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Delayed Technology Transfer to Developing Countries in Strategic Sectors: A Case of the Indian Space Sector

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The strategic significance of the space sector has been highlighted since the 1991 Gulf War and the Iraq War, extending to the recent Russia-Ukraine conflict. It has played a crucial role in delivering precision strikes, gathering intelligence, and conducting surveillance and reconnaissance missions. Strategic technologies in the space sector include satellite technologies, launching technologies, and systems related to launching. The magnitude of strategic technology transfer to developing countries is less due to various political reasons. Technology control regimes often hinder developing countries in their efforts to acquire technology. This article attempts to analyse the international transfer of strategic technologies to developing countries, particularly India. Historically, the Indian space sector was developed through technology import and collaborations with Western and the Soviet bloc countries. This article places India's space program in the context of international technology control regimes and India's relations with the space- haves in the Cold War and post-Cold War period. India's acquisition of cryogenic technology for its launch vehicle development is chosen as the case study. The study is purely based on secondary data.

Keywords: Delayed Technology Transfer, Strategic Technology, Space Technology, Developing Countries, Missile Technology Control Regime, India, Cryogenic engine.

In most developing countries, technologies for economic development, industrialisation, and national security are obtained primarily through international technology transfer (ITT). ITT involves the transfer of concepts, know-how, and technologies from one country to another, which results in the development of the "technological capability" of the importing country (Kasych & Medvedeva, 2020). Strategic (critical, key, or emerging) technologies are defined as those that increasingly impact our daily lives and can enhance or risk the security of a nation (Meltzer, 2022). It mostly referred to 'weapons systems and aerospace technologies' during the Cold War. Their export was subject to tight controls to delay technology transfers that could considerably improve the military capability of potential rivals (Lenzer, 1995). The latest list identifies "strategic" or "critical" technologies, encompassing artificial intelligence, quantum computing, the Internet of Things, blockchain, biotechnology, and military and space technology (USGAO, 2021). Within the scope of this paper, "strategic technologies" refer to those influencing national security and strategic capabilities, comprising defence, space, and nuclear technologies.

With the advent of such technologies, the measurement of state power came to be defined in terms of science and technological progress. Still, the fundamentals of power politics- the dynamics between the 'haves' and 'have-nots' remain unchanged. The dominance in the military, space, nuclear, and industrial technology by developed countries makes others dependent and subordinate. Consequently, the transfer and trade of these technologies between the haves and have-nots are controlled by the technological haves through international law, multilateral treaties and agreements, regimes, and intellectual property rights. Strategic sectors, especially the space sector, are cooperative endeavours, and the peaceful and equitable exploration of outer space requires the transfer of technology from the space haves to the have-nots, which, on the contrary, does not occur due to developed country dominance.

Technology Transfer to Developing Countries in Strategic Sectors

The industrial modernisation of the developing world since the mid-20th century has shown the trend of its dependency on the developed world. While technological progress in more advanced economies involves generating new knowledge that can be applied to productive activity, technological progress in developing countries is heavily influenced by their ability to access, adapt, and disseminate technological knowledge generated elsewhere (UNCTAD, 2014). As a result, the implications of the technological gap between developed and developing nations for trade and development and how to promote technology transfer and diffusion have been part of international discussions for decades. Much of the literature on the transfer of technology between nations focuses on the export of technologies from developed countries to developing or less developed countries. International technology transfer (ITT) is significant because most developing countries that were previous colonies lacked a conducive technological innovation ecosystem (Redor & Saadi, 2011).

An analysis of the process of technology transfer to developing countries shows various trends. In developing countries with fragmented innovation ecosystems, the 'black box' syndrome has often arisen in strategic sectors. Black box syndrome denotes the complexity of the transferred technology, which prevents developing countries from understanding it. The black box is considered closed if technology transfer is not followed by innovation due to inadequate local circumstances. This prevents the host country from adapting, innovating, or developing spin-offs to meet its needs. The Malaysian example in defence, aerospace and electronics industries is noteworthy. As a small country with limited industrial development, Malaysia struggled to assimilate high-tech in the early years. Malaysian experience in the high-technology sector saw successful International Joint Ventures (IJVs) with Western industrial powers (Malairaja & Zawdie, 2004). Similarly, China's rigorous modernisation drive in different sectors helped China reach 11th among the 132 nations in the Global Innovation Index 2022 (GII, 2022). Still, the experience from defence industries, especially the air force, points out the problems in China's unique model. China's indigenous innovation strategy involved Introduction, Digestion, Assimilation and Re-invention (IDAR). Though China has been accused of cyber espionage and spying to obtain important technological information[1], there are also arguments that they were not wholly successful in producing complex systems like

5th-generation light combat fighters (Cheung et al., 2019). Scholars also argue on the inadequacy of imitation in the complex systems and point out the success of China's neighbours- Japan and South Korea- who depend upon the formal mode of technological acquisition. The latter is pointed out as a preferable and sustainable mode of innovation (Gilli and Gilli, 2019). This shows the importance of technology transfer and collaborations between developed and developing countries.

