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Sustainability qua maxim of Russia's electronics industry

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Abstract. Electronics industry in Russia is an example of how inefficient old approaches to production can be. In XXI century, most companies have abandoned integrated device manufacturing, thus separating design and production. The main goal of this article is to analyze prospects for development of electronics in Russia with Government strategy being a huge supporting factor. Worldwide deficit of semiconductors, worsened by COVID-19, together with export sanctions imposed upon this country put a strain on both national fabless companies and IDMs, depriving them from future growth and undermining their stability. The authors employ induction, deduction, analysis, synthesis, analogy, and description, basing their work on scientific papers of the Russian and world economists as well as tech specialists. Government strategy and increased financial support may generate positive impact and assist existing foundries. However, the cherished goal of reducing dependency on market leaders (which is coveted by many nations) cannot be achieved as most producers stand in a long line before they can purchase equipment for their foundries. Therefore, the best-case scenario implies second-hand lithography systems from manufacturers wishing to upgrade. This is sufficient for sustainable development of microcontrollers but hinders high-tech aspirations of fabless companies in Russia. At the same time this issue is not limited to Russia alone — many countries have realized the need for production localization and changed their focus from either self-reliance or import substitution to partnership with leading foundries.

Keywords: sustainable development, electronics industry, high-tech, state regulation, digital economy, fabless company, integrated circuit, import substitution, localization of production, production chain

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Устойчивость как максима электронной промышленности России

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Аннотация. Электронная промышленность России представляет пример неэффективного подхода к производству в XXI веке. Сейчас большинство компаний отказались от полного цикла производства полупроводников в рамках одного предприятия, отделив разработку и проектирование от собственно производства. Основная цель исследования — проанализировать перспективы развития электроники в России с учетом существенного поддерживающего фактора в виде Стратегии Правительства. Дефицит полупроводников в мире, который усугубила пандемия COVID-19, а также экспортные ограничения на поставки в нашу страну, оказывает огромное давление на отечественные компании-разработчики чипов и производителей полупроводниковой продукции, лишая их перспектив роста в будущем и подрывая их стабильность. Авторы используют следующие методы научного познания: индукция, дедукция, анализ, синтез, аналогия, описание. Работа опирается на труды российских и международных экономистов и специалистов по технологиям. Стратегия Правительства и рост финансовой поддержки со стороны государства, возможно, положительно повлияют и окажут поддержку действующим производственным компаниям. Тем не менее идеал в форме снижения зависимости от ведущих игроков рынка (о котором мечтают многие страны) недостижим — многие производители уже стоят в длинной очереди на приобретение литографического оборудования. Таким образом, оптимистичный сценарий включает в себя покупку этого оборудования на вторичном рынке у компаний, обновляющих свой фонд. Для устойчивого развития базовых микроконтроллеров этого достаточно, однако не решается проблема разработки высоких технологий российскими проектировщиками без собственного оборудования. В таком положении находится не только Россия. Многие страны осознали необходимость локализации производства и перешли от импортозамещения или опоры на собственные силы к партнерским взаимоотношениям с ведущими производителями полупроводников.

Ключевые слова: устойчивое развитие, электронная промышленность, высокие технологии, государственное регулирование, цифровая экономика, бесфабричная компания, интегральная схема, импортозамещение, локализация производства, производственная цепочка

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Introduction

Modern electronics is very complex industry spanning from simple microcontrollers tailored for one task e.g., lifting a robotic arm, to deeply integrated systems-on-chip (SoCs) that can be used in both smartphones and supercomputers. Nowadays no country can turn away from digital transformation which comprises technological development, human capital and improvement in governance.

Russia has long cherished the idea of catching up with the position that the USSR occupied in 1960s when the it could achieve self-dependence in electronics. These times are long gone, and leading manufacturers of equipment, for instance, ASML and TSMC represent the new age of electronics production. Today companies have distinct specialization: design and firmware (fabless companies like Apple), lithography equipment (ASML was already mentioned), fabrication (e.g., SMIC, TSMC, GloFo), assembly (the most famous is Foxconn), integration. This list does not even include software (apart from low-level microcode) and the client side for electronic products. Every aspect of specialization is capital-intensive and relies on modern approaches to economic efficiency, lean management, sustainability in governance. It requires considerable time and effort for research. Moreover, issues like inability to scale production short-term and long lead times for equipment and fabrication on the best available nodes do not leave a chance to retail designing companies.

