Article

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The "duality" of technological duality[1]: implications for developing countries

La "dualidad" de la dualidad tecnológica: implicaciones para los países en desarrollo

Abstract: Although developed countries defend free trade, paradoxically, they exercise protectionist practices to maintain their technological supremacy on the international stage, as well as the technological dependence of peripheral countries. In the defense sector, prominent nations seek to achieve autonomy and technological sovereignty in their military capabilities, as well as to hinder the domination of critical and sensitive technologies by developing countries. In this regard, technological restrictions stand out, whose actions aim to deepen or at least maintain technological asymmetries. In this context, using a qualitative exploratory approach, this article aims to discuss a relevant and original aspect identified during the study: the "duality" of technological duality. For developing countries, duality presents itself as an opportunity to mobilize support not only financially, but also in the political and strategic spheres to obtain military investments. For developed countries, the hypothesis that duality can be used as a tool for selective technological restrictions was validated.

Keywords: Technological duality. Defense market. Technological restriction. Developing countries.

Resumen: Si bien los países desarrollados defienden el libre comercio, paradójicamente, ejercen prácticas proteccionistas para mantener su supremacía tecnológica en el escenario internacional, así como la dependencia tecnológica de los países periféricos. En el área de defensa, las naciones prominentes buscan obtener autonomía y soberanía tecnológica en sus capacidades militares, así como obstaculizar el dominio de tecnologías críticas y sensibles por parte de los países en desarrollo. En este sentido, destacan las restricciones tecnológicas, cuyas acciones apuntan a profundizar o al menos mantener las asimetrías tecnológicas. Insertado en este contexto, a partir de un abordaje exploratorio cualitativo, este artículo tiene el objetivo de discutir un aspecto relevante y original identificado a lo largo del estudio: la "dualidad" de la dualidad tecnológica. Para los países en desarrollo, la dualidad se presenta como una oportunidad para movilizar apoyo no solo financiero, sino también en las esferas política y estratégica para la obtención de inversiones dirigidas al sector de defensa. En cuanto a los países desarrollados, se validó la hipótesis de que la dualidad puede emplearse como herramienta para la restricción tecnológico selectivo.

Palabras clave: Dualidad tecnológica. Mercado de defensa. Restricción tecnológica. Países en desarrollo.

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1 The term duality of technological duality was introduced in opinion articles on the Brazilian Army Blog - EBlog (Galdino, 2022) and on the Military Observatory of Praia Vermelha - OMPV (Galdino, 2024).

1 INTRODUCTION

Developing new technologies is essential to gain a competitive advantage for technology-driven organizations (Cetindamar, Phaal, Probert, 2016) and promote economic growth and social development in countries (Coccia, 2019). The relevance of this ability is proportional to the complexity of the technologies involved in the Research and Development (R&D) process, given that in addition to the technological risks inherent to the R&D process, it encompasses technological management, which in turn includes planning, directing, controlling, and coordinating the development of technological capabilities so that organizations can design and achieve their strategic objectives (National Research Council, 1987). These tasks become more sophisticated as they deal with complex technologies.

The growing importance of science and technology in developing elements of military capabilities drives the search for technological management models that aim to optimize processes for obtaining[1] systems and materials for military use (França Junior; Galdino, 2022). In these processes, the decision between carrying out local R&D or importing critical technologies is a common problem faced by senior management not only in the Armed Forces but also in other organizations that develop complex products, in which good compromise solutions are sought between deadlines, costs, and technological autonomy (Girardi; França Junior; Galdino, 2024; Kiamehr; Hobday; Hamedi, 2015; Lee; Yoon, 2015; Ren; Yeo, 2006).

Full national autonomy in the scientific and technological field is a utopia. Even the most developed countries in the world depend, to some extent, on others for the survival of their high-tech industries (Kirkpatrick; Nixson, 1983). However, dependence is usually specific and controlled in these countries, as they have efficient sectoral and national innovation systems (França Junior; Galdino, 2022).

On the other hand, in developing countries, whose high-tech demands are often not met internally (Amann, 2002), technological dependence can become a chronic problem (Gu, 1999; Niosi; Zhegu, 2010), particularly in defense. In these countries, R&D investments in the military sector are generally modest because governments prioritize social and infrastructure agendas (Bresser-Pereira, 1997). This situation tends to worsen as the defense sector is the target of technological restriction actions (Longo, 1984; Moreira, 2013), depends on high-value technologies, and developing countries have modest national innovation systems (Galdino, 2018, 2019).

In this context, a concept that is gaining relevance in the defense scenario is technological duality. Because discoveries initially intended for military applications can have their base technologies used for civilian applications (Amarante, 2013; Brustolin, 2014), developing countries have exploited duality to mobilize financial support and political and strategic spheres to obtain investments aimed at the defense sector.

In developed countries, according to data from the latest annual report by the Stockholm International Peace Research Institute (SIPRI), the defense budget is significant (SIPRI, 2024),

1 R&D and/or acquisition of systems or materials with the technical, operational, and logistical characteristics established by the organization (Brasil, 2016b).

reducing the need to explore the concept of duality to obtain support for the development of technologies of military interest. This article presents the hypothesis that duality in these countries is explored from another perspective: as a subterfuge to encourage or enhance the practice of selective technological restrictions in the civilian sector, aiming to maintain asymmetries between developed and developing countries in the high-technology sectors.

In this regard, this article discusses how the concept of technological duality can assume different roles according to the scenario in which it is inserted. In other words, it seeks to analyze the "duality" of technological duality. This original analysis has direct implications for technological development efforts in the military area, especially in the context of developing countries. From this perspective, it seeks to answer the following research question: **What implications does the "duality" of technological duality have for developing countries?**

This study addresses this issue and presents theoretical contributions to broaden the understanding of how technological duality can be used differently, depending on the economic and geopolitical context. As practical contributions, the study can assist policymakers and managers in defense, highlighting the importance of strategies that consider the synergy of military and civilian technological development, and the challenges posed by technological restriction practices. Thus, this article supports the advancement of theoretical knowledge and provides practical guidelines for strategic decision-making in a sector crucial for national development.

