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EXPORT CONTROL REGIMES AND INDIA'S SPACE AND MISSILE PROGRAMMES

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Abstract:

Multilateral export control regimes such as the London Club and Missile Technology Control Regime (MTCR) aim to prevent the flow-of complex dual-use technologies to certain 'target' countries. The underlying' belief has been that these regimes would be able to delay or cripple strategic weapon programmes in 'target' countries. However, little attention has been paid to understand the factors that influence the effectiveness of these regimes. In recent years, the limitations of export controls have become increasingly' clear. This paper introduces a conceptual framework and analyses the case of India's space and missile programmes to trace the factors that determine the effectiveness of export control regimes and to understand why these regimes, particularly the MTCR are increasingly ineffective on certain 'target' countries.

Introduction:

Multilateral export control regimes Such as London Club, the Missile Technology Control 'Regime (MICR), Australia Group and Wassenaar Arrangement aim to prevent certain ‘target' countries from building capabilities in complex dual-use technologies: While they are mainly aimed at military programmes such as missile programmes, they could seriously affect civil development programmes such as space programmes as a number of technologies involved are dual-use. The argument is that if a country acquires significant capabilities in key areas, this can provide a basis for technology production capabilities in certain other related areas. Therefore, if a country acquires significant capabilities in building satellite launch vehicles, it will not be beyond its capability to develop ballistic missiles. For this reason, when India launched its first satellite launcher, the SLV-3, in the early 1980s, the western countries, particularly the US started imposing stringent export controls on India. Subsequently, the US took initiative to form the MTCR, which came into force in 1987. Therefore, India's space and missiles programmes make an interesting case study to analyse how and when the export control regimes will be more or less effective in preventing capability building. Further, India has been one of the primary targets of various export controls, as it has been the principal opponent of the Nuclear non-Proliferation Treaty (NPT). Since India exploded a nuclear device in 1974, the Western "technology controls against India have grown steadily over the decades rising sharply after the end of the. Cold War"[1].

A good number of writings (between the late .1980s and mid-1990s) discuss how the restrictions imposed by the export control regimes on transfer of dual-use technologies would affect 'target' countries. in different ways[2]. They have almost totally ignored the importance of conditions or factors, which would make the export controls more or less effective. Again, the impact of MTCR on 'target' countries is invariably discussed without any detailed analysis of the technology development system or the process within a 'target' country. By the late 1990s it became. increasingly clear that export control regimes, particularly the MTCR, failed to have expected impact on a number of 'target' countries including India, Pakistan Korea, and to some extent Iran[3]. Further, the initiative to formulate an International Code of Conduct Against Ballistic Missile Proliferation (ICOC) and the subsequent adoption of The Hague Code of Conduct on Missile Proliferation on 27 November 2002 outside the MTCR suggests that he regime is increasingly ineffective in achieving its intended objectives[4]. This paper aims to analyze why and how. The effectiveness of export control regimes changes or varies over a period of time and what are the factors that determine the effectiveness of export controls.

It appears that the effectiveness of export controls, such as MTCR, on a particular country depends upon the stage of its technological capability at the time export controls are imposed and its potential to sustain innovative activities on its own. If it is in the formative stage, the export controls are likely to be more effective, as foreign inputs are very important at this stage. On the other hand, if the recipient country is in an advanced stage, where the role of foreign inputs is less determinant, the export controls are likely to be influential.

This paper will first discuss a two-phase model of technology accumulation to provide an understanding of various elements involved in .competence building process. Then, it will analyze different-phases of the technology accumulation process in India's space and missile programmes to determine the factors that would influence the impact of export control regimes such as MTCR on this process.

Two-Phase Model of Technology Accumulation and Impact of MTCR:

Technology accumulation process could be seen in two phases, that is, the formative phase and the accumulative phase. Formative Phase is the initial phase in the process of acquiring technological capabilities. During this phase the government invests massively in education and training to create a pool of human resources which would supply the necessary skills to firms and research institutions. It builds R&D. institutions and their associated infrastructures. Initially firms are mostly dependent on imported technologies for their production operations. They are capable of carrying out only minor changes to the imported technologies to suit local conditions, such as the available raw materials, and market demand. The major effort of the firm is towards mastering the know-how which "involves the mastery of production technology utilising a given set of technological parameters. If does not involve the understanding of how the parameters themselves (the basic scientific, metallurgical, engineering principles involved) are derived[5].

At the beginning of formative phase the linkages among various institutions such as universities, public R&D institutions, and the industrial enterprises are either absent or very weak. This is also the case between firms and public R&D organizations. The presence of suppliers and sub-contractors or ancillaries is insignificant. However, towards the end of this phase the inter-firm linkages and inter-institutional linkages and the presence of ancillaries become more significant. The balance between imported foreign technical input and the indigenous input towards the technological accumulation starts shifting in favour of the latter. The firms acquire the capability to master the knowhow: of the imported technologies. From this point onwards, which can be termed as crossing the threshold, the country comes to possess the ability to sustain the development of technological capabilities on its own without any foreign input, though such input may still have some role to play. The difference is that the pace of the technological accumulation will be faster with such input than without it. In other words, during the formative phase, technological accumulation is not possible without foreign input. The rate of acquiring capabilities is certainly influenced by foreign input. The rate of growth of technological capabilities is not dramatic at this stage.

Once a country has attained 'the threshold, it enters into the accumulative phase. Then, the space of technological accumulation is mostly influenced by internal factors which include continuous investment in R&D, effort towards further strengthening of linkages among various institutions; emergence of suppliers and subcontractors, competition and so on. During the early period of this phase, firms are able to master fully the know-how and become capable of carrying out major improvements to existing technologies. In the next step, they go on to master the know why that enables a firm to make "substantial changes to product design[6]. Following the mastery of knows why, the final step is to create new technologies. This means the capability to design, develop, and produce a new technology. However, that involves original innovative performance that is possible only through a strong effort in basic research. For example, when Korea has reached the accumulative stage where it found difficult to import technologies to enter complex areas and therefore it needed to build a strong basic research base in order to sustain its competitiveness by entering new markets[7].

The impact of the export control regimes such as MICR on a particular country may depend upon whether it is in the formative phase or in the accumulative phase of technological development. If it is in the formative phase, then the impact is likely to be greater to the point of crippling the growth of technological accumulation as the importance of foreign inputs is greater. On the other hand, if the country is in the accumulative phase, when the role of foreign inputs is less important, the MICR, is likely to be less influential. This argument is illustrated with an explanation of the following two figures.

