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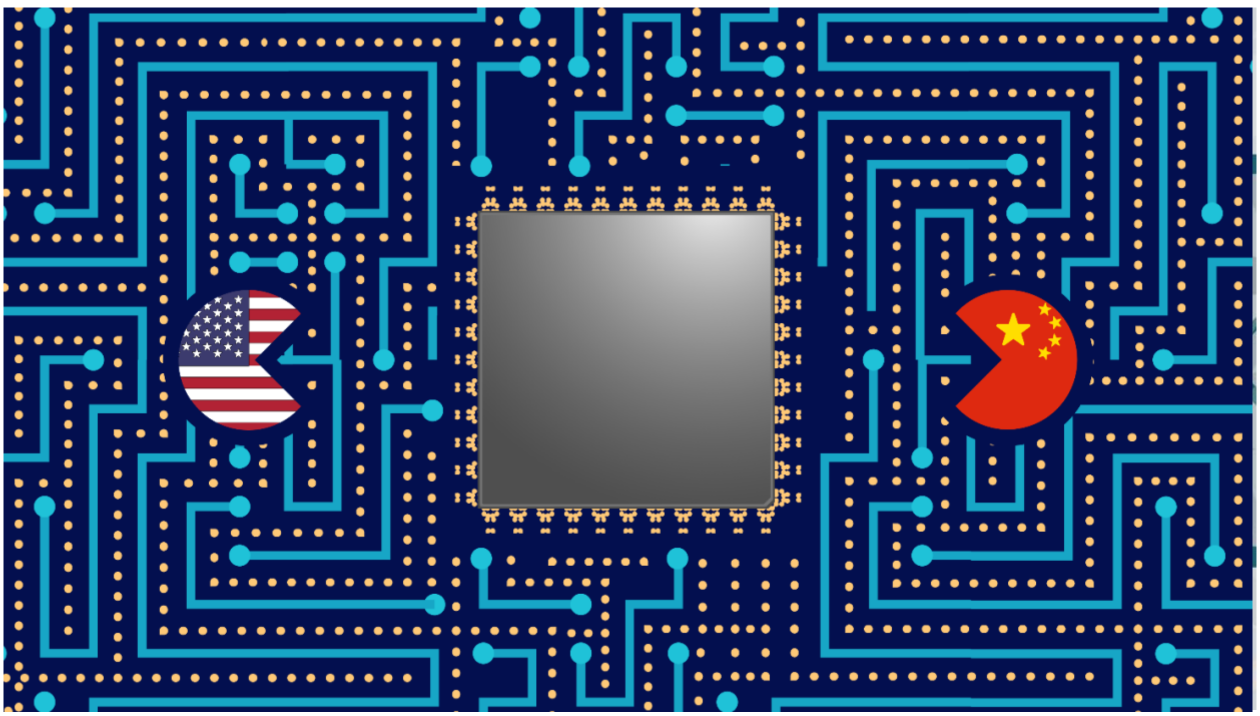

The Chip War Has Started

The Aerospace and Defence Industry is one of the Battlefields

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Summary

A 'chip war' between the United States and China has been often announced in the last few years, with several US imposed restrictions on the export to China of technologically advanced semiconductor products. The US has also banned the import of advanced telecommunication products from China to the US and Europe: the Huawei 5G case. The war seems now to have started in earnest on October 7, 2022 when the US Department of Commerce published new, extensive, and very stringent rules limiting the export to China of advanced semiconductor products from the US and some foreign countries that are currently suppliers to China. So far, the Chinese reaction has been quite controlled; any retaliation, however, especially if it should include Taiwan and its TMSC industry with its almost unique production capabilities (TMSC today represents a choke-point for practically all Western and Asian semiconductor industries) would be extremely serious and disruptive.

The purpose of this paper is to describe the quite complex present situation and its possible evolutions, with special attention to the aerospace and defence industries. Even in the absence of real hostilities, we note a distinct trend in several world areas such as the USA, Europe, China and Japan, of making large investments to attain a higher level of independence. This is done by a more extensive "in shoring" of the semiconductor supply chain through increased national activities for the near, medium, and long-term future. The forecast envisioned here is a period of transition with various possible levels of instability and of uncertain duration, with obvious impacts on all industries that use semiconductors, and a very unpredictable end point.

