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Emigration of scientists and engineers from the Russian defense industry in the 1990s: consequences for national defense and international security*

Emigración de científicos e ingenieros de la industria de defensa rusa en la década de 1990: consecuencias para la defensa nacional y la seguridad internacional

Abstract: The defense industry maintains an intrinsic relationship with science, technology, and innovation, making strategic human capital a central element, particularly in light of the increasing technological sophistication of contemporary conflicts. While the literature on skilled migration often emphasizes mutual benefits for both origin and destination countries, analyses of the effects of emigration by professionals linked to the defense industrial base remain scarce. This article examines how academic literature interprets the impacts of the emigration of scientists and engineers from the Russian defense industry during the 1990s, following the collapse of the Soviet Union. The methodology involved bibliographic research and critical analysis of English-language literature retrieved via Google Scholar. The studies reviewed reveal diverse interpretations influenced by geopolitical interests. For Russia, the loss of scientific capital stands out, whereas at the international level, concerns are centered primarily on the proliferation of weapons of mass destruction.

Keywords: Defense industry; Skilled emigration; Brain drain; National defense; Russia.

Resumen: La industria de defensa mantiene una relación intrínseca con la ciencia, la tecnología y la innovación (CT&I), lo que convierte al capital humano estratégico en un elemento central, especialmente ante la creciente sofisticación tecnológica de los conflictos contemporáneos. Si bien la bibliografía sobre migración cualificada suele hacer hincapié en los beneficios mutuos entre los países de origen y destino, existen pocos análisis sobre los efectos de la emigración de profesionales vinculados a la base industrial de defensa. Este artículo pretende examinar cómo la literatura académica interpreta las repercusiones de la emigración de científicos e ingenieros de la industria de defensa rusa en la década de 1990, una década marcada por el colapso de la Unión Soviética. La metodología adoptada incluyó investigación bibliográfica y análisis crítico de la literatura en inglés disponible en Google Académico. Los estudios analizados revelan diversas interpretaciones, influenciadas por intereses geopolíticos. Para Rusia, destaca la pérdida de capital científico, mientras que a nivel internacional la preocupación radica en la proliferación de armas de destrucción masiva.

Palabras clave: Industria de defensa; Emigración cualificada; Fuga de cerebros; Defensa nacional; Rusia

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1 INTRODUCTION

At the time of writing this article, it is possible to observe that scientific knowledge is being widely and rapidly disseminated, making it increasingly difficult for any single State to maintain technological hegemony (Paarlberg, 2004). In this regard, the defense industry, as a knowledge-intensive sector, maintains a close relationship with science, technology and innovation (ST&I) (Brasil, 2020). Faced with the growing technological complexity of contemporary conflicts, highly qualified "strategic human capital" (Scott, 1997) has become a critical resource for ensuring national defense, both in the operation of complex weapons systems (Paarlberg, 2004) and in the development of innovations within a sector that requires expertise in cutting-edge technologies (Azevedo; Borba; Araújo, 2021; Koroglu; Eceral, 2015). In these circumstances, both the military power and the strengthening of the Defense Industrial Base (DIB) are directly related to the innovative capacity of the sector, which, in turn, depends on the availability of qualified human resources (Azevedo, 2018).

However, the emigration of DIB-related professionals remains an underexplored topic in the literature, and studies examining its characteristics and implications are relatively scarce. The Russian example during the 1990s is the most extensively analyzed case in this field and provides valuable insights into this phenomenon, although there is still a lack of data and scientific research (Katsva, 2000). Following the collapse of the Soviet Union (USSR), Russia entered a period of profound political, economic, and social turbulence (Edmond, 2025), whose effects compromised the scientific system (Rabkin; Mirskaya, 1993; Yegorov, 2009) and also the defense industry (Davis, 2002), both structured under the Soviet regime. In this context of instability, a significant contingent of Russian scientists and engineers specialized in military technologies began to emigrate, mainly to Israel, Germany, and the United States (USA), and, to a lesser extent, to Algeria, China, North Korea, Cuba, Egypt, Iran, Iraq, Libya, Mexico, and Pakistan (Katsva, 2000; Kramer, 2002; Shalkovskyi, 2002).

This article aims to analyze how academic literature interprets the impacts of the emigration of scientists and engineers from the Russian defense industry in the 1990s, especially in terms of national defense and international security. For the methodology, this study combines bibliographical research with a critical review of the literature. The bibliographical research encompassed studies on skilled international migration, the relationship between ST&I and defense, and Russian emigration in the context of the post-Soviet transition, thereby providing a theoretical and historical overview of the topic. The critical review of the literature, in turn, focused mainly on the impacts of the emigration of scientists and engineers from the Russian defense industry in the 1990s. As for the inclusion and exclusion criteria, studies were selected if they addressed the topic—whether in the title, abstract, or introduction—and were available in English in the Google Scholar database, covering different types of publications, such as scientific articles, theses, undergraduate dissertations, and reports from governments and think tanks; works that merely mentioned the emigration of professionals in the sector without engaging in deep analysis were not considered.[1] Of the 1,790 results initially identified, only 11 met the inclusion criteria and

1 The search was conducted using the following search string: ("*brain drain" OR "scientific migration*" OR "*STEM migration"*) *AND Russia AND* ("*defense industry" OR "military-industrial complex*" OR "*WMD"*) *AND* (*scientists OR engineers*).

were subjected to critical analysis based on the theoretical framework, enabling the identification of gaps and also of relevant contributions in the literature.[2]

This study is justified by the observation that, although the dominant strand of literature on skilled international migration emphasizes a perspective of mutual gains for both sending and receiving countries (Kone & Özden, 2017; Marsh & Oyelere, 2018), theories of skilled migration cannot be automatically extended to cases involving the emigration of defense industry professionals. According to Silva et al. (2025), this is one of the most strategic sectors for States. Furthermore, this article contributes to the defense literature by highlighting the importance of strategic human capital and the DIB sustainability capacity in crisis contexts, providing support for the analysis of the Brazilian case, for which no scientific studies were identified. In Brazil, the DIB is inserted in a context marked by structural challenges, including technological inequalities on the global stage and external dependence on critical technologies. In this context, although investment in human resources is essential to mitigate these challenges (Brasil, 2020; Brum, 2025), shortages of qualified human capital in certain sectors persist (Schmidt, 2013), compromising the capacity for military innovation (Azevedo, 2018), a scenario worsened by the emigration of qualified Brazilians (Brum, 2024).