The remainder of the article is organized as follows. Section 2 presents a theoretical background on essential concepts associated with the topic discussed, namely technological duality, defense market, technological restriction, and developing countries. Section 3 describes the methodological aspects used in the research. Section 4 explores events that occurred in the Brazilian context. Section 5 discusses the "duality" of technological duality and its implications for developing countries. Finally, Section 6 presents the final considerations, identifying gaps to be addressed by future studies.

2 THEORETICAL BACKGROUND

2.1 Technological duality

Orlikowski (1992) coined the concept of technological duality, which refers to the idea that technologies and organizations are interconnected and influence each other. The author argues that technology is not only shaped by the organization during its development and implementation but also shapes organizational practices in its use. This duality concept highlights the reciprocal relationship between technology and organization (Orlikowski, 1992).

In the field of defense, the concept of technological duality is often used to describe how innovations or technologies initially intended for the military area can be used for civilian use (spin off) and vice versa (spin in) (Amarante, 2013). In this sense, in the defense context, technology can be considered dual when there is the possibility of having military and civilian applications, current or potential (Brustolin, 2014). This concept highlights the permeability of the boundaries between military and civilian technological development, showing that innovations can move between these two domains.

When connecting the two approaches, both are shown to address technology's fluid and interactive nature. While Orlikowski (1992) focuses on the interaction between technology and organization, technological duality in defense highlights the interaction between military and civilian technological development (Amarante, 2013; Brustolin, 2014). Both recognize that technology does not exist in a vacuum but is influenced by its surroundings and the context in which it is developed and used, allowing the transfer and adaptation of innovations between different fields.

2.2 Defense market

The defense market is an economic sector that involves research, development, production, marketing, and supply of goods and services related to national security and defense (Brasil, 2016a). It is worth noting that this is a rapidly expanding market. The latest SIPRI annual report indicates that global military spending in 2023 reached US$ 2.443 trillion, showing growth for the ninth consecutive year (SIPRI, 2024). The main characteristics of this market are:

- **Strategic importance:** The defense sector is related to the set of attitudes, measures, and actions of the State, with an emphasis on military expression, for the defense of the national territory, sovereignty, and national interests against predominantly external, potential, or manifest threats (Brasil, 2016a).
- **High technological level:** The defense industry demands high investments in research, development, and innovation to create advanced and complex products, such as aircraft, ships, weapons, and systems that must operate safely and with high reliability under severe conditions, even facing artificial obstacles caused by belligerents (Bitzinger, 2009; Girardi; Galdino; Pellanda, 2024). For this reason, defense systems are often associated with the concept of Complex Products and Systems (CoPS), which, in general, are characterized by the need for customization of components and subsystems, production in few units and few integrating companies, aggregation of several areas of knowledge and a life cycle that lasts for decades (Girardi; França Junior; Galdino, 2022; Hobday, 1998);
- **Technological duality:** As Section 2.1 shows, technological duality in the defense sector highlights the reciprocal relationship between military and civilian technological development (Amarante, 2013; Brustolin, 2014). Two emblematic examples of duality in the sector are the GPS (Global Positioning System) and the Internet. The United States Department of Defense developed these technologies for military purposes and are now widely used by civil society.
- **Government dependence:** The defense market is highly regulated by governments and dependent on government contracts, which means that sector companies heavily depend on public resources (Urbano, 2019). In this sense, from a demand

perspective, the defense market can be considered a monopsony since the State is the leading buyer of the goods and services offered by companies (Araujo *et al*., 2011; Galdino; Schons, 2022).

- **High market concentration:** Few companies dominate the global defense market, which leads to limited competition and protectionist practices (Galdino; Schons, 2022). According to Anderton (1995), these oligopolies in the defense market present the potential for collusion and strategic behavior on the part of the participating companies. They may act together to increase prices and, consequently, their profits, or they may accept lower profits to make it difficult for competitors to enter (Anderton, 1995 *apud* Matos; Foresti, 2022). They may also charge prices below the market in specific countries to prevent the development of strategic sectors in the industrial base of these nations, an action known as dumping (Ethier, 1982).
- **Vulnerability to geopolitical issues:** The demand for defense equipment is driven by geopolitical conflicts and relations between nations, making the market highly volatile and subject to sudden changes and interference (Silva, 2019). Foreign companies that exploit war as a form of commerce may, for purely financial reasons or to meet the geopolitical and ideological interests of host countries, fail to fulfill their commitments, and this generally tends to occur in times of greatest need and national crisis (Galdino; Schons, 2022).

In summary, the defense market is strategic, high-tech, dual, volatile, and far from perfect competition. According to Araujo et al. (2011), it is simultaneously a monopoly/oligopoly and a monopsony since, respectively, there is a supply dominated by large global players and a demand centralized by States.

2.3 Technological restriction

While the most developed countries defend free trade, paradoxically, they exercise protectionist practices to maintain their technological supremacy in the international scenario and the technological dependence of peripheral countries (Chang, 2003).

In defense, prominent nations seek autonomy and technological sovereignty in their military capabilities, hindering developing countries' dominance of critical and sensitive technologies. This game is a natural manifestation of preserving the *status quo* and conditions the movement of the pieces on the geopolitical board. In this regard, technological restrictions stand out, with actions aimed to deepen or at least maintain technological asymmetries (Galdino, 2022).

The concept of technological restriction is intrinsically related to the characteristics of the defense market set out in Section 2.2, especially concerning the vulnerability to geopolitical issues. This perception is confirmed in the definition proposed by Moreira (2013): technological restriction is the

> [...] set of policies, norms, and actions undertaken by States, international organizations, or companies to restrict, hinder, or deny access, possession, or use of sensitive goods and directly linked services, by States, research institutions or third-party companies (Moreira, 2013, p. 252, our translation).