In addition, it must be noted that since the Chip War has been quietly adopted by the US as a new Offset Strategy toward China, any prediction is obviously tied to the future relations of the two superpowers. In the event of a crisis, the US industry is certainly in a more favourable position with respect to other parts of the world, although it is not entirely immune to unpredictable developments. It would certainly pay a hefty price for the loss of the Chinese market.

A seminal book

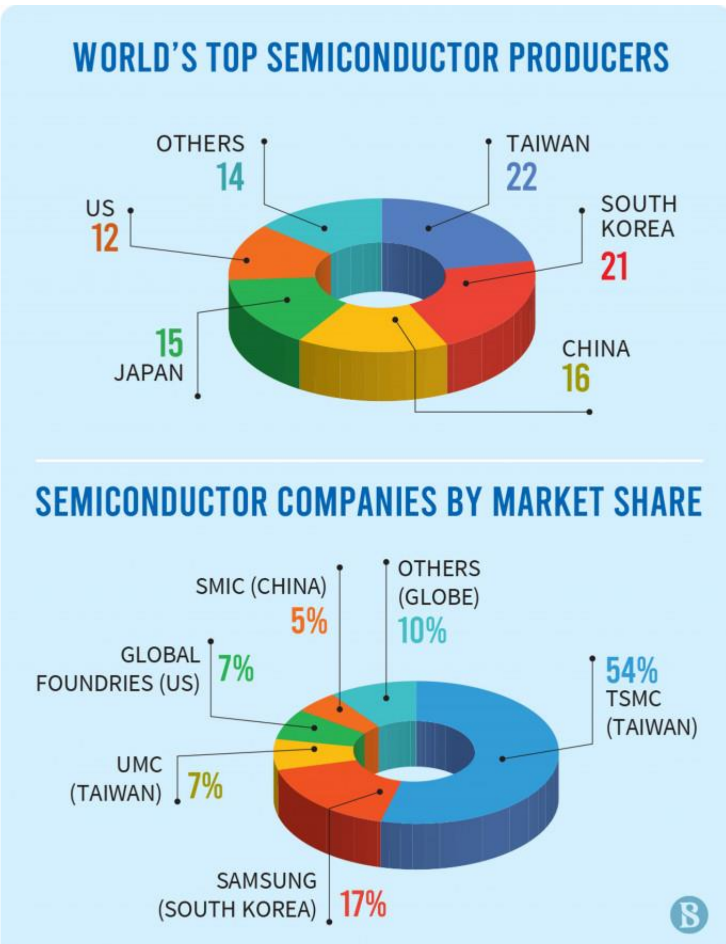
The attention to the strategic and economic importance of semiconductors and their role in trade conflicts mainly between the US and China, and even possible weaponisation, has increased in the last decade, particularly in the last five years, even though with a variable level of intensity and therefore impact. After more or less serious skirmishes during the Obama and Trump presidencies, a sign of the intensification and somewhat threatening aspect of the problem was the media attention, especially that of The Economist, which in the Dec 1-7 issue of 2018 dedicated its cover to "Chip Wars-America, China and Silicon Supremacy." Inside the issue, one of the leaders on trade and technology was "Chip Wars", and the briefing column was on chipmaking: "The Chips are Down". The focus of the magazine was well summarized in the subtitle of the leader "America cannot afford to ignore China's semiconductor ambition. It cannot tame them easily either."

In the briefing we read "Industry shows the power of globalization. Superpower politics may unravel things." One important and somewhat striking piece of information contained in the articles is that China had been spending more on importing semiconductors than on oil. Furthermore, it was clear that while firms from America and its allies, like South Korea and Taiwan, dominate the most advanced side of the industry, China relied mostly on the outside world for supply of all high-end chips. We have spent so much space quoting The Economist, not only because of its reputation and its ability to spot early trends and risks in the world political and economic affairs, but because it contained, in a very clear way, all the basic elements of the issue in question here. The purpose of this paper is to illustrate the possible evolutions of the semiconductor conflict today, both economic and technological, and the impact it might have on the world semiconductor industries, with a brief zoom on aerospace and defence.