It should be noted that one of the grave challenges to electronics industry is shortage in semiconductors that can be traced to 2016 when Moor's law as a concept for stable improvement in performance has finally stopped with Intel's inability to increase density of its microchips. At the same time ideas of Internet of things (IoT), Data Science e.g., machine learning and artificial intelligence, increased the need for advanced electronics. COVID-19 is detrimental to logistics, but the pandemic did not ruin the industry that was already facing problems on the demand side.

China has managed to establish competitive electronics industry due to import of capital, government support of human capital and export orientation. Other countries have followed the same route with various degrees of success. Their main weaknesses are reliance on imports of most valuable elements in production chain and low added value in nations themselves. This implies that imbalances in production cannot be changed without sound strategic decisions such as setting up design centers and foundries onshore.

Development of electronics is not limited to semiconductors themselves. Telecommunications allow humanity be connected 24/7 in real time, and the speed and density of information transfer are enormous. Some ten years ago smart devices were a gimmick, and streaming content via Internet was only possible in form of discrete downloads.

Electronics industry in Russia is one of sectors heavily reliant on demand from state producers of weapons. Contrary to the popular point of view, they are not the most technologically advanced as they always require legacy compatibility, robustness and modularity. At the same time weapons themselves rarely offer any form of information disclosure — no country undermines its security and keeps hardware more or less secret and software — close source which generally implies lack of competition which forms the basis for digital transformation together with capital intensity mentioned above.

Overall situation in Russia's electronics sector stems from dependence on traditional models in production and competition. Companies which dominate the global market have either invested the bulk of required capital long ago, thus having risked with their prospects at that time, or chose specialization on design and small-scale fabrication. The latter group consists of researchers and engineers whose value added has the greatest share in production. This idea can be a guide for Russia — Nvidia is one of leading producers of general-purpose video cards and Data Science solutions, and it is fabless i.e., has no factories or plants of their own.

We aim to analyze assumed vectors for economic development in electronics industry of Russia as the basis for digital transformation in XXI century. Therefore, several steps should be considered and described: the current state of electronics in Russia compared to the world, Government strategy for development and its potential benefits to the industry.

Materials and methods

Production of advanced equipment and hardware have been thoroughly observed by Pecht (Pecht et al., 2018), Lee (Lee & Pecht, 2020), Ngoc (Ngoc et al., 2019), Raj-Reichert (Raj-Reichert, 2020), Hou (Hou, 2020), and Yaghmaie (Yaghmaie et al., 2020). The issues of corporate governance and sustainability were stressed by Balkenende (Balkenende & Bakker, 2015), Helo (Helo et al., 2009), and Yun (Yun & Lee, 2022). Intensive cooperation and flexibility in value chain management have been discussed by Sodhi (Sodhi & Lee, 2007). Chen (Chen & Tang, 1987), Zhou (Zhou, 2008) and Reshetnikova (Reshetnikova, 2020) have highlighted governance factors of high-tech development in PRC. Ecological innovation is emphasized by Selitto (Sellitto & Hermann, 2019).

Russian researchers focus on prospects of national electronics industry. Governance as the primary development factor is articulated by Ganichev (Ganichev, 2014), Kozlova (Kozlova, 2014), Malinetskii (Malinetskii, 2020), Shpak (Shpak, 2021). Technological areas for improvement as well as best practices from market leaders are shown by Teodorovich (Teodorovich et al., 2016), Kulikova (Kulikova, 2017), Kirtadze (Kirtadze, 2017), and Kryukov (Kryukov, 2018) stresses the importance of human capital.

The authors also use materials from the Russian Strategy of electronics industry development up to 2030.