This article is organized into four sections, in addition to this introduction. The first section analyzes the phenomenon of highly qualified emigration of scientists and engineers in post-Soviet Russia. The second section outlines the theoretical framework, focusing on the impacts of qualified international migration and the strategic role of ST&I for defense. The third part critically examines the consequences of the emigration of scientists and researchers from the Russian defense industry in the 1990s. The final section presents the final considerations of the article.

2 EMIGRATION OF HIGH-SKILLED SCIENTISTS AND ENGINEERS IN POST-SOVIET RUSSIA

The dissolution of the USSR in 1991 preceded a period of transition and modernization that profoundly transformed Russia's economy and political system (Minakov, 2016; Rabkin & Mirskaya, 1993). This transition triggered a crisis of major proportions in the political, social, and economic spheres (Edmond, 2025), with severe impacts on the country's scientific system (Ball; Gerber, 2005; Rabkin; Mirskaya, 1993; Yegorov, 2009). Against this background, the opening of borders and the possibility of voluntary emigration (Aleshkovski; Grebenyuc; Vorobyeva, 2018) encouraged many highly qualified professionals to pursue career opportunities abroad (Aref'ev; Sheregi, 2015; Ganguli, 2014; Gokhberg; Nekipelova, 2001). This section addresses the impacts of the post-Soviet crisis on Russia's scientific environment and discusses the emigration of scientists and researchers throughout the 1990s.

2 In the initial stage of the search, most of the literature identified focused on the Russian DIB, the proliferation of weapons of mass destruction, or skilled migration in general, without specifically addressing the emigration of scientists and engineers from the Russian defense industry.

2.1 Crisis in post-Soviet Russia and its impacts on the scientific environment

The first wave of reforms implemented in Russia following the collapse of the USSR initiated a process of economic restructuring characterized by privatization and efforts to implement a free-market system (Edmond, 2025). However, the post-Soviet experience was marked by structural contradictions, setbacks, and persistent disputes over the reconfiguration of the country's political, economic, and social order (Minakov, 2016), generating profound impacts on those domains (Edmond, 2025).

Politically, the process failed to consolidate robust democratic institutions (Edmond, 2025). Economically, the 1990s saw a GDP contraction of approximately 50% (Boettke, 1999). Rather than fostering competition, the privatization process enabled a small group of privileged actors to appropriate state assets, thereby exacerbating socioeconomic inequality and undermining institutional development (Edmond, 2025). Access to basic services, such as electricity and telephone services, was limited (Ball; Gerber, 2005). The social costs were also substantial, involving rising poverty, the collapse of public healthcare, and the weakening of social safety nets (Edmond, 2025). Since Soviet social welfare provision was tied to state-owned enterprises, their mass closure left millions without access to basic services. Consequently, by the end of the 1990s, approximately 30% of the population was living below the poverty line, and life expectancy had dropped to just over 50 years (Boettke, 1999).

This crisis also affected the scientific community and individual scientists (Ball; Gerber, 2005). Following the collapse of the USSR and Gorbachev's reforms, the Russian scientific system—once globally renowned—entered an unprecedented period of crisis marked by restructuring and contraction, driven primarily by the country's severe economic decline (Rabkin; Mirskaya, 1993), which resulted in a sharp deterioration of its prospects and status. This prolonged crisis led to declining wages, drastic cuts in research funding, and the widespread deterioration of equipment and laboratories (Ball; Gerber, 2005). A decline in the social prestige of science was also observed. In some cases, scientific institutions became involved in criminal activities, further exacerbating the process of devaluation (Rabkin; Mirskaya, 1993). Consequently, after decades of state propaganda promoting science, it abruptly ceased to be perceived as a socially valuable activity (Rabkin; Mirskaya, 1993).

Throughout the 1990s, scientific productivity in Russia remained low, largely due to two main factors. The first factor was the drastic reduction in research and development (R&D) funding during this period, when almost the entire available budget was consumed by the payment of salaries and basic utility bills, such as water and electricity. In this context, the acquisition of modern equipment became virtually impossible, leading to the interruption of essential experiments for the continuity of research (Yegorov, 2009). The second factor is associated with the migration of researchers to other economy sectors and the rise in emigration—particularly during that period (Yegorov, 2009)—resulting from the Russian economy's inability to absorb the skilled human resources it was producing (Shalkovskyi, 2002). In this new environment, research institutes and scientists began to pursue contracts independently, entering a highly competitive environment. However, the significant reduction in available

opportunities hindered adaptation for many (Yegorov, 2009), frequently resulting in the emigration of talent.

2.2 The emigration of researchers and scientists from Russia in the 1990s

In Russia, voluntary emigration began in the late 1980s, when the country initiated a process of liberalization of its migration regime and exit registration procedures. Until 1989, this type of emigration was virtually non-existent in the USSR. From that year onward, however, exceptions began to be granted, particularly to German, Jewish, and Greek origin individuals. A significant increase in emigration flows occurred from 1993 onwards, following the introduction of more liberal regulations governing entry and exit, which guaranteed citizens the right to freely leave and return to the national territory (Aleshkovski, Grebenyuk, & Vorobyeva, 2018).

