machine learning
- Nature inspired cognitive computing algorithms
- Cognitive Feature Extraction
- Extraction of latent semantics from big data

Conclusions: ANIS in China and its prospects during the 4th Industrial Revolution

It is clear from the above analysis that China is firmly on its way towards forming an ANIS for the 4th industrial revolution. Among other things, this has led to a new model for indigenous platform economy. A study of the Chinese platform firms such as Tencent and Alibaba demonstrate that in contrast to the US Silicon Valley model (internal development and introduction, acquisition, and venture capital investment) PRC firms have developed two different strategies. The first is listing some of their existing operations separately on the stock market but still maintaining control. The second strategy is interfirm cross investments. They are not identical but have similarities with the Japanese *Keiretsus*. As the 4th Industrial Revolution in China proceeds further the corporate forms for AI-related firms will evolve further and corporate governance in Chinese State-Private Sector mode will develop. Khan (2004a, 2004b) indicated this line of development for corporate governance in technology sectors for Japan, Taiwan, Singapore and Korea in particular that prefigured the path for China today. Of course, since 2012 if not earlier, Chinese state has become even more involved in corporate governance of high technology sectors during the fourth industrial revolution.

Consideration of the East Asian high technology development experience and the Chinese innovation system leads to an important geoeconomic conclusion regarding China during the 4th Industrial Revolution. China is an exceptional case that will be impossible to replicate under the current neoliberal geoeconomic rules of the game instituted by the US and other advanced capitalist countries since the 1980s. Even if these rules change and some other countries can move forward on the path of industrialization, the older 20th century modes of industrialization based on fossil fuel-based technology will not be sustainable. I have sketched such an alternative strategy for China in Khan (2010) and Jiang and Khan (2017) that relies much less on fossil fuels and emphasizes regional cooperation. Here I have shown how the ANIS of China can begin to move towards a leading and socially beneficial institutional structure. Methodologically, the nonlinear modelling approach has been shown to be especially relevant for studying the properties of multiple equilibria and complex dynamics. Technically, the availability of intertemporal ecological disaggregated SAMs can make the models of this paper fully applicable and policy-relevant. But even the partial empirical demonstration illustrates the usefulness of this conceptual framework.

However, time is of the essence. Given the path dependence of development unless strategic disengagement from the existing path followed by a strategic engagement with the alternative strategy is begun within the next five years, it may well be too late. The stakes are indeed very high. The crucial question is what kind of transformations in the global economic environment and development discourse will influence the policies in the right direction. A related question is: how can China play an enabling role in furthering sustainable industrialization and development for the developing countries?

More broadly, we can conclude that during the 4^{th} industrial revolution, the geoeconomics for region-building, much like the economics of nation-building earlier, will consist of developing connectivity and dependencies with strategic industries, transportation corridors, and financial instruments. Our analysis predicts that these are indeed the areas that will receive increased attention from PRC strategists. In particular, as geopolitical tensions continue to increase, China will put increased emphasis on creating innovation and manufacturing capabilities in defense related technologies including advanced semiconductors.

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