Delayed Technology Transfer

Technology transfer can be implemented in different ways depending on the stage of the product or process's technological life cycle. Three basic formats exist-parallel, delayed, and sequential introductions into another country (Keller & Chinta, 1990). In a parallel introduction, new technology is introduced simultaneously in both the home and foreign host countries. In delayed technology transfer, new technology is first introduced in the home country. Later, after the experience is gained and improvements are made, the technology is transferred to a foreign country. This method is successful if the product has a longer life cycle or has a significant learning curve that enables modifications. Often, developed countries resort to delayed technology transfer to developing countries[2]. In a sequential transfer, technology is transferred to a foreign country only after it has completed its life cycle in the home country. Though sequential and delayed technology transfers allow for helpful adaptations and the formation of a learning curve for the developing nation's innovation system, the positive effect is restricted to products having a longer product life cycle. In the case of strategic technologies, the delay in technology transfer as systems, components, or know-how can hurt the national interests of developing nations. Delayed technology transfer also has problematic aspects like the lag in the technological development of host country companies, competitors gaining an advantage, and the denial of state-of-the-art technologies like nuclear and space technologies.

Cold War and the Political Economy of Strategic Technology Transfer

The Cold War period saw the extensive development and deployment of strategic technologies. For strategic technologies like space technology, missile technology and military equipment., the US and USSR were depended on by the developing countries. However, scrutiny of the policies of these two powers vis a vis technology transfer to developing countries reveals the difference in their attitudes.

The transfer of technology from the US to other nations is premised on US national security and foreign policy considerations and governed by a series of export control policies set by the US government in the form of regimes, agreements, and treaties. Wortzel (1987) identifies the main goals of US technology transfer during the Cold War period. Firstly, transferring weapons or technologies may be considered a

[1]China's Chengdu J-20 fighter jet is alleged to be an imitation of US F-22 Raptor plane. US officials argue that China employs a variety of techniques for espionage to steal critical US military information (Moore, 2023).

[2]A fitting illustration is the transfer of the F404 engine from the US to India. Originating in 1969 from General Electric, a US company, the F404 engine and its subsequent models have been chosen to propel 20 aircraft applications since the late 1970s. Interestingly, the initial transfer of this engine to India occurred in 2004, over three decades after its introduction in the US.

"penetration mechanism" that serves American foreign policy interests by tying the recipient state to the US for replacement parts, training programs, and long-term financing. Another purpose of US policies governing the transfer of weapons, technologies, and strategic commodities is to strengthen ties with allies, most notably those in the North Atlantic Treaty Organization. The destination of the transferred technology is significant in this regard. National security is paramount if the technology is transferred to the USSR or other US rivals. On the other hand, economic issues may be the primary factor for technology transfers to other industrialised nations. In contrast, political issues may be essential when considering transfers to less developed countries (Bucy, 1977).

According to Fischer (2023), the US mainly maintained its technological superiority in two ways. Firstly, the success can be attributed to the robust R&D system the US had and continues to have. Secondly, the US ruled technology through its well-crafted technology denial mechanisms. The Arms Exports Control Act, the Export Administration Act, the COCOM (Coordinating Committee for Multilateral Export Controls) agreement, and other export control regimes like the MTCR and NPT are instruments of technology denial, constituted under the US initiative to prevent the diffusion and transfer of strategic technologies. The US extensively accumulated missile technology for its national security purposes, and at the same time, they argued that other countries should not acquire such technology since they lack political maturity and may make wrong decisions (Gusterson, 1999). This argument reflects the orientalist discourse, which views the West as disciplined and rational and the third world as vice versa. Today, with the enactment of the US Export Controls Act in 2018, the US is infusing economic considerations into export control policy, thereby widening its scope to include commercial technology apart from military technologies (Whang, 2019).