In Pedone's (2009) view, technological restriction can be practiced by a myriad of actors, such as States, groups of States, companies, and/or consortiums of companies that seek to restrict, block, deny, or even hinder access to goods and technologies considered sensitive, especially in the area of defense.

From this perspective, Moreira (2013) establishes the following six models of technological restriction (Table 1) to classify how restrictions can occur.

Table 1 – Models of technological restriction

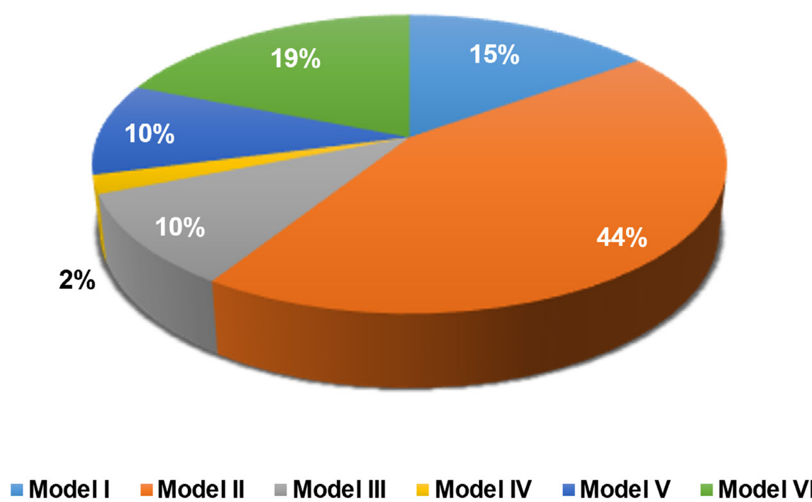
Model	Manifestation of restriction
I	Supplier company denies on its own accord.
II	Government agencies do not authorize the purchase, sale, or transfer operation.
III	Intervention by State agencies in initiated processes.
IV	Intervention using brute force.
V	Company absorption, brain drain, or discontinuity of supply.
VI	Political, economic, or social pressure by the State, IGO (International Governmental Organization), or non-governmental communities.

Source: Moreira (2013).

In addition to proposing models for the manifestation of technological restriction, Moreira (2013) presents a survey covering the period from 1989 to 2011 on which models were most practiced (Figure 1) and which countries or institutions used this practice the most (Figure 2). Figure 1 shows that most restriction cases (44%) occur when government agencies do not authorize sensitive technology purchase, sale, or transfer (Model 2 in Table 1). Figure 2 shows that the USA has a very significant predominance (73%) in cases of technological restriction, followed by its European allies and Israel.

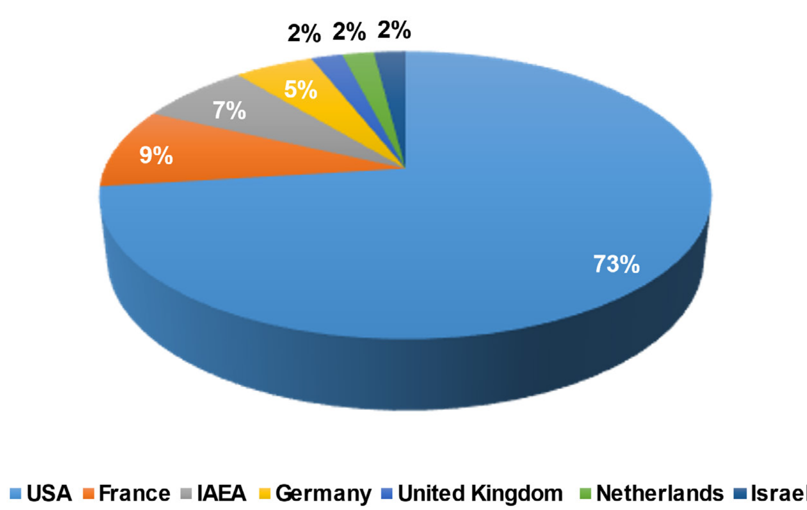
The USA's predominance in technological restriction cases is mainly due to its regulatory system. The USA's export control legislation aims to control the export of sensitive equipment, software, and technologies to promote its national security and foreign policy objectives (Silva; Nascimento, 2018). Amarante (2013) states that other developed countries also use regulatory systems to promote technological restriction.

Figure 1. Proportion of technological restriction models



Source: Moreira (2013, p. 203-207).

Figure 2 – Proportion of technological restriction by country or institution



Source: Moreira (2013, p. 203–207).

2.4 Developing countries

The terms "developing countries," "late industrializing countries," "recently industrializing countries," and "emerging countries" can be used interchangeably in some contexts, but they can also have specific connotations.

The term "developing countries" is more comprehensive and refers to countries that have not yet achieved high economic, social, and human development (Furtado, 1974). Tavares and Belluzzo (1979), Canuto (1993), and Figueiredo (2009) use the terms "late industrializing countries" or "recently industrializing countries" to refer to countries that began the industrialization process at a later time than the pioneering countries. In turn, O'Neill (2001) coined the term "emerging countries" to refer to developing countries with more potential economic growth and global influence. From this perspective, the acronym BRICS was created and disseminated to highlight Brazil, Russia, India, China, and South Africa as the leading countries on the rise on the international scene.

Since there are several classification systems (Hoffmeister, 2020) and to avoid ambiguities, this study follows the classification maintained by the United Nations Statistics Division (UNSD). In May 2022, the UNSD released an updated spreadsheet that classifies 249 countries or areas, except Antarctica, into two categories: "developed" and "developing" (United Nations, 2022). For this reason, the terms "developed countries" and "developing countries" are adopted as references in this text.