Figure-1 helps in understanding how the growth of capability in a particular technology, in this case space technology, can vary in different countries, influenced by their individual national innovation systems. Ts_1, to Ts_n, represents the scene of the growth of capabilities in space technology, in *n* number of countries. They take different time periods to cross the threshold in space technology. While Ts_1, takes 10 years, Ts_2, takes 11, $Ts_{(n-1)}$ and Ts_n, take 17 and 20 years respectively.

Figure 1: The Space Technology Scenario In Different Countries

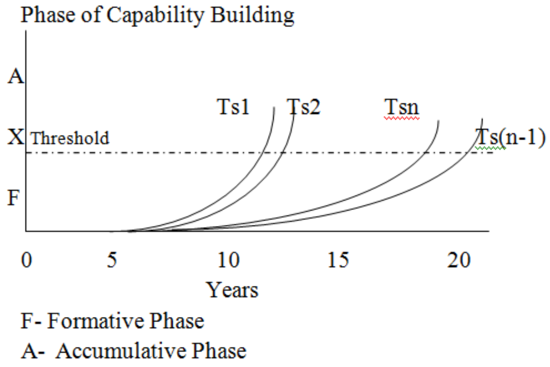
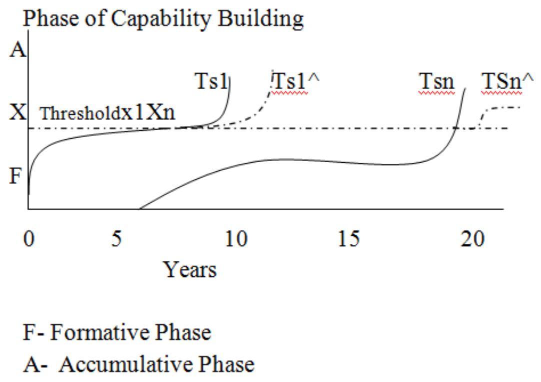


Figure-2helps to explain the impact of the MTCR on countries trying to acquire space technological capability. Here, Ts_1 and Ts_n represent respectively the most efficient and least efficient space/ missile programmes in different countries. That means *country*-1 and country-n represent the most efficient and the least efficient programmes respectively, because the former crossed the threshold in 10 years while the latter took nearly 20 years. Between X_1 and X_n the other countries cross the threshold. As the need for foreign technological input is likely to be much greater in the formative phase than in the accumulative phase, the space/missiles programmes of those countries which are in the zone X_1X_n will be affected to a maximum extent. It is possible that most of these countries could be affected to the point of totally halting their programmes, as opposed to those programmes, which reached a level above the line between X_1 and X_n. In .these latter cases, the impact is likely to range from almost none to some significant level. For example the most efficient programme, Ts_i may be affected to some extent, which might retard the technology accumulation process slightly. It is represented in the figure by the slight distortion Ts_1. In the same way, the least efficient programme Tsn may be affected to a considerable extent, which is represented in the figure by a very significant distortion $Ts_{n.}$

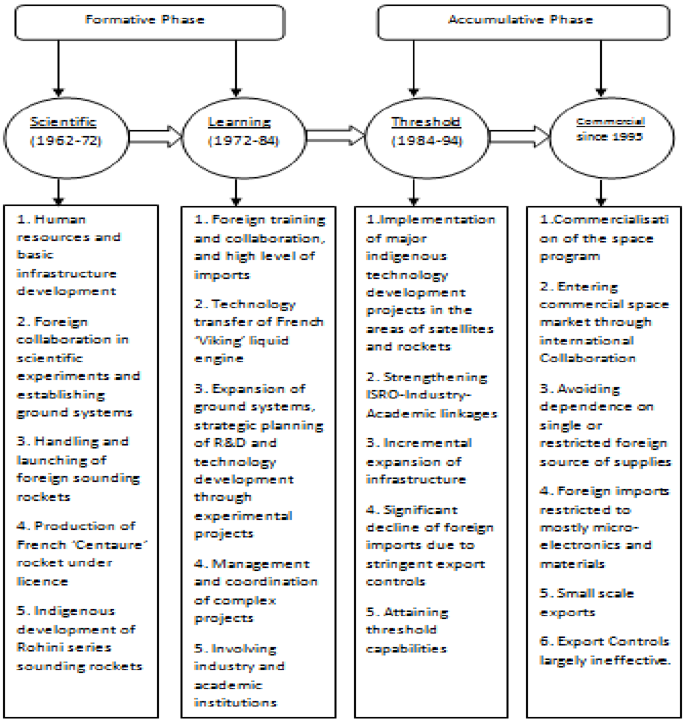
Figure 2: Relationship Between MTCR and Technological Accumulation



The above two-phase model of technology accumulation will be used to analyze the process of capability building in both India's space and missile programmes and to examine the impact of export control regimes on this process. As the impact of export controls on a 'target' country is directly proportional to its dependence on foreign imports, the following sections would focus on varying degree of India's dependence on foreign technological inputs at different phases.

Capability Building in the Space Programme:

Figure: Process of Technology Accumulation in India's Space Programme



Scientific (1962-72)	Learning (1972-84)	Threshold (1984-94)	Commercial since 1995
1. Human resources and basic infrastructure development 2. Foreign collaboration in scientific experiments and establishing ground systems 3. Handling and launching of foreign sounding rockets 4. Production of French 'Centaure' rocket under licence 5. Indigenous development of Rohini series sounding rockets	1. Foreign training and collaboration, and high level of imports 2. Technology transfer of French 'Viking' liquid engine 3. Expansion of ground systems, strategic planning of R&D and technology development through experimental projects 4. Management and coordination of complex projects 5. Involving industry and academic institutions	1.Implementation of major indigenous technology development projects in the areas of satellites and rockets 2. Strengthening ISRO-Industry-Academic linkages 3. Incremental expansion of infrastructure 4. Significant decline of foreign imports due to stringent export controls 5. Attaining threshold capabilities	1.Commercialisation of the space program 2. Entering commercial space market through international Collaboration 3. Avoiding dependence on single or restricted foreign source of supplies 4. Foreign imports restricted to mostly micro-electronics and materials 5. Small scale exports 6. Export Controls largely ineffective.