Given that the temporal scope of this article is the 1990s, only the first two waves of modern Russian emigration identified by Aleshkovski, Grebenyuk, and Vorobyeva (2018) are analyzed, as they differ in terms of migrant profiles and motivations. The first wave (1990–1994) coincided with the collapse of the USSR and was driven by a severe political and economic crisis resulting from ongoing structural reforms. In this context, emigration intensified, particularly among ethnic migrants—such as Jews and Germans—and members of the intellectual and scientific elite. Many of these individuals sought improved living conditions abroad and were well positioned to benefit from immigration policies in Israel, Germany, and the United States, which largely adopted ethnic criteria for admission. Consequently, these countries became the main destinations, jointly receiving more than 94% of Russian emigrants from the former USSR in 1993 and 1994 (Aleshkovski, Grebenyuk, & Vorobyeva, 2018).

The first migration wave was the largest in Russia's post-Soviet history, composed predominantly of middle-class working age individuals, with high education levels and professional qualification—including scientists with specialized technical expertise. Official Russian statistics significantly underestimated these flows when compared to data from receiving countries. It is estimated that between 1992 and 1994 approximately 1.5 million people emigrated officially, although the actual figure may have reached 2.1 million (Aleshkovski, Grebenyuk, & Vorobyeva, 2018). Western projections suggested that tens of millions could leave Russia if the crisis worsened; however, stabilization after 1993 contributed to a deceleration of migration flows (Aleshkovski, Grebenyuk, & Vorobyeva, 2018).

In the second half of the 1990s, the second wave of Russian emigration (1995–2000) became primarily characterized by short-term labor migration to developed countries, encompassing both low-skilled occupations and positions requiring higher education (Aleshkovski, Grebenyuk, & Vorobyeva, 2018). During this period, labor migration surpassed both repatriation and ethnic migration (Korobkov & Zaionchkovskaia, 2012). Although capital accumulation in Russia remained limited—hindering large-scale entrepreneurial emigration—many Russians engaged in commercial and entrepreneurial activities abroad, often without relocating their families. There was also a rise in educational migration, frequently used as a strategy for integration in destination countries, as well as a marked increase in marriage migration, predominantly involving women (Aleshkovski, Grebenyuk, & Vorobyeva, 2018).

Approximately 2 million people are estimated to have emigrated during this period, although official records account for only 1.47 million. The reduction in total emigrant numbers compared to the previous wave is attributed both to the partial stabilization of the crisis and to the prior departure of the most mobile segments of the population. This wave was also characterized by a diversification of both origin and destination. While Moscow and St. Petersburg accounted for 40% of emigrants in the early 1990s, this share fell to just 11% by 1999, indicating a growing contribution from other regions of the country. At the same time, the geographical range of destination countries expanded significantly. In addition to Germany, Israel, and the United States, significant Russian emigrant communities emerged in various other countries. (Aleshkovski, Grebenyuk, & Vorobyeva, 2018).

In summary, during the 1990s, Russia experienced a sharp increase in emigration flows, which exceeded, according to official estimates, three million people (Aleshkovski, Grebenyuk, & Vorobyeva, 2018), with Germany and Israel as the main destinations, followed by the United States (Gokhberg & Nekipelova, 2001). Overall, emigrants who left the country in the 1990s displayed heterogeneous profiles (Aleshkovski, Grebenyuk, & Vorobyeva, 2018), with a significant presence of highly skilled professionals (Nekipelova & Ledneva, 2003, as cited in Yegorov, 2009).

Emigration represented a major challenge for Russia (Gokhberg & Nekipelova, 2001), particularly in the case of scientists and engineers (Yegorov, 2009), as it contributed to the weakening of the country's scientific and technological system (Yegorov, 2009). In Russia, the number of emigrants from the "Science and Scientific Services" sector ranged between 1,000 and 2,000 per year (Gokhberg & Nekipelova, 2001). The collapse of the USSR expanded the freedom of scientists, particularly with regard to international mobility. In this context, emigration came to be seen as a means of continuing their scientific careers (Ganguli, 2014). This trend was driven by worsening of domestic conditions in research and development funding, a decline in employment opportunities and wages, and the loss of prestige associated with S&T careers (Gokhberg & Nekipelova, 2001). Simultaneously, the attractiveness of emigration increased among university students, most of whom showing little intention of returning (Aref'ev & Sheregi, 2015).

This section has sought to demonstrate that the process of economic and political transition and modernization in Russia in the first half of the 1990s led to a profound economic, social, and political crisis that persisted throughout the decade. This process severely affected the Russian scientific environment, resulting in rising unemployment, the deterioration of laboratories and equipment, and reductions in public funding and scientific productivity. As a consequence, a significant number of researchers and scientists emigrated in search of better living conditions and professional opportunities. Although these migrants initially originated mainly from major Russian cities and were primarily directed to Germany, Israel, and the United States, the second half of the decade witnessed a diversification of both origin regions and destination countries.

3 THEORETICAL FRAMEWORK

The literature has extensively debated skilled migration, highlighting different effects on countries of origin, such as "brain drain," "brain gain," "brain circulation," "brain networking," and "brain waste." However, this study argues that these concepts cannot be automatically applied

to contexts involving professionals working in strategic sectors, such as defense, where national autonomy is directly linked to the scientific, technological, and innovation capabilities. Under these circumstances, the theoretical framework is divided into two parts: the first examines the main concepts related to the effects of skilled migration; the second discusses the strategic role of ST&I in national defense.

3.1 Skilled emigration and its impacts

Initial discussions on academic and scientific mobility emerged in the 1960s, driven by the significant increase in the migration of European academics and researchers to the United States. This phenomenon was characterized as "brain drain" (Brandi, 2006). In the following decades, the debate shifted toward the migration of highly skilled professionals from developing countries to developed nations (França; Padilla, 2019), consolidating the use of the term to describe this type of migratory flow (Brandi, 2006). Until the early 1990s, the prevailing view was that this phenomenon was unidirectional, definitive, and permanent, whereby highly qualified individuals left their countries of origin for the industrialized world, generating exclusive gains for receiving countries and significant losses for countries of origin, thereby reinforcing an essentially negative perception of skilled emigration (Brzozowski, 2008; Santos, 2021).