From this perspective, the main characteristics of developing countries stand out:

- **Dependence on foreign investment:** Developing countries have limited capital and technology to drive their economic growth. Foreign investment can come from various sources, including multinational companies, international organizations, and individual investors (Li; Resnick, 2003). Although this dynamic can benefit economic development, it can create vulnerabilities, such as chronic dependence on foreign sources and the risk of sudden capital flight in times of turbulence (Dooley; Folkerts-Landau; Garber, 2004). Hostages to this dynamic, many developing countries end up not developing their internal capacities to finance long-term development (Kose; Prasad, 2011).
- **Importation of technology and know-how:** Companies operating in the context of developing countries usually start their business using technologies that they have acquired from companies in other countries. When they start their activities, they do not even have basic technological capabilities (Amann, 2002). To become competitive and approach companies on the "international technological frontier," they must learn to build and accumulate their technological capacity (Figueiredo, 2009). Excessive dependence on foreign suppliers can harm the development and competitiveness of the national industry, as well as leave the national industrial base vulnerable to geopolitical issues and fluctuations in the international market (Ariffin; Figueiredo, 2003).
- **Strong State presence in promoting national development:** Due to the economic limitations of developing countries, essential issues for driving national development are highly dependent on State action, such as investments in infrastructure, promotion of strategic sectors, and establishment of incentives for investment and innovation (Chang, 2003). According to Rodrik (2004), this State protagonism can generate corruption and inefficiency, given that this class

of countries tends to have a low degree of transparency and efficiency in public management (Rodrik, 2004).

- **Poor innovation capacity:** In national terms, the concept that best describes innovation capacity is the National Innovation System (NIS) (Cimoli, 2014; Godin, 2009; Lundvall, 2007). Freeman coined this expression in the late 1980s to designate a set of public and private institutions whose activities and interactions contribute to creating, advancing, and disseminating a country's technological innovations (Freeman, 1995). There are several indicators for evaluating an NIS, among which those produced by the Global Innovation Index (GII) stand out. Based on the GII, developing countries tend to present modest indicators both in terms of innovation inputs (institutions, human resources and research, infrastructure, market sophistication, and business sophistication) and innovation outputs (knowledge and technology products and creative products) (Galdino, 2018, 2019).
- **Limited investment in defense:** In developing countries, there are usually many social and infrastructure demands (Bresser-Pereira, 1997). Furthermore, many countries in this class do not have a warmongering culture due to their low history of participation in military conflicts, creating obstacles to prioritizing investments in the defense area (Bijos; Arruda, 2010). Given this scenario, resources for the R&D of military systems in these nations tend to be modest. This perspective is confirmed by the data provided by the SIPRI report. For example, while the USA had, in 2023, budgetary investments of 916 billion dollars, which is equivalent to 3.4% of its Gross Domestic Product (GDP) and 37% of all annual global defense spending, Brazil had a budget of 22.9 billion, equivalent to 1.1% of its GDP (SIPRI, 2024). In this context, developing countries seek to explore the concept of technological duality to obtain resources from other sources, aiming to develop technologies that are important for military capabilities and the progress of the broader industrial sector (Squeff, 2016).

3 METHODOLOGY

Based on a qualitative exploratory approach, the aim is to investigate how the concept of technological duality can assume different roles according to the scenario in which it is inserted. Exploratory studies are appropriate when little is known about the reality in question, and the aim is to pave the way for new research (Yin, 2017). In addition, the qualitative approach is used in descriptive, subjective works and inductive analysis of observed facts and collected evidence (Cauchick-Miguel *et al*., 2018). Within this perspective, this study was based on collecting and analyzing primary data (interviews) and secondary data (academic literature, technical reports, and news reports).

Initially, based on repositories of scientific papers and data from technical reports by organizations such as SIPRI and the Institute of Applied Economic Research (IPEA), the aim was to survey features associated with the defense market, developing countries, and models of technological restriction undertaken by developed countries. This review was the basis for developing the study's theoretical background (Section 2).

Data collection was complemented with news reports and an interview with a researcher involved in defense-related R&D activities. Through this approach, examples from the Brazilian scenario were listed to illustrate how technological restriction actions can affect developing countries and provide a better understanding of how technological duality can be used differently. These examples are detailed in Section 4. It is worth noting that the interview was in-person and followed a semi-structured approach, allowing flexibility to explore emerging topics (Brinkmann; Kvale, 2014).

The analysis of the collected data supported the discussion that is the object of this study—the "duality" of technological duality—and its implications for developing countries. This discussion is presented in Section 5.

4 EXAMPLES FROM THE BRAZILIAN SCENARIO

After addressing the concepts of technological duality, defense market, technological restriction, and developing countries, it is necessary to present examples from the national scenario to illustrate how technological restriction actions can affect these countries' development. The examples are presented chronologically and categorized within the six models proposed by Moreira (2013), presented in Table 1.

4.1 Israel's technological restriction in the Iraqi nuclear program and its influence on the Brazil-Iraq nuclear agreement

As detailed in Domíngues (2022), in 1980, Brazil and Iraq signed the Agreement on the Peaceful Uses of Nuclear Energy. Among the areas of cooperation identified by the parties was the supply of natural uranium and slightly enriched uranium to fuel nuclear reactors.

At the time of the events, Saddam Hussein's regime had contracted with the French government to build a modern nuclear research center in al-Tuwaitha, located south of Baghdad. The project was very close to completion when a precise and surgical Israeli air strike took place on June 7, 1981.

The attack provoked important political and diplomatic reactions, bilaterally, regionally, and globally, undermining the credibility of the international system for monitoring and verifying nuclear activities performed by the International Atomic Energy Agency (IAEA).