The methods of scientific research used primarily include induction, deduction, analysis, synthesis, and description with the latter three being crucial to assess Russia's strategy for development of electronics. Furthermore, the authors employ analogy to highlight the best practices of developing countries where electronics industry receives similar treatment from government authorities. In order to uncover the reasons of the current state of this industry in Russia and its prospects in the next 10 years, we use logical and dynamic methods.

Methods

General scientific methods are actively utilized in this study: analysis and synthesis, induction and deduction, extrapolation and interpolation. Assessments and analyses by international researchers are presented in the Literature review section, which enables to see the scope of coverage offered by the existing studies. Apart from that, in the Results section the author understandably resorts to elements of statistical and comparative analysis to reveal the most promising areas of development for China's nuclear sector. As such, the statistical data, readily available from the open sources, is presented in the form of tables in the chronological order, thus disclosing the underlying trends in Beijing's atomic industry since 2015. Scenario analysis is also of assistance in predicting the conceivable trajectories in the near future, contingent upon the circumstances. While it is vital to admit that using political economy as a theoretical framework for studying the problem would be most beneficial, the limitations of the paper make it possible to unveil the full potential of this school of thought in the future work.

Results and discussion

Electronics industry caters to other industries and end customers like government authorities and citizens. In both cases it serves as infrastructure for digital transformation of the country and relations between entities and people.

In the past when the first computers were used only for calculations, electronics industry on the national level could be described as integrated device manufacturer (IDM). This means inhouse design, production and subsequent integration. Rapid advancement in global trade has made it possible for various companies to specialize in separate areas: research and development (RnD), design and standardization, production of principal components and peripheral ones, assembly, and, finally, integration and software development.

Newly industrialized countries have supported production and assembly. Their strength lies in dependence of other elements in production chain on their capacity and ability to fabricate efficiently a wide range of electronics. In the meantime, the USSR preferred its own solutions and licensed hardware from IDMs of the era like IMB. While this strategy seemed to be sustainable, the country quickly lost its pace when fabless companies appeared. With the ability to quickly test ideas born in RnD process and fast production cycle, the USSR faced many more competitors than ever before. It is widely accepted that the country ignored this industry and underestimated its impact on the future. The USSR used the products of electronics and failed to keep up with global competition.

Furthermore, even today the electronics industry in Russia is still viewed as an IDM when it does not produce most devices inhouse. This shows that proper understanding of modern production chain of electronics (in the form of end product) is required:

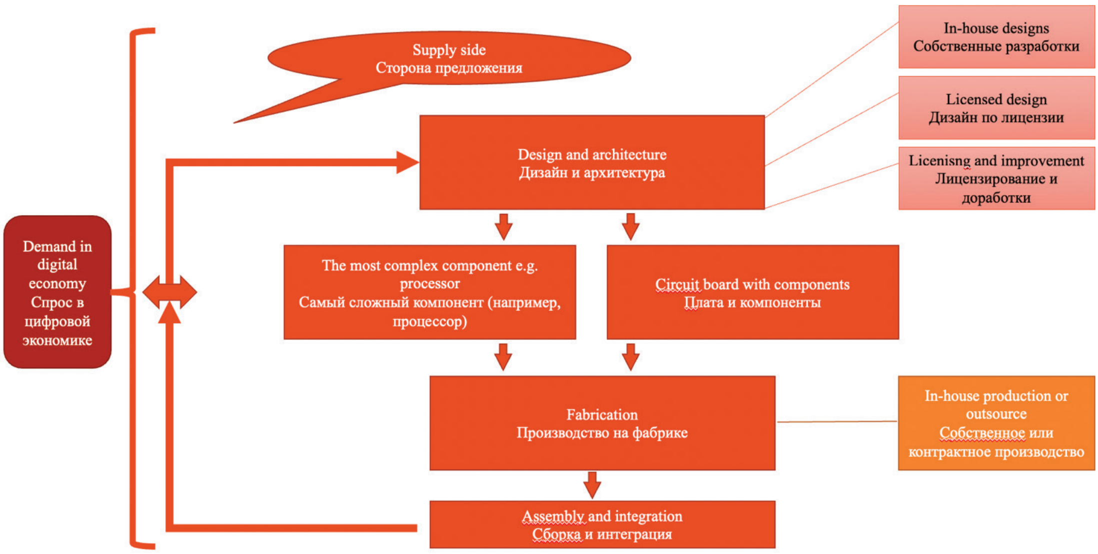

Figure 1. Production chain of advanced electronics (disregarding software).
Source: compiled by the authors