Fast forward, and we move to October 2022 with the appearance of the book *Chip War: The Fight for the World's Most Critical Technology*, by Chris Miller, Professor of History and Economics at Tufts University, in Boston. The book was immediately recognized by The Financial Times as the winner of the "Business Book of the Year" award. It is certainly excellent reading and a considerable part is devoted to a discussion and justification of the subtitle "The fight for the world's most critical technology". We will quote its content at length because it provides a thorough description of the stage in which the conflict is unfolding today.

The first part of the book contains a history of semiconductor technologies and the related industries, particularly in the USA, Taiwan and China (and briefly Russia) and explains its relevance in the world economy. It also describes the basic elements of the technology and the continuous so-far successful attainment of the Moore's Law, up to 3 nm today (with 2 nm envisioned) also using new technologies such as 3D transistors (FinFET) and other innovations. Chips come in a variety of types, according to their functional use, active, passive, analogue, digital, processors, memories and the more advanced types such as ASIC (Application Specific Integrated Circuit), FPGA (Field Programmable Gate Array), SoC (System on a Chip), etc… The substrate may involve different materials, although 80% use silicon.

In spite of this variety, the process of going from the raw material to the finished product is somewhat similar for all semiconductors, and involves the same basic steps: design, preparation of the material, manufacturing, packaging, assembly at various levels, with several cycles of testing during most steps of the process. A good part of the book is dedicated to its complexities, each step is really a complex process in itself, and renders the supply chain very complex and rather unique.



Today, the making of a chip is a triumph of globalization, and involves many actors from many countries and their industries. It is also, however, an ensemble of very specialized suppliers, often leaving users with few options: for example, advanced chips (up to 3nm) are manufactured today by an oligopoly of TMSC (Taiwan Semiconductor Manufacturing Company) with almost 90%, Samsung (South Korea) and Intel (US), the machines for EUV lithography necessary for these chips are an essential monopoly of ASML (The Netherlands), while Tokyo Elektron (Japan) has machines mostly for its own use, and the tools that deposit the layers of materials on silicon wafers are made by another oligopoly of US companies (Applied Materials, Lam Research and KLA). In addition, all these companies are certainly not vertically integrated but need a score of very specialized, sometimes unique, suppliers like those for silicon ingots of large dimensions, or other more exotic materials, and special gases from Japan necessary for the production line of TMSC; some other special gases, like neon and palladium are even supplied by Ukraine. Similarly, lasers and extremely precise optics from only one company in Germany (Trumpf) are necessary to ASML for their EUV lithography machines.

Some of these suppliers have become so specialized and they have required such large investments, that today customers do not have practical alternatives.

One of the most important messages of the book is thus that the production chain of semiconductors today is extremely efficient, reliable, and competitive. It is also, however. extremely critical given that it is subject to the vagaries of politics, shifting economic convenience, and even natural disasters (Miller mentions a 7,8 Richter scale earthquake in Taiwan in December 1999, reminds us that Silicon Valley sits on the San Andreas fault in California and that Japan is also a well-known seismic area). The book, however, indicates Taiwan and TMSC as the most critical element today in the whole chain, at least for the most advanced chips: the last chapter is tellingly entitled "The Taiwan Dilemma". The political problem of Taiwan is well-known and most of the chapter is a "what if" discussion: what would happen if the US approach of "strategic ambiguity" towards Taiwan were no longer feasible and/or the Peoples Liberation Army "exercises" around the island degenerated into various forms of destructive military power against Taiwan, or also just seize control of TMSC, or if the island was hit by a major earthquake, as happened in the recent past. The consequences for the world economy would be catastrophic. This last chapter also contains a very critical assessment of the Russian industry semiconductor capabilities. Apparently, most of the needs of Russian semiconductor industry are outsourced, and the only chip making activities at home are earmarked for space and defence projects where the modest production volume does not justify the enormous investment needed for a strong and innovative national industrial capability. The military and space industries are also limited by heavy sanctions, imposed after the Ukraine War. Closing the review of the book, one could observe that while the title is certainly appropriate, an alternate just-as-appropriate title could have been borrowed from that of Churchill's first volume of *The History of World War Two,* "The Gathering Storm". This, in fact, is the feeling one has after reading *Chip War.*