Five days after the attack, the issue began to be debated in the United Nations Security Council. At the time, despite not being a full member of the Council, Brazil could actively participate in the discussions due to its ties and direct interests in the matter. This connection was intensified after the Israeli embassy in Tokyo released a document insinuating possible cooperation from Brazil (as well as Italy and France) through the export of uranium concentrate to Iraq in the context of an alleged clandestine atomic weapons program.

This Israeli accusation began to lose visibility in the press over time. From a technical-scientific and logistical perspective, in fact, the accusation was considered to be hardly consistent, either regarding the supply of nuclear fuel to Iraq or the bilateral partnership for the joint and coordinated construction of atomic weapons.

Today, even after more than 40 years since the event, the matter is still considered an "unfinished soap opera." In any case, nuclear cooperation—for peaceful purposes—between Brasília and Baghdad was confirmed and recognized and was directly impacted by the Israeli airstrike on the Iraqi nuclear research center (Domínguez, 2022).

From this perspective, the alleged counterproliferation of weapons of mass destruction mentioned above can be considered an emblematic case of technological restriction with the use of brute force. It can, therefore, be classified under model IV of technological restriction proposed by Moreira (2013).

4.2 Pressure from the USA to inspect ultracentrifugation machines developed by Brazil

At the turn of the 2000s, Brazil announced a project to produce enriched uranium domestically to supply the Angra 1 and 2 nuclear plants. The contract, worth US$ 130 million and lasting eight years, provided that the Navy would *supply Indústrias Nucleares do Brasil* (INB) with ultracentrifugation machines developed at the Aramar Technology Center (SP) in partnership with the Nuclear and Energy Research Institute (IPEN) and the University of São Paulo (USP). According to the original plan, Brazil would be self-sufficient in uranium enrichment by 2007, except for the product gasification stage, a cheap and non-strategic process (Santos, 2004).

In April 2004, the USA questioned the Brazilian nuclear development. They demanded that Brazil sign an additional protocol with the IAEA to allow greater access to the country's commercial enriched uranium production plants in Resende (RJ). The pressure to sign the new agreement was justified as a measure for nuclear non-proliferation and included possible trade sanctions (Cariello, 2004).

American researchers like Liz Palmer and Gary Milhollin from the Wisconsin Project on Nuclear Arms Control supported this movement. In an article published in the *Science* journal, they estimated that the Resende facility, in its 2004 configuration, could produce enough enriched uranium for six warheads per year. Using the plant's expansion projections, they also predicted that the annual warhead production capacity could increase to 26 to 31 in 2010 and 53 to 63 in 2014 (Nogueira, 2004).

Brazil refuted the allegation that enriched uranium could be used for military purposes, given that the country was a signatory to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and had guaranteed in its Constitution the commitment to use nuclear energy only for peaceful purposes (Salomon, 2004).

The Brazilian government's evaluation of the incident was that the USA wanted access to uranium enrichment ultracentrifuges, which were manufactured using Brazilian technology and were cheaper since the country could produce them on an industrial scale and export them to other countries, thereby gaining relevance in the international nuclear market (Cariello, 2004).

This example aligns with the perception of Longo and Moreira (2009), who assert that the international regime for the non-proliferation of weapons of mass destruction provides the normative basis for restrictive controls on sensitive technologies and pretexts for hidden purposes of selective restriction. Additionally, the example can be framed within model VI of technological restriction proposed by Moreira (2013), as it reports the USA's pressure in an attempt to interfere in Brazilian nuclear development.

4.3 US technological restriction in PROSUB

According to reports by Silva and Nascimento (2018), in 2007, the Brazilian Navy sought to import carbon fiber from the company Toho Tenax America for its Submarine Program (PROSUB).

Following the Brazilian request, the US company formally consulted the Bureau of Industry and Security of the DoC (US Department of Commerce). In a formal response to the consultation, the DoC prohibited Toho Tenax America from complying with the import request made by Brazil. The justification for denial was based on the EAA (Export Administration Act), which states that the USA must "restrict the export and reexport of items that would make a significant contribution to the military potential of any other destination or combination of destinations that would prove detrimental to the national security (NS) of the United States." The text shows that it is up to the DoC authorities, at their discretion, to establish what may be considered harmful to US national security (Silva; Nascimento, 2018).

The example can be classified under model II of technological restriction proposed by Moreira (2013) since it involves a US government agency (DoC's Bureau of Industry and Security) not formally authorizing a purchase operation requested by the Brazilian Navy.

4.4 Technological restriction of a German group in the national production of HTPB

In addition to being a fundamental input in the production of solid-based propellants for rockets, hydroxyl-terminated polybutadiene (HTPB) has an extraordinary conventional market, particularly in civil construction, petrochemicals, and industry (AVIBRAS, 2018; FAN, 2012).

The domestic production technology for HTPB emerged in the 1970s through a partnership between Petrobras and the Department of Aerospace Science and Technology (DCTA). In 1982, Petrobras began industrial-scale production of HTPB within Petroflex. With Petroflex's privatization in 1994, the HTPB unit was acquired by Braskem. HTPB production in Brazil was interrupted in 2008 when the new unit owner, the German company Lanxess, discontinued the business (Silveira, 2013).

This situation began to change in 2012 when Avibras planned to invest R$ 46 million to install a new industrial unit in Lorena (SP) to manufacture HTPB (Fan, 2012). The resumption of

HTPB production in the country was considered strategic by Avibras, given that all rockets manufactured and used by the Armed Forces in Brazil adopted solid propellant based on HTPB, and the purchase of the input abroad was subject to international embargoes (Avibras, 2018). In addition, it is worth highlighting the prediction that this resumption of national HTPB production would have an even more significant impact on the civilian market, given that the potential consumption of the product in civilian applications was 20 times greater than in the defense and aerospace segments (annual consumption estimates of 5,000 and 250 tons, respectively) (Fan, 2012).