Most of the elements on Figure 1 conform to certain standards like sockets or input-output connectors. Processors as examples of advanced components conform to architectures. Only the most efficient and scalable design solutions exist in form of widely used architectures like x86-64 and ARM. All other designs in general purpose computers are licensed from these two. Certainly, there are many more examples but the persistence of derived products should have already resulted in some stumbling block due to legacy of old microcode. However, the very fact that many servers and computers use these designs shows the extent of scalability and genuine success in development.

Designs like above rarely become mainstream but require substantial RnD, therefore focus of market players has shifted to other elements in the production chain. Some prefer to build upon the architecture itself and introduce improvements while others shift their attention downstream to fabrication and assembly. We do not touch upon lithography equipment producers in this paper as currently this field is divided between the Netherlands (ASML), Japan (Canon, Nikon) and the USA (KLA, Applied Materials, Lam Research), with the former being indisputable leader in the most precise machines for smallest chips. The base to these chips is referred to as nodes and calculated in nanometers, or nm.

Digital transformation of global economy has plunged countries into a race for the best hardware and software they can acquire. While agriculture, for instance, can be a strategic goal for national security, there is a conviction that electronics industry requires the same approach. However, most researchers observe economics of this industry without noticing complexity in value chain creation. Today no country or company is truly secure, and many forces are dependent upon each other. This is the reason why shortages in components have driven up prices in automotive industry. The deficit was evident from the beginning as the physics of silicon, the basic material for production in electronics, are limited. It is impossible to improve production indefinitely, and it has become extremely expensive already. Specialization allows sharing risk and costs. On the other hand, any deficit becomes severe.

Therefore, the issue of national security is secondary to sustainability in the industry. It is not enough to produce small volume of tested electronics — in digital era requirements grow exponentially and leave no chance to those lagging behind. The authors see that Russia has chosen to be consumer of products in electronics industry and add to the value chain of other sectors like services and oil and gas.

This value chain notion is of utmost importance in the context of electronics industry. Digital infrastructure is the combination of hardware and software. Russia has successfully used the global chain of this industry to improve its most competitive sectors but failed to introduce anything in return. Thus, the country is the pure consumer who used the product for other goals, and this has become a burning issue amid the global deficit and in 2022 — export restrictions. Russia cannot compete for supply from large factories as it is a relatively (compared to companies like Apple and Samsung) small consumer of modest means.

The supply side, however, has a grip over the market but does not behave like OPEC or similar structure due to contracts with large clients. Apparently, while the world places importance on digital transformation, suppliers aim to saturate it fully.

It can be seen that there is still place for newcomers — nations which endorse digital economy need to add to the value chain by improving existing designs, offering stimulus for onshore production or by purchasing written-off or mature equipment. New machines are often out of scope as they are booked by oligopolies.

In this sense sustainability is constant connection to the global value chain in electronics industry. All efforts should result in creation better conditions for digital transformation. If Russia desires, as its Strategy implies, to become a manufacturer, it has to pursue smaller goals — limited scale of production, purchasing licenses and equipment, booking capacity with contract manufacturers. Overall, electronics industry owes its progress to three groups of factors (Table 1).

As we can see, all the above relies on R&D, capital spending and agile organization. However, the Russian authors focus on superficial implementation as if more focused investment can instantly book capacity or create lithography equipment without know-how. On government level, there is understanding that human capital has a significant role. At the same time economists in Russia share belief in strictly organized management as the most fitting stimulus for the industry.

Existing companies in Russia have already adapted to current conditions. Despite underdevelopment, they have managed to sustain their operation and can benefit from increased funding. Nevertheless, the authors doubt that rigid structure of operation without competition has left any room for reform. Unfortunately, Government strategy builds upon industrial practices of the past, highlighting need for abstract innovation, improved processes and increased share of national added value.