The publication of the book was certainly very timely and also interpreted the awareness in Europe, the US, and other parts of the world, that the international semiconductor situation was becoming in danger of being out of control and in need of better resilience and governance. A wake-up call to action came from the shortages of semiconductors experienced in 2020: this was mostly due to the pandemic, and its varying impacts in different nations, but also to the acceleration of digital transformation of industry. Europe moved first with the European Commission proposal "European Chips Act" in February 2022. The Chips Act will mobilize 43 bn Euros over seven years in public and private investments focussed on three pillars: 1) Chips for Europe initiatives supporting technological capability building and related research and innovation 2) a new framework to ensure security of supply and resilience by attracting increased investments 3) a mechanism to monitor the semiconductor supply chain and coordinate action in crisis situations. The European Council adopted a position in December 2022 essentially agreeing on the proposal, albeit asking the Commission for clarifications and a few changes. The Council also obtained the mandate to negotiate with the Parliament for final approval.

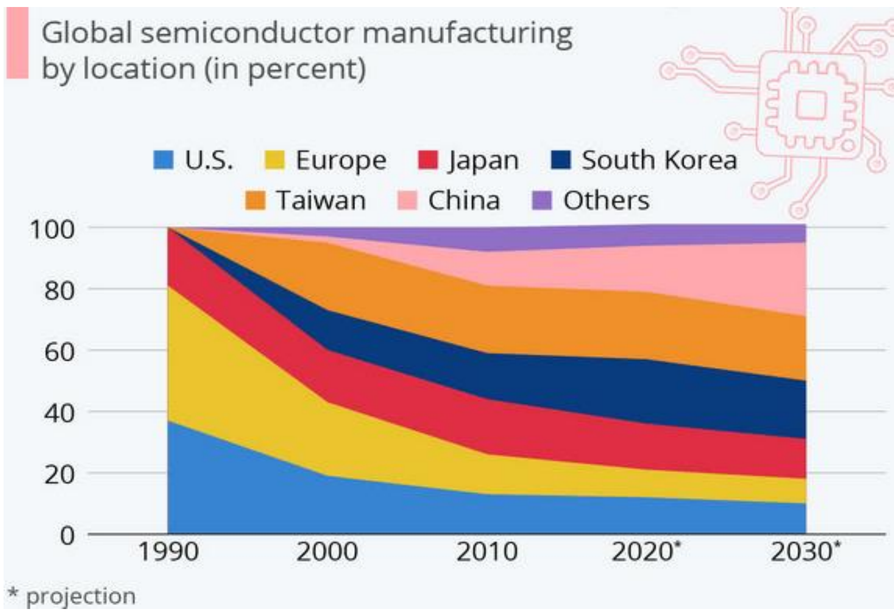
The European Chips Act, the CHIPS and Science Act and export controls

The shortage of semiconductors has also been felt in the USA, together with an increasing uneasiness over the complexity and vulnerability of the supply chains, especially when it comes to TMSC. A bipartisan flurry of activities started in various directions, and the first important success was that in

May 2020 TMSC decided to invest 12 bn dollars to open a plant in Arizona, with work starting in 2021 and a target to be operational in 2024. Congress continued working to strengthen the semiconductor and telecommunication national position with a proposal of allocating 106 bn dollars, of which 52 would go to semiconductors to build new chip manufacturing plants and to fund scientific R&D in the field. All these proposals found their way into a new wider initiative, "CHIPS and Science Act" that was signed into law by President Biden on August 9, 2022. The act provides roughly 280 bn dollars over the next ten years, distributed in three divisions, A) The CHIPS (Creating Helpful Incentives to Produce Semiconductors) Act of 2022; B) R&D Competition and Innovation Act; C) Supreme Court Security Act of 2022.