Following the above model; the competence building process in Indian space programme can be broadly divided into two phases. The first two decades from 1962-1984 can be called as formative phase. The period since 1984 can be called as accumulative phase. During the formative phase, the main emphasis in that period was on human resources and infrastructure development, learning about project management and co-ordination, strategic planning of R&D, and implementation of experimental technology development projects. During this period foreign inputs such as imports, training, technology transfer, and technology assistance appear to have played an important role. The main emphasis during the accumulative phase was on achieving threshold capabilities in satellite and rocket technologies. By the late 1990s, the focus appears to have shifted towards commercializing the space programme. Since the mid-1980s, the contribution of foreign inputs appears to have declined significantly, partly because of export controls.

Figure-3 illustrates the competence building process in three major areas of Indian space programme - rockets, satellites, and ground systems between the 1960s and 1990s. The export controls target nearly the whole of rocket technology, some aspects of satellite technology such as composite materials and spacecraft propulsion systems, and some aspects of ground systems such as rocket launching, and support equipment. Therefore, this paper mainly concentrates on developments in the area of rocket technology and then discusses briefly the other two areas.

Competence Building in Rocket Technology:

India started its space programme in 1962. Initially, it started launching small sounding rockets provided by countries such as the US, UK, France, and the former Soviet Union. Subsequently, it acquired the know-how for the Centaure sounding rocket from France that laid the foundation for the indigenous development of Rohini-series sounding rockets. These rockets were solid propellant rockets and the experience gained from them made India capable of building solid propelled rocket systems to launch small satellites by early 1970s. Over the next twenty years, India has built and launched three different types of satellite launchers. The first two, the satellite launch vehicle SLV-3 and the Augmented Satellite Launch Vehicle (ASLV), were all solid, experimental rockets with the payload capability of 40kg and 150 kg respectively. The next one, the Polar Satellite Launch Vehicle (PSLV), was an operational launch vehicle with the capability to launch a. l tonne satellite into the polar orbit. In April 2001 India launched successfully the next generation launcher--the Geo stationary Satellite Launch Vehicle (GS LV) with a capability to launch 2.5-tonne class satellites into geo-stationary orbit. It is considered as major achievement for a developing country, as only a few countries (US, Russia, China, Japan and the European Consortium of Arianespace) have this capability.

Foreign collaboration appears to have played an important role during the first two decades initially in the form of supply of sounding rockets and ground equipment for scientific experiments, then in the form of training. In 1963 India established the Thumba Equatorial Rocket Launching Station. (TERLS) at the magnetic equator, near Trivandrum in South India. When the United Nations Committee on the Peaceful Uses of Outer Space had recommended the establishment of a rocket launching facility at the magnetic equator, India proposed to make TERLS as an international facility for scientific experiments. The UN accepted India's offer. This helped India to forge relationships with other space organisations such as NASA. These organisations helped to setup TERLS by providing ground equipment and also provided sounding rockets for various experiments.

As India had to start from scratch, it tried to get as much help as possible from other countries to provide a foundation for its scientists and engineers.[8] in 1962, NASA was the first organisation to collaborate with India. It was followed by the Hydro meteorological Services (HMS) of the USSR in 1963 and the Centre National d'Etudes. Spatiales (CNES) of France in 1964. To a lesser degree, Japan (Institute. of Space and Aeronautical Sciences, Tokyo University), and the UK (Science Research Council and British Meteorological Office) also collaborated with India. Throughout the 1960s, international collaboration was mainly in the form of joint scientific experiments. For this, the NASA, CNES, HMS and the Science Research Council and British Meteorological Office of UK mainly provided the rockets while India provided the payloads and 'launch services. In some cases, the payloads were jointly developed or provided by foreign collaborators. After India started producing Centaure sounding rockets in the late 1960s, it provided them for some joint scientific experiments. NASA and CNES also donated a considerable number of Nike-Apache and Centaure sounding rockets respectively as well as certain equipment for the ground facilities[9].

From the early 1970s, the nature of foreign collaboration started changing. The emphasis shifted towards foreign training and application oriented joint experiments. Mostly, France and then West Germany and in some cases the US provided training. However, in the area of rocket technology, foreign training was limited to rocket launching operations. In 1972, three Indian engineers went to the French Guyana Space Centre for, training in vehicle handling and preparations, radar tracking and-range safety operations[10]. A number of Indian engineers and scientists continued to receive training in France until 1979.[11] In the 1970s, Indian scientists collaborated with the French to develop Viking liquid engine technology for Ariane rocket, which was later transferred to India. Between 1973 and 1979, Deutsche Forschungs-und Versuchsanstalt fur Luft and Raumfahrt (DFVLR), the West German space research organisation and the German industry also trained Indian scientists and engineers in various fields such as "remote sensing techniques, microwaves, PCM telemetry, wind tunnel testing, etc."[12]

Between 1967 and 1973, India developed indigenously various types of sounding rockets such as RH-70 and RH-75, RH-100, RH-125, RH-200, RH-300 and RH-560. It also developed meteorological rockets called Menaka-II and Menaka-II. Initially, India used imported PVC plastisol propellant gains for Rohini sounding rockets such as RH-125 and RH-200 This was later replaced by an indigenous composite propellant based on lactose terminated polybutadiene binder system.[13] During the early period, the emphasis was on the development of some hardware and import substitution of raw materials enquired for propellant processing. By 1970 ISRO had developed eight types of propellant The motor casing was made locally by using low carbon alloy steel sheets and graphite was used a throat insert for all sounding rockets.[14]

By 1973, India became capable of building a satellite launch vehicle and started the development of SLV-3, a 1 in diameter four stages all solid rocket. It was modeled on the American rocket 'Scout', as- ISRO received some unclassified technical reports on the Scout's design from..NASA.[15]To build -SLV-3, India procured materials and components from abroad. Also, it made effort locally to develop composite propellants and materials used in propellants such as plasticisers, inhibitors, insulators and bonding agents. ISRO developed two propellants, VELI-21 and VELI-22 using imported Carboxyl Terminated Polybutadiene (CTPB) and polyurethane. To avoid total dependence on imports of critical chemicals, India established the Propellant Fuel Complex (PFC) in 1974, even before a laboratory process was ready.[16]Subsequently, it indigenously developed CTPB substituting the imported resin and a large-scale production started in 1975.[17]The area of navigation, guidance and control is one of the most challenging fields in space technology. India was largely dependent on imported components. SLV-3 employed indigenous rate gyros and its inertial measurement unit (IMU) was built indigenously using imported sensors.[18]