Table 1

Sustainable development factors in electronics industry

Group	Factors	Effect	Examples
Technology	Research and development	Risk of time and effort invested in RnD is only apparent in case of market success	AMD has started developing its Zen architecture in 2012 and even had to license it to sustain its operation. Success of this design came to light in second generation released in 2019
	Focus on qualitative criteria like unconventional underlying structure rather than numerical values	Quality of design and its scalability in products and applications weigh more than process in nanometers or operations per second	Netburst architecture by Intel (usen in Pentium 4 series) relied on high frequency and failed against alternative designs on the same speed
	Efficiency of production as metric for sustainability	Designer teams and foundries search for cost-cutting measures without hampering the initial idea. Economy of scale improves production of premium products provisioned issue of initial defects is solved	TSMC started full-scale production of 7 nm silicon when yields were near 70 %. At the same time some products that did not comply with high-end specification could be adapted for other market segments. So a defect gained second life e.g., that is how 6-core processors appeared
Economy	Capital spending	Massive funding is required to increase scale of production. Contract manufacturers accept the risk while designing companies focus on RnD	TSMC alone claims to be spending USD 100 bn from 2022 to 2024
	Salary premium in electrical engineering	Machines have to developed by specialists with expertise. Digital transformation implies more demand for electronic infrastructure	Electrical engineering together with computer science meet high demand from the market
	Choice of adequate scale for each element in production chain	Design companies do not have production capacity, while capital-intensive factories specialize on one of the elements in production chain	Apple builds upon Arm architecture, improves it and supports its device and service ecosystem without its own factories. ASML produces lithography equipment, Samsung provides silicon substrate. TSMC combines all three to a SoC, then Foxconn assembles the device
	Demand drives supply up	Oligopolies on the market cater to supply should the order quantity be sufficient. This will be the case until digital transformation is completed which may or may not happen	ASML and TSMC invest in tools and machinery instead of increasing their margin
Governance	Yearly planning	Contracts in electronics industry are year-long so as to ensure stability short-term and leave possibilities open	Apple has become the most prominent client of TSMC and can book all the capacity it needs. The company is ahead in technology, because it annually orders all available state-of-the-art nodes
	Agile order system	Range of products changes at least yearly. Keeping pace with trends is essential	Smartphones with newer hardware are introduced annually
	Establishment of long-term relations with workforce and investors	Leaders in the market consistently follow environmental, social and governance (ESG) practices	TSMC has many awards related to ESG and in included in sustainable development-focused portfolios
	Government support of initiative	Countries welcome onshore production of design and fabrication	China has given rise to companies like Xiaomi

Source: compiled by the authors.

The quantitative criteria in the Strategy implies the existence of added value to the global electronics industry while experts stress national security. The latter does not exchange (with some exceptions like cryptography) with open market. We assume that added value is miniscule and should be created rather than improved. Russia aims to take part in production while the global idea has already shifted to ecosystems which are people's ideas. These are neither means of production nor any explicit design.

Furthermore, electronics industry in Russia suffers from comparison with heavyweights like oil and gas or machinery. They share capital intensity as precondition but ultimately differ in their scope. Electronics have become more than machines or means of delivery — this industry is the backbone of the whole world together with Information Technology (IT). Both these sectors rely on knowledge economy where human factor is the cornerstone. At the same time security is mistakenly defined as a homebrew solution without any connection to the existing technology. Digital security as a field of research thoroughly studies existing vulnerabilities and ways to mitigate them, while development from scratch usually struggles against known issues — there is no solution of acquiring complete knowledge without learning every step made before.

Therefore, knowledge can serve as epitome of sustainable electronics. All countries that have earned their place in global value chain like China, Vietnam, Malaysia have pursued a strategy of integration and partnership. Russia's focus on security is a sign that more R&D and deeper understanding are urgently needed.

Russia will not be able to catch up with global electronics industry, because there is not a single country that can absorb all the knowledge or the whole value chain. Sustainable industry will be a permanent resident of the production chain, whether on design phase or in assembly. Yet the Russian companies in electronics industry never fuel the global or national digital transformation. Instead, they just borrow from the global industry which brings profits to the global value chain but doesn't infuse it with knowledge.