As mentioned earlier, the publication of *Chip War* was timely. In a striking coincidence, the war started in earnest on the 7th of October, when the Department of Commerce released an announcement, "Commerce Implements New Expert Controls on Advanced Computing and Semiconductor Manufacturing Items to the People's Republic of China (PRC)". This strengthened rule came shortly after a more limited one intended to deny the export of chips and related technologies if such items were likely to be used for military purposes. The new Export Control restricts the PRC to obtain advanced computing chips, advanced chip manufacturing tools and related software. While the emphasis is always on military applications, the new rules in fact aim to exclude the PRC also from any activity in artificial intelligence and advanced computing based on foreign imports. Furthermore, what the new rules also do, is expand the jurisdictional scope of EAR (Export Administration

Regulations) over foreign products in the areas of semiconductors and telecommunications for their commercial activities toward export to China. The US move in this "fight for the world's most critical technology" is quite far-reaching and can be considered as a novel type of Offset Strategy towards China, i.e., a conflict strategy that seeks to maintain leadership over an adversary by shifting competition to more favourable ground. The USA, in this case, stunts China's growth in all areas of modern technology that need advanced chips, by preventing China from having access to most of the advanced semiconductor technologies available in the West and the best of Asia.



As mentioned earlier, China's reaction has so far been relatively muted, although it is almost impossible to predict its behaviour in the future. Almost immediately, China responded by filing a dispute with the WTO (World Trade Organization). China's Commerce Minister affirmed that its WTO complaint was a legal and necessary measure to defend its "legitimate rights and interests". But, at the same time, China unveiled a plan to invest 1 trillion Yuan (143 bn dollars) in its chip industry over a five-year period, with a focus on advanced manufacturing. It is also significant to mention that, again at the same time, Japan became the latest country to take steps towards at least partial independence, announcing a partnership with IBM, aiming to have advanced chipmaking running in Japan for the second half of the decade.

It is hard to predict the impact of the new rules on the world supply chain of semiconductors, especially for the most advanced chips and the US semiconductor industry and the world users of semiconductors. It is probably just enough to preface our considerations mentioning a quote that the book attributes to a US semiconductor executive: "our fundamental problem is that our number one customer is also our number one competitor." It is also certainly worth mentioning that shortly after the Biden announcement, TMSC, probably one of the most affected industries, decided to more than triple its investment in Arizona, bringing it from 13 bn to 40 bn to build two more fabs (a semiconductor fabrication plant, commonly called a fab; sometimes foundry). It also began negotiations with Germany to open a plant in Dresden. To date, however, what is not clear is whether TMSC will completely transfer all its technological assets and know-how outside of Taiwan.

We continue by complementing what we said earlier about China's reaction: China could, in retaliation to the US and other nation's moves, enact a similar rule by blocking its export of semiconductors around the world. Having invested over 100 bn dollars in the recent past to support the local chip industry, that industry is today selling semiconductor products at considerably lower prices than its rivals; even though its technology allows only low-end chips (up to 14nm), China accounts for almost one-fifth of the world's production, even more than the US. This form of retaliation, however, does not seem really likely due to its cost for China (economics, however, are not the only criterion used in China to make decisions). China could instead retaliate on other fronts, perhaps over rare metals and other rare earths. It holds, for example, 65% of the world's lithium. China could also, as it has declared recently, use its massive new investments to strengthen its market position by also competing in the high-end chips sector. Such a move, however, even starting now, would not yield results soon because China has yet to travel a long road.

The new US export rule will considerably affect all semiconductor companies in the US, but also in Europe, Japan, and other parts of the world that have significant interest in, and exposure to, the Chinese market. Here are some examples:

- in the US, companies that sell and were planning to continue selling advanced chips to China (such as Qualcomm, Intel, NVIDIA and AMD, etc…), all the chipmaking equipment producers (such as Lam Research and KLA Co.) and the leading provider of automatically design chips i.e., Cadence (whose total export from the US to China is about 10 bn dollars);
- Across the world there are AMSL (EUV Lithography) in Europe, Samsung in South Korea, Tokyo Elektron in Japan and TMSC in Taiwan.

> All these companies are now, in one way or another, negotiating with the US government to better assess the application of the new rules: the SIA (Semiconductor Industry Association, an international organization), issued for example, a statement immediately after the new export rule, stating that "*we are assessing the impact of the new export rules and working with the member companies, and the US government to ensure compliance. We understand the goal of ensuring national security and urge the US government to implement the rules in a targeted way and to collaborate with international partners to help level the playing field and mitigate unintended harm to US innovation*". A prudent but also concerned statement, for sure. The impact will naturally depend on the specificity of each industry and on the extent of the application of the new rules, and on the "case by case" approach of the Department of Commerce.