In the 1970s, various test facilities such as wind tunnels, integrated structural test facilities, environmental test facilities and static test facilities were set with both imported and 1ocally made equipment. ISRO had set up the Solid Propellant. Booster Plant (SPROB), with .design capacity of 500 tonnes /year, for large scale production of solid propellants. The SPROB was built using mostly indigenous equipment. However, India had to import a variety of processing equipment "such as large mixers and the linear accelerator needed for X-raying the finished propellant grains” from foreign countries.[19] Similarly, the Static Test and Evaluation complex (STEX), an important facility to test large solid motors, was established with French assistance and the high altitude test facilities were setup with German assistance in the 1970s.[20] This would not have been possible years later, after MTCR was in place by the late 1970s, India's capability to develop and produce a number of solid propellant's polymers and materials appears to have reached maturity[21]. When "the American company involved refused to accept orders for bulk supply” of CTPB resin, India decided to develop the resin indigenously and came up with a substitute called HEF-20.[22] For producing hardware such as motor case, nozzle, the fins and nose cone, ISRO used the industry for the first time. In all, over 46 firms, from both private and public sectors, contributed to the fabrication of SLV-3. Also, a number of special purpose machines were indigenously developed and commissioned[23].

ISRO seriously started developing liquid propulsion systems only in the early 1970s. When its indigenous effort was at an early stage, ISRO became involved in a joint project to develop the Viking engine for Ariane launcher with the French under a technology transfer arrangement. This helped India to take a big leap in liquid propulsion technology[24]. In the 1980s, ISRO has built different types of test stands and facilities for assembly and integration of liquid engines and stages. These test stands were designed, reviewed and built by coupling the internal .and external knowledge[25].

After SLV-3, in the early 1980s, ISRO had undertaken two projects, the ASLV and the PSLV, in parallel. ISRO built the ASLV by drawing on many features of the SLV-3 as well as developing many new technologies. Some of them were developed with the aim of incorporating them in the PSLV. By then, there were clear indications .that the export controls on rocket technology were becoming stringent. It was becoming increasingly difficult to import critical items such as PBAN (for making propellant). However, ISRO was able to. manage the ASLV project first by using up the imported items and then by substituting it with indigenous items[26]. For example, when the US stopped supplying PBAN during ASLV project, it was replaced by indigenous HTPB.

After India exploded a nuclear device in 1974, the nuclear energy programme faced serious export control problems. Because of this the space establishment anticipated similar problems with the space programme and a major indigenization programme was set in motion to develop locally .a number of critical items in collaboration with industry. By the mid-1980s, most of the R&D projects under the programme started yielding results. When MTCR came to force in 1987, at least 15 critical items controlled by the regime were indigenously developed[27].These included items such as titanium alloyforging, managing steel, ammonium perchlorate hydroxyl terminated polybutadiene (HTPB), unsymmetrical dimethy1 hydrazine (UDMH) and nitrogen peroxide (N_2O_4).

In the early 1980s, ISRO started the Inertial Guidance System Project to develop closed loop inertial guidance systems for ASLV and PSLV. This included both the hardware and the software required for Stabilized Platform Inertial Navigation System (SPINS), Redundant Strap Down Inertial Navigation System (RESINS), and a Guidance and Control Processor (GCP)[28]. During 1985-86, SPINS was developed for the ASLV, using imported sensors. However, gimbals servo components like resolvers and torquers were made indigenously[29].RESINS was also developed for the PSLV initially using imported dynamically tuned gyros (DTG). Subsequently, in 1991 indigenous servo-accelerometers and dynamically tuned gyroscopes substituted them[30]. India could not import fluorolube required to develop rate or rate integrating gyros. Although India could import beryllium from Germany, it appears that India established beryllium machining facility to produce this strategic metal locally anticipating export control problems[31]. Also, by 1988 it developed successfully the DTG which does not require fluorolube. Similarly, by 1986 India developed indigenous accelerometers to avoid export control problems. Since early 1990s, only indigenous gyros and accelerometers were used in Indian launch vehicles[32] In 1983-84, under the ISRO-DFVLR (Indo-German) collaboration programme, the development of an on-board computer for autonomous payload control was started. This was called the Autonomous Payload Control Rocket Experiment (APC-REX), which involved many new technologies like packet telemetry, on-board ranging module and on-board processors[33]. However, the experiment (APC-REX) flight failed[34]. When export controls became increasingly stringent in the 1980s, India appears to have increased its indigenous effort in critical areas such as propellants, materials and inertial systems[35]. ISRO had indigenously developed propellants based on HTPB, different kinds of insulator systems and phenolic adhesives, different types of nozzle throat inserts with different thrust levels (10 kg, 250 kg, and 300 kg), and the technology to fabricate CAA-3 carbon cloth[36]. It developed alloy-processing techniques such as melting, forging, rolling and hot forming activities connected with various alloys such as titanium alloy, aluminium alloy, and magnesium-lithium alloy. For this it forged links with other public R&D institutions such as Defence Metallurgical Research Laboratory (DMRL), Hyderabad, and Ordnance factory, Ambernath[37]. When the US government blocked the sale of bogies and wheels required to build the mobile service tower for integration and launching of PSLV, India designed and developed them within the country[38]. All the accelerometers and gyros used by the PSLV were locally developed[39]. PSLV's third stage submerged flex nozzle motor and the fourth stage liquid engines were designed and developed by ISRO. It also developed titanium alloy gas bottles to carry helium for the pressure fed propellant system[40].

ISRO imported some special alloys and. components from France for the Vikas engine. One of the critical items imported was the throat insert, a special lining, which protects the nozzle throat from the high temperature gas. It is made of composite material (silica fibre embedded in phenolic resin) called Shepen, then manufactured by SEP However, after the MTCR came-into foree, the SEP[41]. Totally discontinued the supply. Therefore; ISRO was forced to develop throat inserts indigenously for both the PSLV and GSLV. Another critical item that was denied to ISRO was the engine catalyst. Only a few companies in the West were producing it. ISRO had been getting its supplies from the US but this stopped after 1987 under the MICR However, this did not affect its programme seriously, as ISRO. Had enough stock to draw on until the engine catalyst could be indigenously developed[42].