In this sense, this example can be classified as model V of the technological restriction proposed by Moreira (2013) since it involves the absorption of a Brazilian company by a German group and subsequent discontinuation of the national production of a strategic input for the production of rockets, in addition to being an input with high potential for use in civilian applications.

4.5 Technological restriction of a North American company in the Brazilian Army's thermal camera project

An interview and documents obtained from a researcher at the *Instituto Militar de Engenharia* (IME – Military Institute of Engineering) raised a case of technological restriction related to the Brazilian Army's development of a thermal camera.

In 2015, the IME, in partnership with the *Centro Tecnológico do Exército* (CTEx – Army Technological Center), completed the development of thin films of Vanadium Oxide (VO_x) to provide a modern solution for infrared sensors for thermal vision cameras.

Integrating the technology into the optronic equipment required a suspended architecture of the infrared sensor devices due to heat dissipation. This architecture could only be implemented with the help of a special resin produced exclusively by a North American company at the time.

In a first attempt to acquire the resin from the manufacturer, the purchase was denied, alleging that the product was unavailable for sale in Brazil, even though the company had a branch in the country.

The second attempt sought to acquire the input via import through the Brazilian Army Commission in Washington (CEBW). Once again, the company responded negatively regarding the sale of the resin.

The third attempt to obtain the input sought to separate the request from the military area. Thus, the *Universidade Estadual de Campinas* (UNICAMP), a civilian institution partner of IME, was requested to acquire the product. The manufacturer again claimed that the resin was unavailable.

In the fourth and final attempt, an importing company with an office in the USA requested the product. The manufacturer's response was again negative.

In all four attempts to acquire the resin, the manufacturer's justification for the refusal was vague: "At this time, the company cannot ship to Brazil." Despite this, the researcher believes the refusal occurred because the product is a critical input for producing modern thermal imaging cameras, a technology with great dual potential. In the defense area, this technology fosters the development of optronic equipment for military applications. In the civilian area, in addition to its application in surveillance systems, it is used in the medical area through thermography exams.

Given the above, the example can be classified as a model I of technological restriction proposed by Moreira (2013), as the resin manufacturer refused to supply the product on its initiative without justifying the refusal via formal consultation with the government agency, as was the case in the example presented in Section 4.3.

4.6 US technological restriction on the sale of 5G equipment by Huawei

According to an opinion piece in *Folha de S. Paulo* newspaper written by the Chinese ambassador to Brazil at the time, Yang Wanming (2020), the USA made unfounded accusations that Huawei's 5G equipment posed security risks. Under this pretext, they restricted the global manufacturers' supply of chips to the company and coerced other countries to give up Chinese 5G technology. Huawei was supported by formal assessments by intelligence and cybersecurity authorities in the United Kingdom and Germany, which confirmed that there were no grounds for banning the company's equipment for security reasons. In addition, the Chinese manufacturer had a history of reliability in more than 170 countries and territories (Wanming, 2020).

Globo's *G1* news portal (2021) also analyzed this case, reporting that the arrival of 5G worldwide was surrounded by controversy between the United States and China. The Americans forbade Chinese telecommunications companies from participating in their networks and pressured business partners to ban equipment from Huawei, which was at the forefront of the new technology. The US claimed that the equipment from these companies posed a risk to national security since China could use it for espionage or to interfere with the functioning of other countries' infrastructure. The Chinese denied the accusations, saying that the Americans' interest was to undermine their growth and technological development (Globo, 2021).

This US restriction action had repercussions in the Brazilian scenario. At the time of the definitions for the 5G auction, the US pressured Brazil to block the entry of Chinese companies into the country's new-generation internet infrastructure. However, the 5G auction, held in November 2021, involving only telephone operators, did not impose any rule preventing operators from using Huawei technology (Carvalho, 2022). The Ministry of Communications only included in the notice the obligation to build a private communications network in Brasília to meet the request from then-president Jair Bolsonaro, who was against using Huawei equipment in government networks (Globo, 2021).

This example can be framed in model VI of technological restriction proposed by Moreira (2013) since the USA used the claim of cybersecurity risk to pressure commercial partners to ban Huawei equipment to contain the Chinese company's advance, which was then at the forefront of new technology.

4.7 Germany's technological restriction on the export of Guarani armored vehicles

According to a report in *Correio Braziliense* newspaper (2023), the German government embargoed the export of 28 Guarani armored vehicles manufactured in Brazil to the Philippines.

The Brazilian government saw this as retaliation for President Luiz Inácio Lula da Silva's refusal to sell tank ammunition to Berlin for shipment to Ukraine, which Russia had invaded.

To embargo the transaction, Germany justified that components manufactured in that country cannot be sold to third parties without authorization. This led the Berlin government's Federal Office for Economic Affairs and Export Control to hold the five Guaranis ready to be delivered to the Philippines. The solution for the deal to be concluded is to replace the components of German origin (Hekally, 2023).

The example can be classified in models III and VI of technological restriction proposed by Moreira (2013).

The classification in model III is justified because a German government agency (Federal Office for Economic Affairs and Export Control) directly interfered in the commercialization of armored vehicles that had already begun between Brazil and the Philippines.

The classification in model VI is due to the understanding that Germany used the embargo to pressure Brazil due to its neutral position regarding the conflict between Russia and Ukraine.

4.8 Interest of Arabs and Germans in the company Avibras

According to a report in *Veja* magazine (2023), in March 2022, the company Avibras, one of the largest in the defense industry sector in Brazil, filed for bankruptcy protection and dismissed 420 of its 1,400 employees. The company then had approximately R$ 395 million in debts, as reported to the courts.

Given this scenario, speculation arose that the Edge Group, a company from the United Arab Emirates known for buying and reselling military projects, was negotiating to buy the Brazilian company. The Arab would be interested in the Astros multiple rocket launch system and the Tactical Cruise Missile, both manufactured by Avibras (Bonin, 2023). In addition, the company based in São José dos Campos also offers software solutions and produces weapons and armored vehicles, such as the Guará 4WS (Vinholes, 2023).