What we are witnessing today is a tendency to unravel the globalization of chip production, and actions in many world areas attempting to gain a much greater, if not total, level of independence in better controlling the process and therefore the supply chain. This strategy is supported by large planned public investments, in the USA, China, Europe and Japan, and is motivated by a concern about the excessive granularity and vulnerability today of the supply chain, as well by an increased concern with, and attention to, security.

For the US, it is also a renewed strong statement of wanting to maintain a clear leadership in semiconductors. As mentioned before, the same statement has been recently made by China, which, however, would start from a technological level which is very distant from today's frontier. All planned investments are, of course, medium or long term, while the US tightening of export control should have an immediate effect even with some possible exceptions. It seems, therefore, more than reasonable, to expect – sooner or later- a new equilibrium at the political, economic and technological levels, with associated new trade policies and new supply chains. It is obviously quite difficult to predict how long the transition will take and how smooth or bumpy it will be in view of the many (known) unknowns that the situation clearly presents.

In addition, the transition takes place in a situation, that is most probably temporary, of market weakness: last year global sales dropped 9.2% with respect to the previous year, and the forecast for 2023 is an additional drop of 4%. The world market, however, is expected to resume growth at 8% per year and to reach 1 trn dollars by the end of the decade. In spite of the many variables involved, the key element of uncertainty, as mentioned earlier, resides in Taiwan's production capability and its future: the stability of Taiwan and specifically TMSC is likely to lead to a smooth transition, while a serious sudden perturbation concerning TMSC would be catastrophic in the short and medium term.

The critical environment for the Aerospace and Defence Industry

As anticipated in the subtitle of this paper, we wish now to zoom in on the Aerospace and Defence (A&D) Industry, and to devote some space to this important sector. Advanced semiconductors play a crucial role in the A&D industry: the chips generally perform some very special functions and there is therefore a need to emphasize performance over the criteria used in the commercial sector where the priorities are rapidity to enter the market, simplicity of manufacturing and cost. The differences, therefore, are many and significant. The first difference is not technological or functional: the total market value of A&D semiconductors is between 1% and 2% of the total market (almost 600bn dollars) with all the understandable consequences of such a low market leverage.

Owing to the very demanding performance required, design is generally very complex, design for example of ASICs, PFGAs, and SoCs require a high level of expertise and are often done in partnership. In addition, military and space specifications are significantly more stringent because of the demanding operational requirements. Thus, parameters such as temperature, radiation (especially in Space), humidity, shock, etc. have wider design ranges and it must also be taken into account that the design lifetime of A&D chips is expected to be quite a bit longer than that of a commercial chip.

The production of A&D chips follows the same basic steps of all other chips but each step has different requirements and criticalities that make the process need much more scrutiny and different and better resources. For example, ceramic-metal packaging is often used to increase reliability, but also with the effect of adding complexity and cost and the testing requires more attention and more time since A&D chips have to be certified or qualified according to demanding standards. Another example of the difference is the choice of the substrate of the chips: while commercial chips mostly use silicon, A&D require a variety of substrate depending on the application: thus, in addition to silicon and silicon carbide A&D chips often require more exotic materials for better performance such as gallium, with its compounds (arsenide, nitrate, etc…), indium and its compounds (phosphide, etc…), antimonides and others. Special foundries are therefore required and in spite of the many industrial foundries available and large national programs such as the US Trusted Foundry Initiative, much production of these materials is still done in Asia (over 80% of the world production of gallium arsenide, for example, is today done in Taiwan by WIN and TMSC).

Owing to this complexity of the A&D chips, the web of suppliers is more specialized and therefore limits the availability of options. In addition, constant concern in the process of making A&D is about security since cyber threats are present in all phases of the process and require adequate countermeasures. As mentioned earlier, the web of suppliers is even more specialized than for the commercial chips, thus adding criticality to the production process.