During the 1980s, ISRO had set up a number of major facilities for high altitude testing, astro arc welding, precision fabrication, profile machining, micro-electronic components, beryllium machining and electronic beam welding by employing indigenous equipment and knowledge. However, some sophisticated equipment and computers that were not available in India-were procured from other countries. Most were imported before MTCR was established. ISRO also established assembly, integration and test facilities for liquid rocket motors and expanded SPROB and STEX facilities to handle solid motors measuring upto 2.8 in diameter, with a thrust up to 500 tonne

Since mid-1990s, India started developing the GSLV. The Major new technology- in GSLV is the cryogenic engine; which is more efficient than a solid motor or liquid engine and can increase the payload manifold. An agreement with Russia to transfer the technology was scuttled by the US and the agreement was renegotiated for the supply of only engines for GSLV development flights and not the technology per se. Therefore, India was forced to develop the cryogenic engine indigenously and has succeeded now. India has successfully test-fired its .GSLV on 7th May 2003[43]" The US intervention on this issue made it a question of national prestige.

To recapitulate, the export controls were becoming more stringent by the mid-1980s, which appears to have made India to increase its indigenous effort. This was evident from indigenous development of a number of critical technologies for PSLV that included the fourth stage liquid engines, on-board microprocessors, inertial navigation system, new control systems using, engine gimbals and flex nozzle and large light alloy structures. These developments suggest that 1SRO had accumulated threshold capabilities by the late 1980s.

Competence Building in Satellite and Ground Systems:

The satellite building activities under the space programme also can be divided into two phases, that is the; formative phase and the accumulative phase. In the formative phase, India started with the construction of small payloads for sounding rockets. Then, it built a simple scientific satellite called Aryabhata, followed by Bhaskara-I and Bhaskara-II experimental earth observation satellites and APPLE experimental communication satellite. Foreign contributions to these projects were very significant. Aryabhata project started in the early 1970s. ISRO imported a number of subsystems from both the US and the Soviet Union. Nearly all the components like transistors and chips were imported[44]. Bhaskara-I project started in 1975. Soviet Union provided technical assistance, especially in carrying out the final tests and supplied some hardware. The cameras employed imported components from France and the US, and the television tubes were supplied by Thompson-CSF of France[45]. Overall, the import content in. Bhaskara-I was about 25 percent[46].

For APPLE, ISRO received considerable assistance from the European Space Agency (ESA). Particularly, it helped in testing various models of the spacecraft in France[47]. Due to short time schedule to build APPLE, ISRO imported most of the items, as indigenous development would take time. This included momentum wheel, solar array drive, reaction control system batteries, sensors, and transponder elements, ground check out equipment, travelling wave tube and titanium gas bottles[48].During this period, for defining the Indian satellite system (INSAT), ISRO had conducted extensive ground experiments under the projects known as Satellite Instructional Television Experiment (SITE) and Satellite Telecommunication Experiment Project (STEP) using foreign satellites. India also procured the first generation Indian National Satellites (INSAT-1s) from the Ford Aerospace Company.

While employing foreign inputs, India also made strong indigenous efforts to achieve threshold capability in critical areas. For example, a number of critical items such as the reaction control systems, reaction wheels. vertical sensors, horizon sensors, communication systems, vital camera components; solar array drive mechanisms, altitude reference systems, and slip ring unit for the solar array drive assembly were indigenously developed by 1984[49]. These activities clearly indicate ISRO's thrust towards achieving total indigenization in the area of spacecraft control systems, which faced export controls.

During the accumulative phase, India built indigenously both the Indian Remote Sensing satellites (IRS-1s) and the INSAT-2 satellites. Its dependence on imports was restricted to some advanced materials and micro-electronic components such as charge coupled devices and the imaging lenses, radiation hardened integrated circuits, highly polished beryllium mirrors, thermal blankets light-weight, high precision items such as propellant tanks, micrco-thrusters, microprocessor for altitude and orbit control system, and microwave transistors[50]. By the late 1980s, the role of foreign imports in technology accumulation process appears to have diminished and relying predominantly on internal effort India has achieved threshold capability in most of those items such as spacecraft propulsion systems, which faced export controls.

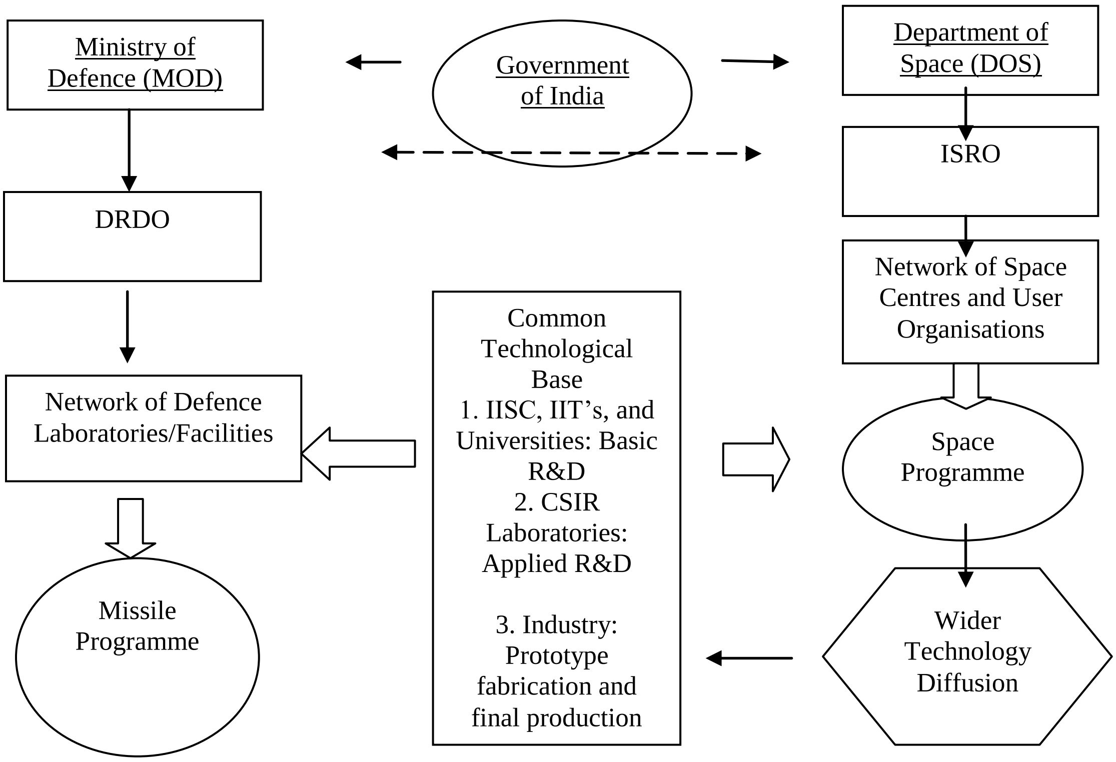
Item-12 (Category II) in the "Equipment and Technology Annex" of the MTCR prohibits the export of "launch support equipment, facilities and software related to complete rockets and unmanned air vehicle systems (with 500 kg payload and 300 km range). It appears that India attained threshold capabilities in ground systems before the formation of MTCR, as the technology was relatively less complex and the local industry was able to master it faster and also due to near absence of export control problems until mid 1980s.