More recent pieces of research have shown that the emigration of highly skilled professionals can also generate benefits for countries of origin, giving rise to concepts such as "brain gain," "brain circulation," and "brain networking" (Kone; Özden, 2017; Marsh; Oyelere, 2018). Since the late 1980s, the introduction of the concept of "brain gain" consolidated the perception that the departure of talented individuals does not necessarily represent an irreversible loss for their countries of origin (Brzozowski, 2008). On the contrary, highly skilled migrants came to be regarded as strategic resources capable of generating future returns (Meyer; Brown, 1999). This perspective gained further prominence from the mid-1990s onward by emphasizing the long-term positive effects of emigration, such as increased investment in education, economic gains derived from financial and knowledge remittances, higher levels of foreign direct investment, and the eventual return of emigrants (Kone; Özden, 2017).

From the 1990s onward, and with greater intensity during the 2000s, a new paradigm became consolidated, which considered skilled emigration a circular rather than a unidirectional process. This understanding stems largely from the diffusion of temporary international mobility as a recurrent and structuring feature of professional trajectories in the scientific and academic fields (Daugeliene; Marcinkeviciene, 2009). In this regard, the concept of "brain circulation" stresses the maintenance of ties and international scientific cooperation. This form of mobility encompasses both extended periods of research and training abroad and frequent participation in academic events, constituting an intensive and collaborative international dynamic (Jöns, 2007). From this perspective, the mobility of highly skilled professionals is understood as generating mutual benefits for both origin and destination countries, as well as for the institutions and individuals involved (Daugeliene; Marcinkeviciene, 2009; Saxenian, 2002).

At the current stage of globalization, the debate on skilled mobility has shifted from a focus on the physical location of individuals to the impact of their contributions on the social, economic, and cultural development of the countries with which they maintain ties of belonging (Rizvi, 2005). In this context, the concept of "brain networking" has gained prominence, and it refers to networks formed by scientists and other highly skilled professionals across different countries (Ciumasu, 2010). Such networks have the potential to expand technical cooperation, facilitate the transfer of financial resources and technologies across national borders, and support scientific and technological development initiatives (Santos, 2021).

Nevertheless, Cruz et al. (2025) observe that, in the case of the Brazilian academic diaspora, the "brain waste" is relatively common, phenomenon that refers to the underutilization of skills, when highly qualified professionals occupy positions that do not require their level of education or expertise, resulting in the devaluation of their human capital (Reitz, 2001). Such waste is rarely the result of individual choice, stemming from migrants' difficulties in accessing and integrating into foreign labor markets, where notions of talent may be redefined and discriminatory practices can constrain opportunities—even in contexts characterized by high demand for skilled labor (Elo; Aman; Täube, 2020).

Therefore, as demonstrated, the prevailing view is that the permanent return of highly skilled migrants to their countries of origin is not a necessary condition for them to contribute to national development; what is fundamental is the maintenance of active and productive ties with those societies (Saxenian, 2002). In that respect, skilled emigration has been reinterpreted and is no longer understood exclusively as an irreversible loss for sending countries, as suggested by the traditional "brain drain" approach (Brum, 2024). However, although diasporas are widely recognized as potential sources of positive externalities, this does not imply that emigration is inherently beneficial for developing countries (Santos, 2021).

3.2 The strategic role of ST&I in national defense and international security

The twentieth century, particularly from the Second World War onward, was marked by the consolidation of a system oriented toward the instrumentalization of science for strategic purposes by major powers, known as Big Science. This concept refers to the political and military dimension of science, focused on the formulation and implementation of research projects aimed at war preparedness and the maintenance of scientific leadership in the international arena. This model came to be supported by a vast and articulated institutional network, the so-called "military-industrial-academic complex," responsible for coordinating strategic research and steering the development of cutting-edge science in accordance with security interests and power projection objectives (Almeida, 2007). In this context, the role of the States was fundamental. Supported by public funding and R&D strategic planning, governments fostered partnerships with universities and industry, accelerating the application of scientific knowledge to technological innovation. This process reinforced the strategic value of scientific and technological mobilization as a central instrument of national defense and geopolitical competition (Hounshell, 1997; Paarlberg, 2004).

As a consequence of the centrality of military technology in interstate competition (Koubi, 1999), defense-related R&D generated innovations that later benefited civilian society on a broad scale—a phenomenon known as *spin-offs*—contributing to the economic growth of the countries that developed them. Such innovations include radar systems, aircraft engines, jet airplanes, computers, the Internet, fiber optics, and nuclear energy as the most prominent examples (Medeiros, 2004; Silva, 2022). In this respect, the concept of dual-use technologies was consolidated, referring to innovations originally developed for military purposes but with significant civilian applications (Mallik, 2004).

However, with the information technology revolution that began in the 1970s, a reversal in the direction of technological diffusion became evident. Unlike previous patterns, technologies developed in the commercial sector were increasingly adapted for military use—a process known as *spin-on* (Chapman, 2003; Cohen, 2019; Mallik, 2004; Medeiros, 2004). This shift expanded the range of technologies with military applications and enabled armed forces to benefit from private-sector R&D investments, as well as from cost reductions associated with large civilian markets (Chapman, 2003). In this new dynamic, different countries began to incorporate advances derived from civilian R&D into their operational capabilities and institutional structures (Silva, 2022). Thus, dual-use technology came to be described as an innovation of civilian origin with potential for adaptation to military purposes (Mallik, 2004).

In parallel, the distinction between military and civilian domains has become progressively blurred, making traditional definitions of these spheres progressively obsolete (Roland, 1995). This also implies that a growing number of countries may acquire military capabilities that, in the past, were restricted to a small group of major powers (Mallik, 2004). In this context, the control of exports of emerging dual-use technologies has become an increasingly complex challenge. Several Global South countries have emerged as markets for high-technology military products. However, since many of these States do not belong to the so-called "supplier club," there are concerns that exports may lead to the proliferation of sensitive technologies (Mallik, 2004). Against this backdrop, knowledge transfers may be deliberately restricted (Markowski; Hall; Wyllie, 2010), and leading S&T nations, together with their allies, resort to technological restrictions—whether explicit or implicit—to limit third parties' access to sensitive technologies (Longo, 2007).