Another important risk for European and Asian A&D industries resides in the fact that, like many other industries whose revenues include a significant component from export, they will be affected by the US trend of bringing home elements of the supply chain. This trend potentially restricts the options of the buyers and increases the share of US made components in their products: this will have the effect of bringing more of those products under the control of US export rules. The A&D industry, which shares an articulated supply chain with other industries, is then in an even more critical situation because of its complexity and the extreme specialization of some of its suppliers, and consequent difficulty of finding options. Needless to say, although we have discussed the A&D industry in general, the difference between the USA and the world remains very large, in terms of technology, capitals and preparedness, with the USA enjoying, of course, a much stronger position.

From another perspective, however, A&D industry almost always enjoys a beneficial link to government: sometimes governments have at least partial ownership of those industries and they always maintain a consistent level of control and attention. Governments also fund a significant amount of R&D and innovation, as has been shown with the European Chips Act and the Chips and Science Act in the US. The US government is also already funding several lines of research in semiconductors especially at DARPA. A particularly interesting example is the funding of several universities in a promising line of research, trying to use novel techniques for a return to silicon as a main substrate for military and space chips, with significant cost reduction in manufacturing. The conclusion of these brief considerations, for the A&D industry is that in a possible 'chip war', the A&D battlefield would clearly see the industry in a more difficult situation than other industries, but would probably enjoy some government support and thus be able to fight more effectively.

Before concluding the paper, it is appropriate to mention that the US new, very far-reaching export control has not been without criticism both at economic and ideologic levels, both within and outside the US. We have chosen two articles, among many, as examples: S.B. Dantzen and E. Kilgram "The Illusion of Controls- Unilateral Attempts to Control China's Ambition Will Fail" (Foreign Affairs, December 30, 2022) and G. Rachman "Halting China's Growth Cannot be West's Goal" (Financial Times, January 3, 2023). The titles are clearly indicative of the authors' opinions. We may also add that US Asian allies have shown concern for the excessive current decoupling of the American economy from that of China and the resulting negative effects on their businesses.

In conclusion, we may summarize by making some predictions, difficult as it may be, on the evolution of the 'chip war', from the situation we have described, in the short and medium term, both for suppliers and users of semiconductors even though. In the short-term, we may assume that China will continue to have a moderate reaction and dedicate most of its efforts to solving its internal problems, and as we have said, try to regain a significant position in the world of semiconductors.

If one feels like being a bit optimistic, one can draw comfort from some recent less aggressive speeches made by President Xi. Also, at the recent World Economic Forum at Davos (2023), the Chinese Vice Minister of Foreign Affairs, Liu He, made a rather conciliatory speech affirming that his country, after the years of pandemic, was now ready for a new engagement with the West, and welcomed foreign investment. In this case, there would be, in the short term, no serious perturbation of the semiconductor supply chain (except for China, of course), but a significant loss of the Chinese market for all those industries, US and worldwide, affected by these new US export control rules: the extent of that loss will depend on how extensively the US will enforce those rules and justify what the media have already dubbed the "Silicon Curtain". An increase in price will anyway be a likely consequence. It must be, however, mentioned that a bit of uncertainty has been already perceived in Western industry when it comes to deciding on large investments. See for example the case of Apple, just "considering" its own fab in the US, or the 80 bn dollar investment by Intel to build several semiconductor plants in Europe, announced months ago but not yet confirmed.

And, if we move ahead in time even in the medium term, it seems quite foolish to make any kind of prediction due to the overriding influence of politics. In any event, a significant change from the present situation will come, as we have mentioned, from a tendency of deglobalization based on large planned public and private investments and government initiatives, and thus a significant tendency towards "in shoring", or bringing home a large part of the supply chain, especially production. The effect of this will have to be seriously analysed, but it is not worth doing at this point in time in view of such great uncertainty.

So, while the term 'chip war' may seem a little too dramatic today, all the elements have been laid out for the real possibility of such a war, with the consequences that we have described in this paper. Even if the waters seem strangely calm now, a better and more informed look indicates a situation of great instability, even possible in the short term.

We close by mentioning that during the preparation of this paper, we have been reminded of a haiku by Taniguchi Buson (the great Edo period Japanese poet - XVIII century):

The butterfly sleeps well

Perched on the temple bell,

Until it rings.

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