Between the early 1960s and late 1970s, that is, in the formative phase of technology accumulation, India established three rocket launching ranges - the Thumba Equatorial Launching Station (TERLS) in the 1960s, and the Sriharikota Range (SHAR) and the Balasore Rocket launching Range (BRLR) in the 1970s. It appears that all these facilities were built by employing a combination of foreign imports and local inputs[51].To setup TERLS, India was helped by foreign collaborations[52]. To establish SHAR India was able to import most of the critical equipment it required without facing export control problems[53]. India also appears to have utilized local knowledge and resources to the maximum possible extent to build these ground facilities. For example, ISRO developed indigenously the acquisition and tracking radars with the help of other national laboratories and local industry[54]. Initially, the computer facilities at SHAR were established by imported systems to provide computing and processing support for rocket launches and satellite operations[55]. However, from 1983, Electronic Corporation of India Limited started. supplying indigenously developed computers[56]. During the accumulative phase, India appears to have continuously expanded and upgraded them mainly by employing indigenous inputs. India's capability in computing power appears to have increased with technological changes in computers while the MTCR controls export computers specially designed for use on missiles, the Wassenaar Arrangement controls the export of information technology in general. However, it appears that rapid technological change in this area enabled target countries to overcome export controls, as it has become possible to assemble powerful computers using commercially available components and software over the years. For example, commercially available uncontrolled systems can now provide the computing power once supplied by ‘supercomputers’ This is clearly demonstrated by India when it developed the Param and Sparc-II super, computers after the US denied a Cray-XMP 14 supercomputer[57]. Furthermore, as military applications do not .require much computing power; performance increases of uncontrolled computers have undercut export controls.[58]

Capability Building in Themissile Programme:

Although India was developing missile systems even in the 1970s its missile programme took shape only in the 1980s. By the time MTCR came to force India appears to have become capable of sustaining its missile programme with indigenous inputs. As the development of missiles started at about the same time when space programme was entering threshold capabilities, the missile. Programme was not as critically dependent on imports as the space programme during the formative phase. Diffusion of technological capabilities in the industry that occurred through the space programme over the years appears to have helped India to run a separate missile programme. The Indian space programme and the missile programme are organized separately, under the ISRO and DRDO respectively. Until the mid-1980s, there was very little co-operation between these two organisations due to personal rivalry and different perceptions among the top scientists of these organisations[59] Subsequently, with the growth of missile programme this appears to have changed and in recent years both DRDO and ISRO appears to have shared skills and information on occasions such as experimental launches and failure. analyzes Also, they draw from a common technology base, that is, they utilize common suppliers/sub-contractors, network of R&D institutions such as the public R&D laboratories, and academic institutions such as IITs and universities.[60] This is illustrated in Figure 4:

Figure 4: Linkages between India's Space and Missile Programmes



Although India started guided missile research in 1958, the origins of India's ballistic missile programme are widely attributed to the experience gained from the handling of SAM-2 missiles procured from the Soviet Union in 1967.[61] The Defence Research and Development Organization (DRDO) started missile development activities in the early 1970s. It began to concentrate its effort on duplicating the SAM-2 propulsion system, particularly its 3-tonne second stage liquid engine. Using the SAM-2, DRDO succeeded in developing an engine called Devil[62]. Subsequently, after overcoming several problems, it developed an improved version of the engine with turbo pump that used red fuming nitric acid (RFNA) and xylidine as fuel. There was some effort to develop a long-range missile called Valiant in the early 1970s, but it failed due to lack of proper funding and infrastructure at the time[63]. However, the project led to the establishment of number of vital facilities which helped India to successfully develop ballistic missiles in the 1980s. These included a facility to test inertial guidance systems employing imported equipment from France and a facility to make fibre-reinforced plastics for nose cone using imported winding machines from the US.[64]

In 1983 the integrated Guided Missile Programme (IGMDP) was formulated after the SLV-3 project in the space programme created significant capability in the industry. SLV-3 project increased confidence that an independent missile programme could be sustained without much dependence on foreign imports. There were five projects under IGMDP: Prithvi, Trishul, Akash, Nag and Agni. Of these missiles, only Prithvi and Agni were ballistic missile. India was able to import a number of items for the programme before the MTCR came into existence in 1987. For example, India imported "gyros from Swedish and French companies, hydraulic actuators from France, computers and motion simulators from the US and three-axis measuring machines from West Germany."[65] Also, India imported machinery and equipment required to develop carbon-carbon nose cones through its industry from Germany and the US[66].

Using the liquid engine that was derived from the Soviet supplied SAM-2 missile, DRDO has built the Prithvi short-range ballistic missile. The successful launching of Prithvi in February 1988created strong reaction from particularly the US and it led to more stringent export controls "making it impossible for India to buy anything remotely connected with the development of the guided missiles[67] Subsequently, by combining the technologies of Prithvi and SLV-3, India built the Agni intermediate ballistic missile[68]. Agni consisted of two stages. The first stage employed the first stage solid booster of SLV-3 and the second stage employed twin liquid engines, a variant of the Prithvi liquid engine. Contrary to claims that India received assistance from Germany and France in developing critical technologies such as guidance system for Agni, India has developed indigenously a number of components and subsystems that were by then stringently controlled by the MTCR[69]. These included re-entry technology, import substitutes for propellant materials, guidance system guidance algorithm, software for Computational Fluid Dynamics for Hypersonic Regimes, missile trajectory simulation software, ferrite phase shifters, Charge Coupled Devices, gallium arsenide gun, and schlocky barrier mixer diodes[70]. The guidance systems for Prithvi and Agni were different from the launch vehicle guidance systems of ISRO. They were developed by DRDO[71]. The guidance system and software packages for Agni were locally developed and the on-board computer system employed "common 16-bit Intel 8086 micro processors[72]. When Agni was launched successfully, again the US reacted strongly and. cancelled a number of export licenses[73]. These included contracts to sell a Combined Acceleration Vibration Climatic Test (CAVCT) system and magnesium alloys, and a precision radar used for tracking missile path[74]. However, India went on to successfully complete a series of Agni test launches despite stringent export controls.