In spite of the growing global diffusion of technology, disparities among countries in access to cutting-edge innovations tend to persist—and in some cases even intensify—due to the high costs and complexity of these technologies (Mallik, 2004). There is a broad understanding that contemporary military superiority is deeply linked to scientific development, given that the most significant innovations in the sector are not limited to the creation of weaponry, but also involve the integration of sophisticated hardware and software systems (Paarlberg, 2004; Schmidt, 2013). The concept of a "weapons system" reflects this integrative logic, in which the efficient articulation of technological components becomes more decisive than the individual performance of each element (Cohen, 2019), resulting in the progressive increase in the costs of military equipment (Schmidt, 2013).

However, with the end of the Cold War, the sector underwent a reconfiguration marked by reductions in defense budgets in several countries and a shift in focus: the priority moved away

from the mass production of new systems toward maintaining existing technological superiority. In this context, the R&D investment became essential to enable modernization, logistical support, and the improvement of weapons systems and embedded intelligence capabilities (Schmidt, 2013). This transformation marked a transition from a "quantitative competition"—centered on large-scale production—to a "qualitative competition," focused on technological innovation as the core strategic element (Koubi, 1999). Consequently, certain elements of knowledge can quickly become obsolete due to the continuous development of new knowledge (Markowski, Hall, & Wyllie, 2010).

Within this framework, human capital occupies a central position both in the operation of these complex systems, which requires highly qualified professionals (Paarlberg, 2004), and in fostering innovation within the defense industry, a knowledge-intensive sector that demands cutting-edge technologies (Koroglu & Eceral, 2015). The availability of qualified human resources stands out among the main factors supporting innovation (Azevedo; Borba; Araújo, 2021). Scott (1997, p. 1) introduces the concept of "strategic human capital," defined as "training and work experience aggregated across employees within public institutions and private industries that are instrumental to the achievement of national security objectives." Accordingly, human capital has become a strategic element within defense organizations due to its direct impact on military capabilities and national security, especially in light of the increasing complexity of armed conflicts (Sarjito, 2023). However, when knowledge is concentrated in specific individuals, there is a risk of losing it if these professionals leave their positions (Markowski, Hall, & Wyllie, 2010). In the words of Duarte (2020, p. 123, our translation), "[...] among all types of resources dedicated to defense, human resources are the most difficult to be replaced."

As demonstrated throughout this discussion, much of the literature on skilled migration has come to understand this phenomenon not merely as a loss for countries of origin and a gain for destination countries, but as a potentially beneficial flow for all parties involved. However, when it comes to strategic sectors such as the defense industry—whose development depends directly on ST&I and, consequently, on highly qualified human capital—the impacts of migration may take on more sensitive dimensions, particularly regarding national security and sovereignty. In this regard, the next section first examines the context that led to the highly skilled emigration of researchers and scientists linked to the Russian defense industry throughout the 1990s and then provides a critical analysis of the literature on the impacts of this phenomenon for Russia and also for the international community.

4 IMPACTS OF THE EMIGRATION OF SCIENTISTS AND ENGINEERS FROM THE RUSSIAN DEFENSE INDUSTRY IN THE 1990S A CRITICAL ANALYSIS OF THE LITERATURE

4.1 Reconfiguration of the Russian defense industry and the emigration of its scientists and engineers

Since the early twentieth century, Russia has maintained one of the largest defense industries in the world. During the Cold War, the USSR consolidated an extensive military-industrial complex by granting strategic priority to the defense sector, which received substantial

State investments to support and sustain its activities. This effort resulted in the large-scale production of modern, innovative, and effective weaponry (Davis, 2002; Kramer, 1992). As a consequence, a significant share of the Soviet economy was devoted to military expenditures. Estimates suggest that the military sector contribution to Soviet GDP during the 1980s likely exceeded 20%, potentially reaching 35% or even 40% (Kramer, 1992). In addition, the USSR stood out as a major exporter of weapons and military equipment. However, from 1976 onward, the priority assigned to defense was gradually reduced, exposing the military sector to the typical shortage economy constraints and intensifying the negative effects of military spending on the civilian economy (Davis, 2002).

During Perestroika, Gorbachev government introduced a "new thinking" approach to international relations and a new national security strategy that prioritized threat reduction through diplomacy and arms control rather than military power. Within this framework, efforts were made to reform the defense sector (Davis, 2002), including substantial and successive cuts to the defense budget from 1989 onward (Kramer, 1992), as well as reductions in the size of the armed forces. Throughout most of the transition period, the Russian military-industrial complex was severely affected by the loss of strategic priority, cuts in defense spending, instability associated with the political and economic transition, and poor economic performance. As a consequence, the defense industry was progressively redirected toward meeting civilian market demands and underwent a significant contraction, characterized by a substantial decline in its capacity to produce military equipment and provide defense-related services (Davis, 2002).

Following the dissolution of the USSR and throughout the 1990s, the Russian defense industry continued to experience profound transformations as a result of the low priority assigned to the sector by the government and the drastic reductions in military spending, which led to the deterioration of workers' salaries and benefits. Defense markets underwent a transition toward a more conventional model in which prices became increasingly influenced by supply and demand, albeit imperfectly. Numerous institutions were privatized, and the major economic reforms—stabilization, privatization, and liberalization—had adverse effects on the military-industrial complex. This situation was further exacerbated by the country's poor economic performance, characterized by GDP contraction, high inflation, and decline in investment levels (Davis, 2002). Military-related R&D, which had previously been a priority in the USSR, suffered from the State support withdrawal and the resulting drastic reduction in funding. This contributed to decreased arms production and exports, marking a period of crisis and technological decline within the Russian defense system (Dezhina & Graham, 2002; Yegorov, 2009).