The US's actions in the post-World War era reflect the political economy aspect of technology transfer. The Western bloc formed COCOM to restrict the technological flow to the countries of the Soviet bloc. The strategic technologies in the COCOM list included technologies of national security and economic importance. The US took a leading role in maintaining the regime. Compliance with COCOM is best explained by the Hegemonic Stability Theory, in which the hegemon enforces the rules of the game and provides an international public good. Violating COCOM resulted in limiting technology transfer as punishment (Kitsing, 2003). The replacement of COCOM with Wassenaar Arrangement (WA) shows the change in the attitude towards export control, loosening controls on technology transfer but protecting the Western strategic and economic interests. The establishment of WA as a successor to COCOM questions the neorealist expectation that the regime would be irrelevant after the disintegration of the USSR. The WA's attempt to provide economic and developmental incentives to the non-members to join this international regime can explain its success. Nevertheless, the US is expected to use the regime to strong-arm members as a hegemon using its economic might (Lipson, 1999). Post-World War preference of the US as a hegemon was to avoid leaking sensitive technologies in the former USSR to rogue states. During the Cold War, collective action was necessary for collective security. Post-Cold War, such treaties have increasingly become questionable in controlling technology transfer. The analysis of the 'sensitive destinations list' provided by the four founding members of WA, the US, the UK, Germany and Japan, shows the diverging interests of these allies[3] (Reinicke & Copeland, 1998). Despite these dissenting voices challenging its leadership, the US could sustain its hegemony in the unipolar world.

The US foreign aid was helpful to developing countries like India in the form of food and economic resources. However, the US saw the concept of aid only as a diplomatic tool that helped forge common political goals (Walt, 1990). Pakistan was another point of contention in Indo-US relations. The US foreign policy, in many scenarios, including the Kashmir conflict, came directly against Indian interests during the Cold War. The US often used arms transfers as tools to influence nations like Pakistan (Paul, 1992). Nixon's plan to establish closer ties with China following the Sino-Soviet split led to a closer Indian association with the Soviets (Mohan, 2006).

Even though the Soviet economic and military aid to third-world countries could not compete with that of the US, they were preferred by third-world nations like India since the Soviets did not mix much politics like the US. The USSR moved to expand its political influence through military means because its economic might could not compete with Western countries. Furthermore, many military governments in the Third World wanted Soviet military aid at that time. During the 1970s, the USSR also signed a series of treaties, primarily military treaties, with eleven third-world nations like Egypt, India, Iraq, Somalia, Angola, Mozambique, Ethiopia, Afghanistan, Yemen, Syria, and the Congo (Guan-Fu, 1983). During the 1960s, Indian attempts to obtain modern Western fighter aircraft and submarines failed. They turned to Moscow for sophisticated military equipment and technology, making them dependent on the USSR as the major source of foreign equipment for the Indian military. The Indian indigenous defence industry benefited from access to Soviet equipment and technology (Meena, 2016).

The Soviet system of technology transfer is well known for its excellence in its maintenance system, which is characterised by large workshops and high repair expenditures. This aspect ensures long-term capital investment and generally discourages upgrading to advanced technologies. The developmental effect this exerts upon the recipient of Soviet technologies is also worth mentioning. The Indian technicians who use Soviet technologies have observed that they are harder than their Western counterparts. The less sophisticated and hardy nature of Soviet technology has nevertheless made it immune to mishandling, making it more 'appropriate' for the developing world (Mehrotra, 1990).

Regarding technology transfer relations between developed and developing countries, the special relationship between the USSR and India is noteworthy. One of the striking aspects is the use of local inputs to assimilate technology better. In the case of the Soviet-Indian technological collaborations, the main production units were designed and supplied by the Soviets, whereas all other units were from indigenous sources (D'Mello, 1988). The progressive indigenous development in the steel and oil sectors is an effect of this dynamic. The initial turnkey model gave way over time to more design and production work undertaken by Indian consultants. Only a few sectors, like oil drilling and pharmaceuticals, saw Soviet efforts to establish local R&D capabilities. Yet, there have been instances of boosted R&D efforts in India

[3] There were dissenting voices among the founding members on a broader list of prohibited countries that each nation would be required to maintain in accordance with its own national export control policy. As result, only 28 countries appear on all the four lists out of the 73 countries combinedly listed by them.

under Soviet influence, such that even reverse technology transfer occurred in some cases. The Soviets seeking the assistance of BHEL in technical matters was also not uncommon in that era[4] (Mehrotra, 1990). The strictly commercial nature of technology transfer in the case of India's industrial and economic development finds an exception in the case of the former USSR. The robust technological interaction between the USSR and the Third World can be seen as a part of the Cold War competition.

The US and the USSR tried to align countries with their respective blocs during the Cold War. A hypothesis on the role of foreign aid in alliance formation claims that providing military and economic aid helps create strong alliances (Walt, 1990). Walt identifies that this idea legitimises most financial and military assistance initiatives during the Cold War period and US concerns about Soviet weaponry shipments and economic aid to numerous Third World countries. Cold War rivalry between the US and the USSR saw the use of aid as a tool to gain the trust and support of developing countries for their respective blocs. The end of the Cold War has thus made the technology transfer to developing countries more difficult as the incentives for the technology transfer to the developing countries eroded.