To capitulate, the wider technology diffusion under the space programme enabled India to run an independent missile programme without critically depending on foreign suppliers. By the time MTCR became stringent in the 1980s, India appears to have crossed threshold capability in rocket technology that reduced the impact of MTCR on its missile programme.

Factors Influencing the Effectiveness of Export Controls:

The analysis of technology accumulation-in the Indian space and missile programmes suggests that mainly three factors have influenced the degree of effectiveness of export controls. These are timing of export controls, existing indigenous technological capabilities of India at different periods of time and rapid technological changes and diffusion of civil technological capabilities in many areas (e.g., Information and Communication Technologies, and commercial microelectronics). Tables 1 and 2 summarize the balance between imported and indigenous inputs in different areas of space technology and the degree of export controls during different phases. Table 1 clearly shows that India's space programme was mainly dependent on foreign inputs in all areas of space technology, that is, rockets, satellites, and ground systems during the formative phase: It also shows that the dependence on imports declined and the balance shifted towards indigenous capability in the accumulative phase .It is evident from Tables I and 2 that denial of foreign inputs during the formative phase, that is, I970s and early 1980s, would have seriously affected the space programme. In the case of missile programme, as the formative phase has begun in the early 1980s when the space programme reached threshold, it was able to utilize the technology base created by the space programme However, it was also dependent on import for certain critical items as shown in the previous section. Because, it was supported by relatively strong indigenous base, it appears to have withstood stringent export controls with relatively less serious impact. In other words, the space programme might have been crippled in the face of stringent controls during formative period, as there was hardly any indigenous capability in space technology. In the case of missile programme, as it was started during the accumulative phase of space programme, it was supported by considerable indigenous capability created by the space programme. Therefore, the likely impact of export controls on the missile programme was limited from the outset.

Table 1: Balance between foreign and indigenous inputs in different phases of technology accumulation

Programme	Formative Phase (until early 1980s)	Accumulative Phase (from mid 1980s)
Space Programme	**Rockets:** Strong indigenous effort. But, critical dependence on imports. Significant foreign technological assistance, that is, international collaborations, technology transfers and supply of critical items.	**Rockets:** Very strong indigenous capabilities in almost all areas Very limited imports due to export controls.
	Satellites: Strong local effort. But, predominantly dependent on imports. Very significant foreign technological assistance, that is,	**Satellites:** Very high indigenous capabilities in all aspects except space electronics and materials. Foreign imports still significant.

	technical assistance to build and test satellites. Cost free launchings, transfer of knowledge through procurement contracts, joint experiments and supply of microelectronics and other critical items.	
	Ground Systems: Very Strong indigenous effort accompanied by imports of large amounts of equipment that was critical and could not be made locally.	**Ground Systems:** Almost completely indigenous capability. Much less imports.
Missile Programme	Until early 1990s: Started with the experience of Soviet SAM2. Largely utilised capabilities created in space programme Employed considerable imports.	From mid 1990s: Almost entirely indigenous. Very little foreign input.

Table 2: The Timing of Export Controls and their Impact on Competence Building in Different Areas under the Space and Missile Programme

Area of Technology 1	Solid Motors/ Propellants 2	Liquid and Cryogenic Engines/Propellants 3	Guidance System 4	Material and Micro-electronics 5	Production and Test Facilities 6	Launch support Facilities 7
I.ISRO and Space Programme						
a. Period of Development	SLV-3: mid 1970s- early 1980s ASLV and PSLV: early 1980s – mid 1990s	PSL V: transfer of Viking engine technology from France in 1979. GSLV : Effort to acquire/develop a cryogenic engine since mid 1980s	SLV-3: mid 1970s-early 1980s ASLV and PSLV : early 1980s-mid 1990s	SLV-3: mid 1970s-early 1980s ASLV and PSLV : early 1980s-mid 1990s	Solid Rockets: Early 1970s-mid 1980s. Liquid Rockets:1980 -1990	TERLS. In the 1960s. SHAR: mid 1970s-mid 1980s
b. Local/Import Content	SLV3: 15 CDV6 steel alloy, PBAN and other propellant materials imported	PSLV Critical components such as throat insert and materials such as engine catalyst were imported	SLV3 and early ASLVs Most of the items were imported	SLV3 and early ASLVs: Largely imported.	Solid Rockets: Some critical machinery and equipment were imported in the 1970s	TERLS: Considerable international assistance. *Table Cont.*
1	2	3	4	5	6	7
	ASLV and PSLV: imported only some components and materials.	GSLV: Cryogenic engines supplied by Russia.	Later ASLVs and PSLV: Initially used some imported sensors and micro electronics subsequen	Later ASLVs and PSLV: Largely indigenous. However, still Imported materials and micro	Liquid Rockets Employed largely local machinery and equipment and some imported equipment.	SHAR: Employed mostly local equipment Considerable number of telemetry and

			tly employed mostly local items	electronics components and parts considerably		tracking equipment and electronic sub systems were also imported
c. Timing of Export Controls	Stringent controls only from early 1980s after SLV3 and in some cases from mid 1980s.By mid 1980s India had created local capabilities in the most of the critical areas.	Stringent controls from 1987 but on certain items only from late 1980s. France stopped supplying critical items. US forced Russia to cancel the transfer of cryogenic engine technology. India has since succeeded.	Stringent controls from mid 1980s and in some cases only from late 1980s.By then India was able to create local capabilities.	Stringent controls from mid 1980s. By then India has created significant Ifailedocal capabilities. However ,the export controls caused some delays to the projects.	Stringent controls from mid 1980s and in some cases only from late 1980s.	Export controls from late 1980s. *Table Cont.*
1	2	3	4	5	6	7
II. India's capability in 1983(When the missile programme was started)	Very high level of capability. Little dependence on imports.	High level of capability Dependence on imports for some critical items.	Significant local capability. But, still dependent on imported components.	Significant local capability in selected items. But, still largely dependent on imported components.	High level of capability.	Very high level of capability.
III. DRDO and Missile Programme						
a.Period of Development	Agni:1984 late 1990s.	Prithvi: 1984 – mid 1990s Agni:1984 – early 1990s	Prithvi and Agni: 1984 – mid 1990s.	Prithvi and Agni: 1984 – mid 1990s	Mainly from 1984	From mid 1980s
b. Local/import Content	DRDO did not have own capability. It used SLV-3's first stage. Later, it created own capabilities using local industry	Prithvi: derived from SAM-2,imported from the Soviet union. Agni: used a variation of the engine employed by Prithvi.	Some parts and components were imported.	Considerably dependent on imports. Strong local capability in some items	Employed mostly indigenous supplies Effort to import certain test equipment failed.	Employed mostly indigenous equipment .
c. Impact of Export	Insignificant .	Insignificant	Small Problems	Caused short term	Caused short term delays	Insignificant