According to Vinholes (2023), the German company Rheinmetall, famous in the weapons and ammunition sector, would also be interested in purchasing Avibras.

This news led the Metalworkers' Union of São José dos Campos and the region to issue a statement warning that a possible sale of the company would seriously threaten national sovereignty and the knowledge accumulated over decades (Vinholes, 2023).

In light of the repercussions, Avibras issued a press release stating:

> The company is strongly committed to ensuring its recovery, facing the challenges and difficulties of the moment with its employees' support, resilience, and engagement. [...] The Brazilian government is also mobilized to actively support the company in its recovery initiatives (Avibras, 2023a).

It is worth noting that amidst the speculation, the only recent formal initiative related to Avibras was the signing of a partnership agreement with SCOPA Defense, a Saudi Arabian company, aiming to promote the development and manufacture of advanced defense equipment in Saudi territory (Avibras, 2023b).

From the perspective presented, the example can be framed in model V of technological restriction proposed by Moreira (2013) as it deals with the possible absorption of a Brazilian company by a foreign group, with the risk of subsequent discontinuation of the national production of strategic products and systems for the defense sector.

5 THE "DUALITY" OF TECHNOLOGICAL DUALITY

Based on the concepts and examples explored throughout the article, the following sections show how developing and developed countries can use technological duality differently. In addition, the implications of this "duality" of duality for developing countries are discussed.

5.1 The role of technological duality for developing countries

As discussed in Section 2.4, in developing countries, the budget allocated to the defense sector is usually modest, given the significant social and infrastructure demands that tend to be prioritized, in addition to the absence of a warmongering culture (Bijos; Arruda, 2010; Bresser-Pereira, 1997).

In addition to being limited, budgetary resources for the military sector are predominantly committed to administrative expenses, personnel payments, and mandatory expenses. For example, 78.2% of the defense budget in Brazil is allocated to personnel payments (Brasil, 2022).

These nations explore the concept of technological duality as a strategy for obtaining financial resources to enable the development of technologies that are important for military capabilities without compromising the Armed Forces' budget for R&D activities while contributing to the progress of the broader industrial sector (Squeff, 2016). Additionally, for these countries, duality is essential for establishing cooperation aimed at technological development and conferring sustainability to companies that work in the defense market (Galdino, 2022).

According to Squeff (2016), the defense sector has consistently gained greater relevance in the Brazilian government's public policy agenda since the early 2000s, and duality has played an essential role in this result.

To illustrate this phenomenon, the author presents a 2012 survey regarding the funding received by national Science, Technology, and Innovation (ST&I) infrastructures focused on R&D in the military area. The data show that only 26.44% of the resources invested in R&D came from institutional budgetary funds. The other 73.56% were obtained from public funding agencies or companies, such as Petrobras (Squeff, 2016).

In fact, the Brazilian Army has developed essential technologies, sensors, communications systems, and elements of weapons systems with the financial support of funding agencies, notably the Ministry of Science, Technology, and Innovation (MCTI), through the National

Fund for Scientific and Technological Development (FNDCT), as well as the National Bank for Economic and Social Development (BNDES). Some examples of Land Force R&D projects included in this scenario are optronics (Castro *et al*., 2014; Souza, 2006), radars (Silva *et al*., 2014; Carvalho *et al*., 2008), Software-Defined Radio – RDS (Branco *et al*., 2014; Paiva Junior *et al*., 2014; Prado Filho; Galdino; Moura, 2017; Ribeiro Junior *et al*., 2014), carbon fibers (Chaves, 2019; Castro, 2014), and Automated Machine Gun Repair X (REMAX) for the Guarani armored vehicle (Dal Bello; Figueiredo; Almeida, 2020).

In 2022, IME, in partnership with other Scientific, Technological, and Innovation Institutions (ICT) of the Army, was awarded resources from the FNDCT to boost research in strategic technological areas, namely Artificial Intelligence (AI), cyber defense, quantum technologies, drone swarm, sensors for Chemical, Biological, Radiological and Nuclear Defense (CBRND), additive manufacturing, and railway infrastructure. The proposals presented by IME to the funding agencies were based mainly on the dual potential of these technologies.

It is worth noting that technological duality is not of great importance in some developing countries, such as China and India. These nations already have significant budgetary investments in the defense area for geopolitical and strategic reasons, according to information in the SIPRI report and summarized in Table 2.

Table 2 – Annual budgetary investment of China and India in the defense area

Country	Position in the world ranking	Budget (billions of US$)	Percentage of GDP invested (%)	Share of world investment (%)
China	2nd	296.0	1.7	12.0
India	4th	83.6	2.4	3.4

Source: SIPRI (2024).

5.2 The role of technological duality for developed countries

In developed countries, the defense budget is generally significant, and there is no need to explore the concept of duality to obtain support for developing technologies of military interest. SIPRI data indicate that in 2023, the USA invested 916 billion dollars for military purposes, equivalent to 3.4% of its GDP and 37% of all annual global defense spending. In addition, the target of a minimum investment of 2% of GDP in military applications is set for the member countries of the North Atlantic Treaty Organization (NATO) (SIPRI, 2024), generating considerable budgetary amounts for defense.

For these countries, however, the hypothesis is that duality is used as a subterfuge to enable or enhance the practice of selective technological restrictions. Access to essential technologies to obtain innovations aimed at the conventional market may be hindered by claiming possible use in military artifacts. Thus, prominent countries seek to perpetuate their hegemony in the industrial field by hindering the progress of developing countries in sectors such as navigation systems, satellites, tracking systems, technologies inherent to the nuclear fuel cycle, communications systems, detection and sensing systems, aeronautical systems, integrated circuits, among many others in which military application is more evident (Galdino, 2022).