According to Davis (2002, p. 172), "The defence industry labour market has shifted from being privileged to deprived." The salaries and non-monetary benefits offered to the sector workers were gradually surpassed by those available in more successful civilian industries, while delays in wage payments became increasingly common. Between 1992 and 2000, employment in the defense industry was reduced by half, falling from 4.8 million to 2.4 million workers. Many highly qualified professionals moved to the private civilian sector in search of better opportunities. Crime within the defense industry also increased significantly. It became common for workers to divert civilian goods, small arms, and reserve stockpiles for sale on the black market. On a larger

scale, organized schemes involving the theft of military equipment, technologies, and supplies came to be orchestrated by corrupt managers (Davis, 2002).

Following the dissolution of the USSR, Russia assumed control over the military assets located within its territory, including the entire nuclear arsenal, as well as most of the remaining military assets situated in the other successor States (Davis, 2002). Russia also inherited the majority of the principal chemical and biological weapons production and development facilities, although many of these installations were deactivated throughout the 1990s. Beginning in 1992, the former Soviet weapons of mass destruction (WMD) programs underwent restructuring processes and faced resource shortages, personnel cuts, and a decline in oversight by the Russian government (Parachini et al., 2005; Shalkovskyi, 2002). Thus, although Russia inherited the world's largest WMD complex, it had only limited governmental support to maintain it (Ball & Gerber, 2005).

At the same time, Russian scientists with expertise in WMD-related fields were, for the first time, permitted to leave the country in 1992, allowing them to attend international conferences and, in many cases, emigrate (Ball & Gerber, 2005; Katsva, 2000). During the Soviet era, the emigration of strategic human capital was virtually nonexistent. Scientists, engineers, and technicians working in the defense sector were subject to strict controls, faced severe restrictions on international mobility, and any contact with foreign companies was closely monitored by the State. Moreover, these professionals were among the highest-paid workers in the country, while those residing in closed cities received additional benefits as compensation for their isolation (Moody, 1996). With democratization and the collapse of the Soviet State order, controls over emigration weakened. In the absence of effective legislation or containment mechanisms, many of these specialists sought opportunities abroad (Katsva, 2000; Shalkovskyi, 2002).

In view of this situation, many weapons experts emigrated (Katsva, 2000), primarily to Israel, Germany, and the United States (Shalkovskyi, 2002; Kramer, 2002). It is also known that some of them later worked for military programs in countries such as Algeria, China, North Korea, Cuba, Egypt, Iran, Iraq, Libya, Mexico, and Pakistan (Katsva, 2000). Nevertheless, contrary to widespread concerns at the time (Hymans, 2010), the defense sector did not experience a massive exodus of Russian scientists and engineers (Fomin, Oswald, & Voronkov, 1995; Moody, 1996). Some WMD-related facilities managed to preserve a degree of stability, due to both the continuation of state funding and the ability of scientists and technicians to supplement their incomes through alternative sources (Parachini et al., 2005).

4.2 The consequences of the emigration of scientists and researchers from the Russian defense industry in the 1990s: a critical literature review

The migration of scientists and researchers from the Russian defense industry throughout the 1990s received significant political attention and became the subject of debate among various authors, from different theoretical and geopolitical perspectives. Based on the bibliographic review conducted, it was possible to identify a limited set of studies that analyze the impacts of this process, both for Russia and for the international community. However, an asymmetry in approaches can be observed: only four works directly address the internal consequences for the

country of origin (cf. Shalkovskyi, 2002; Shkolnikov, 1994, 1995; Stanley; Lock; Gonschar, 1992), while most of the literature focuses on assessing risks to international security, especially regarding the possible proliferation of WMDs (cf. Ball; Gerber, 2005; Fomin; Oswald; Voronkov, 1995; Hymans, 2010; Katsva, 2000; Kramer, 2002; Moody, 1996; Parachini et al., 2005). This section aims to present and problematize the main interpretations identified, highlighting the consensus, controversies, and existing gaps in the academic debate.

4.2.1 Consequences for Russia

Shkolnikov (1994) argues that, at first, the emigration of highly qualified professionals from the former USSR would not result in the underutilization of technologies due to the high number of scientists relative to available infrastructure—according to him, there were "too many brains." However, the author alerts that Russia could suffer from the loss of scientific leadership, since many potential emigrants are among the most brilliant and, despite their youth, already hold prominent positions in their fields. The author emphasizes that scientific excellence depends on interaction between generations and that the departure of young scientists undermines the transmission of knowledge from more experienced researchers, negatively affecting the continuity and quality of scientific production in sectors in which Russia still holds international relevance. In summary, Shkolnikov (1995) considers that the emigration of arms specialists whose research is relevant to national security represents a loss for the country.

Similarly, Shalkovskyi (2002) highlights that the consequences for Russia would be predominantly negative, the main impact being the loss of scientific capital. A significant number of researchers took with them knowledge accumulated over years in R&D institutions and laboratories, which could, in the long term, make the country dependent on foreign expertise in strategic sectors. Complementing this perspective, Katsva (2000) observes that, once abroad, these scientists often act as recruitment vectors for their peers.

Shkolnikov (1994, 1995) also draws attention to other effects, such as the tendency of young scientists—because of their weaker ties to the country of origin—to engage less in scientific collaboration with Russian colleagues, unless they receive specific incentives. Moreover, there is the outflow of financial capital, as many emigrants transferred their resources abroad. Politically, the loss of individuals with a pro-Western profile could weaken reformist movements domestically.

In contrast, Stanley, Lock, and Gonschar (1992) adopt a more cautious view regarding the negative impacts of emigration. For the authors, these effects must be assessed in light of the deep social, political, and economic crisis faced by Russia at the time. They argue that many highly qualified professionals would not find positions in their fields within the country, which minimizes the "loss" for the Russian scientific and technological system. In the specific case of R&D defense specialists, their skills could even be considered a "burden" due to the high maintenance costs and scarce available resources, unless the State made a deliberate effort to maintain or expand such capabilities.