Space Technology Transfer: Politics and Global Regimes

The advent of space technology can be held parallel to the development of rocket launching technologies. The Allied forces in the Second World War saw the might and capability of German V2 rockets that could penetrate the remoteness of the British Isles from continental Europe (Johnson, 1994). The world powers liked to build them as nuclear weapon delivery systems, like missiles. The US and the USSR divided the workforce related to the V2 rocket project among themselves. Then, the same missile technology, with its German equipment, was successfully used by the USSR to kick-start its space program by launching satellites (Sariak, 2017). The space race in the Cold War era was thus also a race for developing missiles with more range and less detectability on enemy radar. The ability of space technologies, from launch capabilities to anti-satellite missiles (ASATs), have made it essential in military reconnaissance, cyber and hybrid warfare, denial of services, and even direct attacks (Tripathi, 2013).

In the era of the space race, the USSR claimed the first victories with the launch of the first satellite and the first manned mission to space. The US caught up quickly and achieved a decisive victory by bringing the first manned mission to the moon. The space race of the 1950s and 60s led the major powers to ensure their security by innovating fast and denying the other side- the military advantage in the space sector (Stojanovic, 2021). The result was a series of unmanned and manned missions to outer space, upgradation and innovation in satellite technologies, and, more importantly, an international treaty to limit the legal right of spacefaring nations to use outer space for weapon installation and colonisation (Khong, 2019). The possibility that both the superpowers would establish a duopoly over all of outer space was the crucial reason for establishing the Outer Space Treaty (OST) (Hickman,

[4]BHEL (Bharat Heavy Electronics Ltd.) was successful in improving the design for the Soviet hydro-turbine. The main part of the hydro-turbine lies in the profile of the blade on which water falls. BHEL had improved the Soviet design, making it more efficient than the original. Much improvements have also been affected in the governing side of hydro-machines.

2007). Armed forces of both nations deployed spy satellites to capture precise images of the military infrastructure of their adversaries. To be able to destroy each other's satellites, the USSR and the US started to develop anti-satellite weapons (Jha, 2017). Interestingly, between 1997 and 2007 alone, the space industry rose from 49 to 110 billion dollars (Early, 2014).

A realist reading places strategic technologies like space technology as integral to national security. The realist paradigm lays down the competition between the global powers to maximise power to protect and project individual national interests. Morgenthau (1948) considered the twentieth century an era of 'total mechanisation, total war, and total domination', considering new technologies detrimental to world security. Race in outer space became an important theme in the great power rivalry during the Cold War. Nevertheless, the benefits of outer space exploration can reach a wide range of fields outside the space sector that can bring social and economic development to a nation. The OST of 1967, in its first article, states that outer space is the 'province of all mankind' and in the second article, that its exploration and use is to be carried out for 'the benefit of and in the interests of all countries (UNOOSA, 1967). While international law mandated equal access to space, the reality is that the developed world would easily dominate space exploration due to its vast technological and economic supremacy. Particularly in space research, developing economies and emerging powers find it harder to compete for many reasons. The high initial cost of infrastructure building, high technical requirements, and the need to maintain highly qualified manpower are some issues (Islam & Hossain, 2018). The technological oligopoly enforced by the US and its allies is alleged to perpetuate technological barriers in the form of regimes that restrict the flow of space technologies to the developing world. (Kumar, 2016). The transfer of space technologies helps the developing world to attain its social, developmental, and security needs without spending its limited and valuable resources on research and development from scratch. However, the developed world, especially the US and its allies, use international regimes and exclusive groupings as the central pillar of technology denial to developing countries. The Missile Technology Control Regime (MTCR) is one of the major export control regimes that limit space and missile technology transfer, which necessitates further introspection.

MTCR and transfer of space technology

The MTCR was formed in 1987 by the G-7 countries. MTCR was formed partly because of the increasing proliferation of Weapons of Mass Destruction (WMDs), including nuclear, biological, and chemical weapons. Similar treaties, including the test ban treaties, the NPT, and the Wassenaar arrangement, kept the strategic technologies confined to a section of the world and denied the rest of the world their benefits. The members of MTCR adhere to common export policy guidelines that apply to an integral standard list of items[5]. The individual members also form national

[5]The MTCR annex is divided into "Category I" and "Category II" items. Category I include e complete rocket systems (including ballistic missiles, space launch vehicles and sounding rockets) and unmanned aerial vehicle systems (including cruise missiles systems, target and reconnaissance drones) with capabilities exceeding a 300 km/500 kg range/payload threshold; production facilities for such systems; and major sub-systems including rocket stages, re-entry vehicles, rocket engines, guidance systems and warhead mechanisms. Category II includes items not listed in Category I and those wide range of equipment, material, and technologies, most of which have uses other than for systems capable of delivering WMD (MTCR Annex Handbook, 2017).

export licensing measures that strictly implement export control on rockets, unmanned aerial vehicle delivery systems, related equipment, materials, and technology. All decisions in the MTCR, including the inclusion of new members, are taken by consensus (Rasmusen et al., 2007). MTCR is not a treaty or even an international agreement like the OST or the Non-Proliferation Treaty. MTCR is considered a set of identical policies to be implemented in parallel.