Conclusion

Government strategy of Russia clearly shows that the country has abandoned all plans to produce lithography equipment. Vague notion of reaching 28 nm corresponds to the second-hand market as this process will be extremely outdated in 2030s. Still, equipment itself can be affordable and repairable. Russia's manufacturers have already tried purchasing written-off 60 nm machines but have not put them into action as of 2021. The authors would like to highlight that one of benchmarks for the national electronics industry was Intel whose in-house production nodes were (and to an extent are) 32 and 22 nm — they are calculated somewhat differently compared to other producers. However, Russia's strategists have chosen 28 nm as the ultimate goal — strange decision if the theoretically followed benchmark has not change. The answer is that other equipment manufacturers skipped 32 nm node, and Russia has a better chance of sourcing still widely used machines. For example, popular Raspberry Pi single-board computer used for teaching computer science and robotics is built on this node.

Lack of prior knowledge and know-how for constructing lithography equipment shows that the Russian industry can only rely on machines that exist on the market.

If Russia aims to compete in the market of electronics, it's high time to choose the role except for lithography. It is still possible to become a home for assembly plants but newly industrialized countries have an advantage — factories are already located there. Design from scratch is an admirable goal but producing architecture is not worth the effort without a complete system. The country dabbles in integration and software to achieve import substitution. Nevertheless, value added is not enough to compete with other players.

The most reasonable area of expertise for Russia and any other country wishing to become is to acquire licensed design and improve upon it, on the one hand, and introduction of certain chips on existing circuits. Two examples exist — security modules meant for integrity check that are favored in personal devices and modification chips that exploit certain vulnerabilities in processors. Either area is built upon a design center with small-scale production onsite that can be outsourced. None of this can be achieved without understanding how the existing electronics function. We stress that Russia has to catch up in engineering solutions to problems rather than means of production or products themselves. The country has to get the hand of know-how, and this means it needs to look for partners and to provide every possibility for advanced learning in electrical engineering.

However, we emphasize that cooperation with other elements of the electronics production chain is crucial. In 2022 export sanctions imposed on Russia have severely limited its potential growth in electronics products, and the latest strategic plans only consisted of increased funding and better governance. Lack of close partners in value chain creation in production allow for quick disintegration of high-level products production, primarily processors. This value chain has always been for the benefit of the government sector which relies on secure solutions. However, many authors insist on security as an inverse of performance which is rarely the case. The backdoors in licensed solutions can be found upon inspection that takes place under cooperation.

Organizational ideas rely on specialization and agile management rather than lightening regulation or another government structure. Thus, the best practices should include promotion of sustainable governance, limiting self-reliance in areas where inefficiency has already manifested itself as well as creation of structures without legacy compatibility e.g., who still cater to weapons manufacturers.

Russia can also focus on less advanced microcontrollers. In the end the country will have to decide how to integrate products of the world's multistandards into its own solutions. Ultimately, leading players offer better value for money. This means any country needs a long-term strategy which does not have to be called self-reliant. Following market leaders is more efficient on a practical level and can only be done in real world. Therefore, Russia has to evolve its electronics industry from the undeveloped semi-self-sufficient state in government sector to a partner in global production chain.

The authors suppose that sustainable development in electronics is impossible without interdependence. Most proponents of onshore production ignore other elements of the chain. Ultimately, the Russian electronics sector has to become more open to trade (imports for starters) and ideas as the place among world foundries or designers will not be vacant in the near future. Improved governance in electronics is more about getting rid of legacy structures rather that setting up organizations. This industry has to be rethought and created — it does not exist in modern understanding, and old institutions cannot be at the helm. Similar situation happened in software where human capital alone has given birth to accounting programs and search engines. Electronics industry requires the same support for research among practitioners and absence of rigidity in regulation, but software did not require massive capital spending in the beginning.

Russia contemplates about its prospects in electronics but it is more an issue of risk attitude with regard to capital and ability to cooperate rather than a matter of import substitution and national security.

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