In addition, the authors also point out that the effects of emigration depend on the nature of the movement—whether permanent or temporary. In the latter case, emigration could benefit Russia by enabling scientists to continue working in their areas of expertise and to establish international collaboration networks. These ties could later benefit the Russian defense industry, either through arms exports or joint projects following the eventual return of these professionals (Stanley; Lock; Gonschar, 1992). Shkolnikov (1994, 1995) also acknowledges this potential, noting that although return is not always easy—especially in terms of labor market reintegration—many professionals are able to apply the skills acquired abroad in their country of origin, increasing their income and contributing to local development.

As has been shown, few authors have analyzed in depth the consequences of this phenomenon for Russia, largely restricting themselves to the works of Shalkovskyi (2002), Shkolnikov (1994, 1995), and Stanley, Lock, and Gonschar (1992). There is no consensus on the phenomenon: while Shalkovskyi (2002) emphasizes the negative effects of scientific capital loss—aligning with the "brain drain" perspective—Stanley, Lock, and Gonschar (1992) argue that the impacts vary according to the possibilities of scientific cooperation, being more in line with the concept of "brain networks." The perspective of "brain circulation" is also present in the studies analyzed, suggesting that Russia could benefit from emigration provided that professionals returned to their country of origin and were able to reintegrate into the labor market in their areas of specialization (Shkolnikov, 1994; Stanley; Lock; Gonschar, 1992).

Nevertheless, a point of convergence among the studies is the context in which they were produced: all are based on diagnoses from the 1990s or the early 2000s, when Russia was undergoing a period of transition and crisis. Although the losses of human capital suffered by the country had not been fully recovered as of at least 2020 (Aleshkobski, Gasparishvili, and Grebenyuk, 2023), none of these works systematically examines the consequences of this migratory flow for Russian military capabilities—a significant gap, especially considering that contemporary military superiority increasingly came to depend on science, technology, and innovation and, consequently, on the availability of highly qualified human capital (Paarlberg, 2004). The absence of analyses of the impact of this emigration on the restructuring and modernization of the Russian defense industrial base in subsequent decades reveals an important gap in the literature, limiting the understanding of the long-term effects of the emigration of defense professionals on national security and Russia's autonomous development in strategic sectors.

4.2.2 ***Consequences for the international community***

Shkolnikov (1994) observes that destination countries were only marginally benefited by Russian immigration, due to the difficulties these professionals faced in integrating into the labor markets of major receiving countries such as Israel and the United States. This context resulted in high unemployment rates and lower wages compared to other immigrant groups. Similarly, Shalkovskyi (2002) notes that the majority of Russian scientists who emigrated to the United States and Western Europe were unable to find employment in their field of expertise. In the specific

case of specialists in chemical and biological weapons, Shkolnikov (1995) points out that only 20% were able to remain in their area after migration.

Despite these difficulties in professional integration, most authors emphasize that the emigration of scientists from the former USSR represented, at least in part, a potential risk to international security. Moody (1996, p. 93) warns that defense-sector scientists, when unemployed or lacking prospects for professional transition, could become a threat to the non-proliferation regime, as long as their expertise remained "dormant." Parachini *et al.* (2005) reinforce this concern by highlighting the interest of different actors—states or non-state groups—that have shown interest in Russian technical knowledge related to nuclear, biological, and chemical weapons. According to the authors, demands for specialized knowledge vary according to the profile of the actors involved: while technologically advanced states seek highly complex technical expertise, countries at early stages of development—or even terrorist groups—tend to settle for more rudimentary capabilities, though still adequate for their strategic or operational objectives.

In this context, Shkolnikov (1995) notes that, due to the significant number of Russians who previously worked in so-called "pariah States," it is plausible that there exist various intermediaries with access to defense specialists. Moreover, the financial resources required to attract these experts would tend to be relatively low. Shalkovskyi (2002) observes that, although the emigration of Russian specialists in chemical and biological weapons was numerically limited in the 1990s, there is evidence that countries such as Iran and Syria managed to integrate Russian scientists into their WMD programs. Katsva (2000), in turn, emphasizes that such programs—especially biological ones—require fewer human and technical resources than nuclear programs, which reinforces the sensitivity of the issue even in the context of limited migratory flows.

On the other hand, part of the literature argues that there was no significant WMD dissemination as a direct consequence of the emigration of Russian scientists (Kramer, 2002; Shalkovskyi, 2002). Moody (1996) notes that the mobility of many of these specialists occurred within institutional frameworks, through projects sanctioned by the Russian State or through contracts with countries that did not threaten the international non-proliferation regime. Hymans (2010) deepens this debate by criticizing simplified models of proliferation present in part of the literature. According to the author, the mere presence of foreign scientists does not, by itself, guarantee the success of WMD programs, especially in countries with weak institutional capacity. In such contexts, identifying, recruiting, and effectively mobilizing highly qualified professionals require organizational capabilities superior to those demanded for local teams. For this reason, the involvement of émigré scientists tends to have limited impact and, in some cases, may even delay projects.

Various obstacles also limited the emigration of Russian scientists throughout the 1990s. Fomin, Oswald, and Voronkov (1995) highlight that many experienced specialists—generally over 50 years old and with consolidated careers in a single institution—were reluctant to restart their lives in different scientific, cultural, and linguistic contexts. Besides, the profound differences between the Russian and Western defense industrial systems further restricted their possibilities for professional reintegration abroad. Ball and Gerber (2005) emphasize

that most of these specialists demonstrated a strong ethical sense of responsibility regarding the dissemination of sensitive knowledge, avoiding cooperation with authoritarian regimes or migration to States seen as pariah. Kramer (2002) reinforces this point by showing that the least preferred destinations corresponded precisely to countries of greatest concern to the international community: Iraq (59%), Pakistan (42%), Libya (33%), Iran (24%), and North Korea (16%). As Parachini et al. (2005) summarize, this set of barriers contributed to limiting the illicit transfer of strategic knowledge.