Experts identify various impacts of MTCR on countries without missile technology. These are slowing down of development, increasing costs, and mounting international pressure. These three impacts are intended to force a country to abandon its missile program. The treaty's effectiveness has forced many countries to abandon missile development projects (Karp, 1988). The treaty produced a spike in missile testing and purchase deals before its enactment,[6] which led to experts questioning the treaty's effectiveness since it could not control the acquisition of missile technology by countries like India, Iran, Israel, North Korea, and Pakistan (Kumar, 2016). Countries like Argentina, Brazil, South Africa, Taiwan, South Korea, and Egypt all reduced their missile activity as a result of the MTCR's technological constraints and political-economic pressures, but Syria, Iraq, and Libya experienced the failure of their missile development projects a decade after the MTCR's implementation (Mistry, 2001). The nations that unilaterally decided to forsake nuclear weapons development also gave up their plans to develop ballistic missiles. Brazil and Argentina stand out among those who attempted to create technologies for launching ballistic missiles. These countries subsequently tried to transfer their know-how in the context of civilian launching programs, albeit initially, space launch programmes had been utilised to jump-start or cover up these programmes. Under intense pressure from the US, South Africa made a special exception by destroying its nuclear warheads and stopping its ballistic missile programme simultaneously (Maitre, 2022).

The MTCR, even though not binding, expects its member states to "exercise appropriate accountability and restraint in trade among Partners, just as they would in trade between Partners and non-Partners." The transfer between two non-partners is not explicitly mentioned in the MTCR guidelines. The discussions on the induction of Russia into the MTCR occurred against the backdrop of its cryogenic deal with India. Even though the USSR or its successor, the Russian Federation, was not a member of the MTCR, Russia was pressured by the US to drop out of its deal with India. The MTCR is often regarded as a discriminatory regime for its lack of transparency, verification, and enforcement mechanisms and its ban on transferring space technologies, which the USA considers to have dual-use characteristics (Kumar & Reghunadhan, 2017). In 1993, the US insisted that states wishing to be members of the MTCR should abandon their offensive missile program (Pande, 1999). MTCR became a major roadblock for India's attempts to acquire missile systems from non-MTCR members like Israel. At the beginning of this century, India showed interest in Arrow-II missiles from Israel. The US needed to be consulted, as they significantly contributed to the Arrow project. Subsequently, the missile systems were denied to India, citing MTCR regulations (Ahlström, 2004).

[6]A series of missile tests by Israel (the Jericho II in 1987, 1988, and 1989), India (the Prithvi in 1988 and the Agni in 1989), Pakistan (the Hatf II in 1989), North Korea (the Nodong in 1993), and China (the shipment of CSS-2 missiles to Saudi Arabia in 1988 and M-11 and M-9 missiles to Pakistan in 1989) were conducted immediately after the establishment of the MTCR in 1987.

MTCR guidelines state that 'the Guidelines are not designed to impede national space programs or international cooperation in such programs as long as such programs could not contribute to WMD delivery systems' (MTCR Annex Handbook, 2017). On the contrary, it shunted peaceful space missions in many nations, including India. The quest of the developed world to limit the proliferation of WMD capabilities has thus delayed and curtailed the ability of the developing world to attain mastery in the strategically important space sector.

India and Space Technology: A Saga of Delayed Technology Transfer

As a nation that became independent in the mid-20th century, India struggled to obtain technology to modernise its industry and economy. It was the leading role of Vikram Sarabhai that helped India to integrate international technology transfer (ITT) and local innovations for its benefit in the space sector (Bhaskaran, 2001). India's space effort began in 1962, at the height of the Cold War. As a poor country, it first had to rely largely on foreign technology transfer to construct its space capabilities. Maintaining a non-aligned stance, India developed its space system in collaboration with the US and the USSR. Several large-scale space cooperation projects have also been signed with countries such as France, Germany, and the ESA. Since the 1970s, this has established its stability as a leading nation in space exploration. When the early space powers gave primacy to the military and state requirements, the Indian space program simultaneously addressed other dimensions such as economic, environmental, societal, and political (Sheehan, 2007).