To shed light on this hypothesis, we will discuss some examples presented in Section 4 in more depth.

By adhering to the main international regimes, mainly in the 1990s, regarding the non-proliferation of nuclear weapons and the missile technology control regime, Brazil hoped to gain greater international credibility and easier access to sensitive technologies. However, technological restrictions continue to hinder the country's scientific and technological development and limit its capacity for innovation (Silva; Nascimento, 2018).

As described in Section 4.1, Israel used the claim of counterproliferation of weapons of mass destruction to justify its airstrike on the Iraqi nuclear research center, even though Iraq had, at the time, the approval of the IAEA's international system for monitoring and verifying nuclear activities for the development of its nuclear program.

Section 4.2 reported the pressure exerted by the USA, attempting to spy on uranium enrichment ultracentrifuges developed in Brazil under the allegation of counterproliferation of weapons of mass destruction. This allegation of possible military use of uranium enriched in Brazil was not justified, given that the country was a signatory to the NPT and had guaranteed in its Constitution the commitment to use nuclear energy only for peaceful purposes.

These two examples linked to the nuclear area corroborate the thinking of Longo and Moreira (2009), who assert that the international regime of non-proliferation of weapons of mass destruction provides both the normative basis for restrictive controls of sensitive technologies and pretexts for hidden purposes of selective restriction.

In Section 4.3, the justification of the DoC's Bureau of Industry and Security for restricting carbon fiber technologies in the context of Brazil's submarine program showed that it is up to DoC authorities to establish what may be considered harmful to US national security.

As an input in the production of rocket propellants, HTPB is subject to technological restriction, as presented in Section 4.4. This hinders its use in the civilian market considerably more so than in the defense and aerospace segments, given its importance in manufacturing sealants and waterproofing materials for the civil construction, petrochemical, and industrial sectors.

Section 4.5 showed that an attempt to acquire resin for use in thermal cameras was subject to a US company's restrictive practices, regardless of the technology request's source, whether military or civilian.

Finally, Section 4.6 reported the case in which the USA used the claim of cybersecurity risk to pressure business partners to ban 5G equipment from Huawei to contain the advance of the Chinese company, which was at the forefront of the new technology. Huawei considered this claim unfounded because it had technical support proven by formal assessments by intelligence and cybersecurity authorities in the United Kingdom and Germany.

These examples validate the hypothesis that developed countries can use the concept of duality as a subterfuge to encourage or enhance the practice of selective technological restrictions, denying access to or hindering the development of sensitive technologies and knowledge that would leverage the industrial progress of developing countries.

5.3 Implications for developing countries

The two ways of using the concept of technological duality presented have implications for developing countries.

The approach presented in Section 5.1 has a direct implication since it describes the strategy used by these countries to use the concept of duality as an opportunity to mobilize support financially and in the political and strategic spheres to obtain investments in the defense area.

The approach discussed in Section 5.2 has a "veiled" implication. By using the concept of duality as a subterfuge to encourage or enhance the practice of selective technological restrictions, prominent countries seek to perpetuate their hegemony in the industrial field by hindering the progress of developing countries in strategic sectors. Given this perspective, it becomes urgent for developing countries to realize that this dynamic of the perpetuation of power will only be overcome through the progressive accumulation of knowledge in strategic areas and the appropriation of this knowledge by productive sectors, counting on intensive investment by the State in research, development, and long-term innovation activities (Galdino, 2022).

6 FINAL CONSIDERATIONS

This article used a qualitative exploratory approach to investigate how the concept of technological duality can assume different roles according to the scenario in which it is inserted.

Initially, the original concept of technological duality coined by Orlikowski (1992) was addressed, emphasizing the reciprocal interaction between technologies and organizations. Based on this seminal reference, a connection was established with the defense area, where the concept expands to encompass the transfer of technologies between the military and civilian sectors, illustrating the fluid and interactive nature of technology in its context of development and application.

In a second moment, the defense market was considered strategic, highly technological, dual, volatile, and far from perfect competition. At the same time, it is a monopoly/oligopoly and a monopsony since there is a supply dominated by large global players and a demand centralized by States.

As the analysis continued, the concept of technological restriction was intrinsically related to the characteristics of the defense market, especially concerning vulnerability to geopolitical issues. Through regulatory systems and restriction actions, developed States seek to prevent sensitive technologies-related knowledge from being created and dominated by developing States, ensuring the stability of their supremacy in the concert of nations. In this context, most restrictions occur when government agencies do not authorize sensitive technology purchase, sale, or transfer. In addition, the United States was found to have a very significant predominance in cases of technological restriction, followed by its European allies and Israel.

Subsequently, in an attempt to level the understanding of the main characteristics of developing countries, this class of nations was highlighted as presenting a high dependence on foreign investments, a need to import technology and know-how, a strong presence of the State in promoting national development, a precarious capacity for innovation, and limited investments in the defense area. Such characteristics make these countries vulnerable to technological restriction practices.

After addressing the concepts of technological duality, defense market, technological restriction, and developing countries, examples from the national scenario were presented to illustrate how technological restriction actions can affect the market of developing countries. The examples were categorized within the six models proposed by Moreira (2013), presented in Table 1.

The concepts and examples addressed subsidized the discussion of the study: the "duality" of technological duality. For developing countries, duality presents itself as an opportunity to mobilize support not only financially but also in the political and strategic spheres to obtain investments aimed at the defense area. The hypothesis that duality can be used as a tool for selective technological restrictions was validated for developed countries.

The perspective herein presented highlights that developing countries, such as Brazil, must invest in developing essential critical technologies to obtain their military capabilities autonomously and for their scientific and technological development (GALDINO, 2022).

Finally, as a pointer for future studies, we emphasize the need to design a criticality analysis methodology for developing countries that consider aspects related to technological restrictions, such as accessibility, dependence, and vulnerability.

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