Even in light of these arguments, part of the literature adopts a more pessimistic approach. Authors such as Ball and Gerber (2005), Parachini et al. (2005), and Shalkovskyi (2002) argue that, even if a minority, scientists willing to cooperate with authoritarian regimes represent a concrete risk. For these authors, the mere possibility that a fraction of these professionals might share sensitive knowledge is sufficient to justify international vigilance.

As has been shown, a small portion of the literature analyzed argues that Russia's post-Soviet skilled emigration generated only limited benefits for destination countries, due to so-called "brain waste"—that is, the underutilization of migrants' scientific and technical potential. However, there is a relative consensus regarding the existence of a proliferation risk associated with the international mobility of these specialists, although there are disagreements about its scale and likelihood. It is important to note that much of this literature is situated within the field of non-proliferation studies and was produced by institutions funded by Western governments, such as the RAND Corporation. Consequently, a strongly Western-oriented perspective can be observed. The definition of "brain drain" proposed by Katsva (2000), for instance, is selective: the author restricts the concept to cases in which scientists migrate to cooperate with WMD programs in States classified as pariah regimes, while disregarding situations in which allied or neutral countries also benefited from Russian expertise without such cases being problematized. This approach reveals a geopolitical bias and a logic of international security anchored in a Western view of the international system.

These studies reflect a context in which the boundaries between civilian and military technologies are becoming increasingly blurred (Roland, 1995), and in which access to sensitive technologies by a growing number of countries generates concern. Nevertheless, it is important to note that the complexity and high costs of weapons systems have accentuated technological inequalities between countries (Mallik, 2004), which in turn hinders proliferation. This argument is consistent with the less pessimistic portion of the literature, which emphasizes technical, financial, and organizational obstacles as barriers to the unrestricted diffusion of military capabilities.

The analysis of the literature shows that the consequences of the emigration of specialists from the Russian defense industry in the 1990s have been interpreted from different perspectives, reflecting both the strategic interests of Western countries and differing conceptions of international security and skilled migration. For Russia, the studies suggest that the effects varied according to the profile of emigrants and the degree of institutional coordination, oscillating between significant losses of human capital and opportunities for scientific cooperation. At the international level, although there is a relative consensus regarding the potential risk of WMD proliferation, part of the literature tempers this concern by highlighting the technical, political, and ethical obstacles

to the transfer of sensitive knowledge. A final observation concerns an important gap: few studies have systematically investigated the long-term effects of this emigration on Russia's military and technological capabilities.

5 FINAL CONSIDERATIONS

This study aimed to critically analyze how the academic literature interprets the impacts of the emigration of strategic human capital from Russia during the 1990s, with emphasis on its implications for national defense and international security. It sought to demonstrate that a significant portion of the literature on skilled migration has come to understand this phenomenon not merely as a loss for countries of origin and a gain for destination countries, but as a complex process capable of generating mutual benefits via mechanisms such as "brain circulation" and the formation of "brain networks." However, at the same time, contemporary military superiority is closely linked to scientific progress, given that the most significant innovations in the defense sector involve the integration of increasingly complex weapons systems, which require highly qualified labor. In this context, when it comes to the defense industry—whose development depends directly on ST&I and, consequently, on strategic human capital— the effects of emigration acquire more sensitive contours, with potential direct implications for state security and sovereignty.

By analyzing the Russian context, this study showed that, throughout the 1990s, Russia experienced a profound social, economic, and political crisis that directly affected its scientific system. This scenario was marked by rising unemployment, infrastructure deterioration, and a decline in funding and scientific productivity. Consequently, many researchers and scientists emigrated in search of better living and working conditions. Furthermore, following the collapse of the USSR, although Russia inherited the world's largest complex of weapons of mass destruction, government support for its maintenance was limited. The Russian defense industry faced budget cuts, a loss of state priority, and deterioration of working conditions. In this context, although comprehensive and precise data on the emigration of strategic human capital are not available, it is evident that numerous specialists in weapons-related fields left the country.

The literature analysis sought to show that the consequences of the emigration of specialists from the Russian defense industry in the 1990s have been interpreted in a heterogeneous manner, reflecting both Western policy interests and distinct conceptions of international security and skilled migration. For Russia, the main consequence identified was the loss of scientific capital accumulated during the Soviet period, although some studies highlight potential positive effects in cases where these specialists returned or maintained remote scientific cooperation. At the international level, the primary concern has been the risk that some of these migrants could contribute to the military programs of so-called pariah States, potentially facilitating the proliferation of weapons of mass destruction, although part of the literature minimizes this risk. Overall, most of the literature analyzed has focused on the implications of this flow for the international non-proliferation regime.

The analysis of the Russian case—the most extensively addressed in the literature, albeit still based on a limited number of studies—contributes to a broader understanding of the

phenomenon and of the impacts of skilled emigration on national defense in Global South countries, including Brazil. Although on a smaller scale and in a different context, the Brazilian defense industry has faced, in recent years, some of the challenges observed in Russia during the 1990s, such as technological gaps in the Armed Forces, international technological inequalities, and budgetary constraints (Brasil, 2020; Brum, 2025). Moreover, the economic and political crisis experienced by the country since 2014 has negatively affected industrial and scientific sectors (Oliveira, 2019), contributing to an increase in Brazilian emigration, including among highly qualified professionals (Brum, 2024).

Future studies could deepen the understanding of the emigration of professionals working in the defense industry, as well as its consequences for countries of origin, especially in developing countries such as Brazil, whose Defense Industrial Bases face significant structural challenges. In this regard, it is essential to make analyses that consider the specificities of these countries and the challenges associated with integrating their defense industries into the international market. In the Russian case, further research is needed to examine the long-term impacts of this migratory flow on efforts to revitalize its defense industry in subsequent decades. In conclusion, caution is recommended in the automatic application of international migration frameworks to the analysis of skilled emigration in the defense sector, given that this field has relevant specificities, is directly linked to national security, and therefore requires a distinct analytical approach.

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