ISRO, since its inception in 1969, has established close ties with foreign space industries. The space program's early phase was devoted to identifying space applications based on ISRO's present and future needs. Thus, the later demonstration phase had visible progress in fields like satellite communication, remote sensing, broadcasting, spacecraft and launch vehicle technology. (Murthi & Sobha, 2010). The experimental phase of the Indian space sector included satellite development, production of components, and launch aided by developed nations such as the USSR, the US and European space-faring nations like France. The end of the experimental phase and the start of the developmental phase were marked by Indian aspirations for satellite systems like the IRS and the Indian National Satellite System- INSAT (Singh, 2017). While ISRO attempted to develop the IRS indigenously, INSAT, as a more complex system, was outsourced to Ford Space and Commerce Corporation (FSCC) (Bhaskaran, 2001). ISRO executed the technology transfer scheme by commercialising imported or indigenously developed new technologies.

Throughout the Cold War, the USSR held the upper hand in ties with India, a member of the community of "developing" states, while simultaneously being a leader of the Non-Aligned Movement. India showed an affinity towards the USSR more than the US due to the geopolitical conditions of the Cold War period (the US supported Pakistan and China, which was against India's strategic interests). The Soviets proved to be a trustworthy ally of India by providing significant support in its space development. The first three satellites of India (Aryabhatta and the two Bhaskara satellites) were launched with Soviet aid. The USSR also offered to fly Rakesh Sharma, a member of the Indian Air Force as part of the "guest cosmonaut" programme (Guruprasad, 2018). A major milestone in India-USSR space cooperation is marked by the failed cryogenic engine deal between Glavkosmos and ISRO, discussed in the next section.

India's Launch Vehicle Development and the Cryogenic Deal

Efficient launch vehicles are crucial for the successful launch of satellites. Launch vehicle development was one of the initial thrust areas of India's space programme. A Space Science and Technology Centre (SSTC) was formed in 1966 to develop rocket and SLV-related technologies. The design of the SLV was similar to the US SCOUT rocket. The technical details of the SCOUT rocket were readily available in the public domain as the US called for experiments from other nations during its launch. Given its 96 per cent success rate and the Indian scientists' experience in the US, ISRO chose the design of the SCOUT for its SLV (Nagappa, 2016). Similarly, the computer IRS 55 from France was procured by the Electronics Corporation of India Limited (ECIL) for the development of an SLV-3 launch vehicle (Singh, 2017). ISRO also sent several Indian scientists for training at the Institute of Space and Aeronautical Sciences (ISAS) in Japan. These scientists also played a crucial role in developing the SLV (Baluragi & Suresh, 2015).

When TERLS was first founded, Sarabhai sent Indian engineers and scientists to prestigious universities in the US to obtain practical expertise in launching rockets. Indian engineers travelled to France to work on the Centaure rocket programme with Sud-Aviation, and to Germany to train at the German Aerospace Centre. Similarly, scientists were sent to South America's French Guyana Space Centre for training in handling launch vehicles, range safety, and radar tracking and to Russia for training in cryogenic technology (Singh, 2017). An agreement was concluded with France that would transfer liquid Viking engine technology to ISRO in exchange for labour and hardware for developing the Ariane rocket. The experience Indian scientists gained from France helped utilise this Viking engine technology in the Vikas engine for India's PSLV.

At the time PSLV was being developed, in the 1980s, the large launch vehicles of space power like the USSR, USA, Europe, Japan, and China were mainly equipped with liquid or cryogenic propulsion systems in their lower and upper stages (Mayilvaganan & Guruprasad, 2019). India did not master the cryogenic propulsion system, which made it lag behind other space powers. The development of a launch vehicle that could carry enough payload became a national priority in the 1980s, necessitating more effective cryogenic propellants for the rocket's upper stage. India has been employing solid propellant fuel, which requires a large fuel tank and much fuel, increasing the cost and limiting the flight distance (Nagappa, 2016). ISRO was always searching for fuel that could be both lightweight and energy-efficient, and the only solution was the cryogenic engine. The GSLV programme initiated to address growing communication needs was planned to be a three-stage launcher made up of a solid motor stage used in the PSLV's first stage, a storable liquid stage powered by the Vikas engine, and a cryogenic stage (Aliberti, 2018). The cryogenic engine was essential for the launch of satellites into geostationary orbit, but the technology for the same was concentrated in the hands of a few space powers, who were unwilling to transfer it to other nations.