Content				delays		

However, Table 2 suggests that the missile programme suffered delays due to stringent export controls in the formative phase. Table 2 also shows the importance of timing to achieve optimum impact on 'target' programmes. It is clear that although there were restrictions in the 1970s on certain exports, they were not multilateral and systematic until the formation of MTCR in 1987. By then, as shown by Table 2, India was able to build threshold capabilities in a number of areas and its industry has reached a high level of technological learning in the space programme (over 10 years). The missile programme started tapping mainly from these capabilities and relied on imports for limited items that were not available locally. Tables 1 and 2 suggest that the impact of export controls on India’s space and missile programmes would have been far greater in the formative phase when they were dependent on significant foreign inputs, that is, before they reached threshold capabilities and entered the accumulative phase. For instance, this appears to be the experience of India's nuclear power programme. When India faced stringent sanctions imposed after its first nuclear test in 1974, the nuclear power programme was in the formative phase and was dependent largely on imports. Consequently, the export controls seriously undermined the development of India's nuclear power programme[75]. This clearly establishes the importance of timing of export controls and the existing indigenous capability of a 'target' country at the time in determining the degree of impact of export controls. It is also evident that over a period of time the indigenous capability of a determined target" country is more likely to increase and thereby becoming more immune to export control regimes[76]. Another factor .that could seriously undermine the effectiveness of export control regimes is the technological .co-operation among 'target' countries. For example, this appears to be main factor in understanding the effectiveness of export controls in the case of Pakistan, North Korea, and to some extent Iran[77].

Conclusion:

The technology accumulation in India's space and missile programme and India's experience with export controls show that the effectiveness of these controls is determined by three major factors: (i) timing of enforcement of export controls; (ii) existing indigenous capability at a particular phase; and (iii) rapid technological changes in many civil technologies that are increasingly becoming complex than military technologies It is evident that during the formative phase of technological .learning, (until early 1980s), foreign technological inputs have played a significant role in building India's capabilities. Foreign inputs such as technology transfers, training, supply of sounding rockets and ground support equipment, and joint experiments appear to have helped competence building to varying degrees. Overall, the role of foreign inputs was significant. In the absence of these inputs, it is likely that the pace and direction of competence building would have been different and less efficient. This factor assumes more importance as India was building the necessary infrastructure and personnel and was trying to gain the required experience to build more complex rockets and satellites in future If India had faced very stringent export controls at this period, it is possible and even very likely, that its progress would have been seriously affected. For example, ring this phase the Centaure technology transfer from. France in the mid-1960s provided initial impetus for a take-off and the Viking technology transfer in the 1970s enabled India to take a big step in liquid propulsion technology. However, India appears to have benefited more from foreign training than technology transfer per se. Also, during the 1970s India was able to import critical items without severe restrictions for its launch vehicle, and satellite projects. In the absence of foreign technological inputs it is clear that these projects would have taken longer development time and more resources. This suggests that export controls could be more effective during the formative phase of capability building in a 'target' country.

The developments since mid-1980s suggest that capability building in India is predominantly being determined by indigenous efforts than by foreign technological inputs. In other words, the importance of foreign imports had increasingly become marginal to project success during this period. For example, it is likely that the effect of the denial of Viking technology in the early 1980s would have affected India to a greater degree than the denial of cryogenic technology in the 1990s. The difference can be explained in terms of the timing of technology denials and the existing capabilities at the time of technology denial. In the 1990s, the valuable experiences accumulated through the absorption of Viking technology were available to help both ISRO and the industry in developing the cryogenic technology indigenously. All the evidences point to the fact that the timing of the introduction and enforcement of export controls is a very important factor if they are going to be effective in preventing or stopping the capability building and learning process in a 'target' country. The positive impact can, under the circumstances described in this paper, lead to a stimulus to indigenous development which extends over existing capabilities in areas which have been built .up previously through a mix of technology transfer and indigenous technology development programmes. This is clearly evident in the case of India, as increasingly stringent export controls led to increased indigenous capability instead of affecting its space and missile programmes[78]. Clearly the timing of MTCR and the status of India's indigenous technological capability at the given time appear to have determined the .extent MTCR could influence, further competence building in its space and missile programmes.

To generalize, export control regimes such as the MTCR cannot have much effect on those countries, which have crossed the threshold capability, as indigenous technology base is likely to sustain their programmes with minimum or no imported input. On the other hand, it could severely affect a space or missile programme in a developing country, which is still at the formative phase of technological learning. That is, when a 'target' country is still building the basic infrastructures and skills, learning the art of coordination and project management, and its overall industrial capacity is weak and dependent on foreign technological inputs to a greater degree. Therefore, the timing of application of export controls and the state of capabilities of a 'recipient' country at that stage are critical factors. Here, it is assumed that the export controls are very stringent and there are no alternative sources of supply. Obviously if a 'target' country could import banned items from an MTCR-adherent or a non-adherent country, its programme will not be seriously affected. This is clearly evident from the experience of countries such as Pakistan, North Korea and Iran. Also, if a country is prepared to invest heavily in terms of money and other resources like human capital over a long period of time (over 20-25 years), it will eventually achieve threshold capability and overcome export control problems. This may be achieved at a very high cost and by diverting scarce resources from other economic activities.

This paper suggests that with increasing technological changes and wider technological diffusion in many civil technologies that are more complex than military technologies and also due to increasing indigenous technological capabilities, the impact of export control regimes on ‘target' countries will diminish in the medium to long term. The effectiveness of export control regimes on `target' countries that are still at the formative phase of technological learning could be very significant and export controls alone may be sufficient in delaying or stopping a missile programme. However, major `target' countries such as India, Pakistan and North Korea appear to have either already attained threshold capabilities or very close to achieving threshold capabilities. Therefore, it is unlikely that export controls will achieve their policy objectives in these countries. With rapid technological changes and increasing sophistication and complexity of many civil technologies, and increasing indigenous capabilities of main 'target' 'countries, the export control regimes in general are going to be less and less effective and increasingly counterproductive in the future.

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