In searching for a cryogenic engine and technology, India got offers from the American company General Dynamics. However, their charges were unaffordable (Aravamudan, 2017). The Russian firm Glavkosmos offered to sell the engine, guaranteeing a total technology transfer and an inert mass of 1,900 kg (Perumal, 2015). The USSR was on the verge of disintegration and needed funds to sustain its economy. The financing for the space programme started to decline in the late 1980s during the perestroika era, and the 1990s economic crisis further sped up this process. Therefore, signing the deal was as necessary for the USSR as for India. This offer was accepted, and two operational 12-tonne KVD-1 cryogenic engines and the technology were agreed to transfer at a lesser cost. They promised to transfer documents, drawings, and all the materials needed to build the engines (Pikayev et al., 1998). The 235-crore contract was signed in January 1991. However, the US banned the deal, calling it a violation of the MTCR. Richard Boucher, a deputy spokesman for the US State Department, underlined that the regime bars their sale regardless of their use, stressing the importance of the technology involved (Scherr, 1992). This meant that if Russia and India fulfilled their agreement's provisions, the Bush Administration concurrently would impose harsher trade penalties on both nations (Smith & Williams, 1993). Russia and India made it clear that the technology would only be used for peaceful purposes, not for the development of missiles, as suspected by the US.

The US was closely observing India's advancements in space exploration and was continuously gathering details about ISRO's future ambitions. India had previously created the ballistic missile Agni, which infuriated the US and made them believe that the transfer of cryogenic engine technology would enable India to advance and possibly become a superpower in rocket and satellite launching (Coll, 1992). Nevertheless, a study released in the US showed that significant components of the SLV-3 and Agni rocket systems were taken from technologies imported from the 1960s and 1970s overseas, particularly from the US and the Federal Republic of Germany (Sheehan, 2007). The US pressured India to suspend its missile programme in the wake of the Agni missile test in 1989 (Wetering, 2016).

Realising that it was doubtful that India would obtain this crucial space technology from any other space powers, ISRO decided to step up efforts to develop it domestically. 1994 saw the negotiation of a new contract, which included seven ready-made Russian engines but no technology transfer for the Indian GSLV Mk-I launcher. Launched on April 18, 2001, the first in the series was only partially successful because the payload was placed in a lower orbit than anticipated. Six of the seven Russian engines were used for various flights of the GSLV Mk-I (Korovkin, 2017).

TABLE 1: List of Cryogenic engines from Russia and their usage

Launch Date	*Launcher and Satellite*	*Stage/Engine*
April 18, 2001	GSLV-D1, GSAT-1	GS3 (C-12) / KVD-1M
May 08, 2003	GSLV-D2,GSAT-2	GS3 (C-12) / KVD-1M
September 20, 2004	GSLV-F01, EDUSAT	GS3 (C-12) / KVD-1M
July 10, 2006	GSLV-F02, INSAT-4C	GS3 (C-12) / KVD-1M
September 02, 2007	GSLV-F04, INSAT-4CR	GS3 (C-12) / KVD-1M
December 25, 2010	GSLV-F06, GSAT-5P	GS3 (C-15) / KVD-1M

Source: Compiled by the authors from various sources

Out of the six engines flight tested, two were unsuccessful (GSLV F02 in 2006 and GSLV F06 in 2010). ISRO faced a loss of 256 crore rupees by the crash of GSLV-F02 and 225 crore rupees by the failure of GSLV F06 (The Economic Times, 2006). The specific nature of the Russian engines made it difficult for India to reproduce Russian technology at the time of indigenisation. For example, it required a long time to perfect the vacuum brazing technique to create the engine's thrust chamber. This raised doubts regarding the appropriateness of the Russian technology transferred[7]. GSLV-D3 rocket, which was the flight-testing of the indigenous cryogenic engine with GSAT-4 as the payload, failed due to issues related to the engine's ignition. The GSLV-D3 rocket, including the indigenous cryogenic stage, cost Rs. 180 crores (Subramanian, 2010). Similarly, India's indigenously developed cryogenic rocket engine was tested in 2014. GSLV Mk II launch vehicles used indigenously developed cryogenic engines for their flight (Thakur, 2014). India took around 20 years to fly an indigenously made cryogenic engine successfully.

Discussions

Space technologies are one of the strategic technologies that enhance a country's national security and economic interests. The early innovators in the space sector, like the US and the USSR, have managed to sustain a technological gap between them and developing countries like India. The Cold War period saw India becoming a contender in the space race. India received technological aid, components, and collaboration from both sides of the Cold War. The end of the Cold War has hampered this phenomenon, making the transfer of strategic technologies tougher for developing nations. The unipolar world with the US as the sole superpower became detrimental to India's interest in having a competent space sector, as made clear by the Glavkosmos-ISRO incident.

The US transferred crucial technologies only to its allies, and India was not an ally of the US during the Cold War period. At the same time, Indo-US relations were overshadowed by the India-USSR friendship and the US' affinity towards Pakistan (Wetering, 2016). The US successfully stopped the cryogenic technology transfer from Russia to India, citing MTCR. Russia could defy the MTCR sanctions because it was a non-member of MTCR and the engines to be transferred under the deal were exempt from Category I of the MTCR Annex because they were an integral component of the rocket stage. The US resorted to this same argument in 1996 when Russia raised concerns about the US's delivery of Army Tactical Missile Systems (ATACMS) to Turkey[8] (Bertsch & Potter, 2013). The Russian Federation yielded to the US interest as the disintegration of the USSR took away its status as a global power.

India's capacity to produce highly effective long-range missiles was constrained and delayed by the Glavkosmos-ISRO incident. India has held off on deploying the Prithvi and has at least temporarily halted the development of the Agni, which suggests that resistance from the US and other countries has caused New Delhi to

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[7]Appropriate technology, as a concept, expects technology to make optimum use of the available resources. It indicates technologies that are both economically and technically feasible in achieving development objectives while also being adapted to the socio-cultural environments of the developing and least developed countries (Farooq, 1988).

[8]The US justified the transfer by pointing to Turkey's proximity to potentially hostile nations like Iran and Iraq. The US also claimed that it will install software in the transferred missiles that will limit the range of the missile within the MTCR norms.

exercise some prudence (Raj, 2010). India took around two decades—a significant amount of time for the indigenous development of cryogenic technology. The Indian Space Programme lags behind the space programmes of Japan, China, and the ESA by one technology generation and the U.S. and Russian space programmes by two technological generations (Mistry, 2001). The failed cryogenic technology transfer has a role in contributing to this delay in India's space programmes. India eventually developed the Cryogenic engine, yet it is significant that, as of 2021, India only accounted for less than 2 per cent of the $447 billion global space industry (Sidharth, 2021).

India's membership in the MTCR in 2016 in the wake of the latest developments in the global order substantiates this. Today, the world witnesses the US and China in active competition, which has the potential to be a great power rivalry. The result is a closer engagement and strategic partnership between India and the US, which resulted in the Indo-US civil nuclear deal, active US backing for India's claim for NSG (Nuclear Supplies Group) membership, and increased US-India strategic engagements. The heightening US-India engagement in critical sectors, including collaboration in defence, space and other technological domains, is evidence of the US and India uniting against a common concern-China. The US, who blocked technology transfer from the USSR to India, quoting MTCR, owing to the change in the strategic environment, took the initiative of India's membership in the MTCR in 2016. The signing of the Initiative on Critical and Emerging Technologies (iCET) in May 2022, became a watershed moment in the strategic relations between India and US. Under the iCET, several key technologies, such as AI, quantum technology, computing, biotech and space technology are included (Patil, 2023). This agreement ensures that the core of India-US relations would lie in technology cooperation.

Conclusion

The developed world continues the trend of denial and delaying technology transfer through politically motivated export control regimes that affect the capacity of developing nations to acquire technology to their interest. Even though the supply nations sugar-coat their motives as non-proliferation efforts, the ultimate motive of technology control regimes is technology denial. MTCR remain an elite club for the US and its allies, where a country can legitimise its missile interests by becoming a US ally.

Given the complexity of the international technology landscape in the 21st century, Chinese technological ambitions are perceived as a threat to US technology and economic competitiveness. US concerns rest on the backdrop of the highly globalised supply chain, increased private participation in the dual use of cutting-edge technologies. (Fischer, 2023). The US fears that China's advancements in emerging technology areas like Artificial Intelligence and quantum technology, along with the technology acquired by China through legal and illegal means, would erode its technology monopoly. As a result, the US imposes stringent controls on selling advanced computing chips and related equipment and products to China (Swanson, 2022). In 2022, the Biden administration formulated a policy targeting semiconductor sales to China, blocking US AI chip designer companies like Nvidia and AMP from selling chips to China (Reuters, 2023). Similarly, as a ramification of the US-China tech war, the US imposed trade restrictions on Chinese Huawei, accusing them of sanction violations and limiting their access to US technology through foreign semiconductor products (G. Allen, 2022). Ultimately, the US foreign policy on export control aims to deny access to cutting-edge technology to its rival, be it the USSR or China.

Today, the diffusion of space technologies has accelerated internationally, thanks to globalisation. The US export control policy has been affected by national security concerns resulting in stringent controls and economic considerations resulting in lesser controls (Dwyer et al., 2012). Unlike the Cold War era, space technology is more integrated into a wide range of daily life activities, and more nations are harnessing the benefits of space. Technology is more accessible to the developing world than before. In response to the 21st-century international demands and call for reforms in space technology export policy, US policy in space is more oriented towards commercialising space technologies and fostering international cooperation (NASA, 2020). But still, in the case of critical and sensitive technology transfer, the export policy focuses on maintaining the USA's technological leadership. The discussions on how the developed world, especially US strategic interests, will shape the future international export control landscape is a matter of profound importance on how developing countries acquire such critical technology.

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