The Impact of Export Controls on Indigenous Technology Development: The Case of India's Space Programme

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A Paper Presented at the Conference:

Arms, Conflict, Security and Development

16-17th June 2000

Middlesex University Business School
London, UK.

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Abstract

The timing of export controls and the state of technological capability of a 'target' country at a given time appear to determine the degree of impact of export controls on a 'target' country. The impact is likely to be much greater in the *formative* phase than in the *accumulative* phase of technology accumulation. Also, the export controls, instead of hampering, could provide an incentive for a strong indigenous effort in building capabilities, eventually making a 'target country more independent and more immune to export controls. India's space programme makes an interesting case study of the impact of export controls on capability building, as India has been one of the targets for export control regimes. The technology developments in India's space programme suggests that the export controls have caused only small delays and did not affect the programme seriously. It appears that the Missile Technology Control Regime (MTCR) came into force too late to have a serious adverse impact on India, as India has already attained threshold capabilities. It also appears that export controls have forced India to plan and strategically manage indigenous technology development to overcome problems posed by these controls.

1. Introduction

Multilateral export control regimes have been established by developed countries to prevent certain 'target' countries from acquiring capabilities in complex dual-use technologies that could be used to develop weapons of mass destruction. It appears that the impact of export controls, such as the Missile Technology Control Regime (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 an initial stage, that is the formative stage, then the impact will be greater to the point of crippling the growth of technological accumulation. For example, if that country is running a missile programme, it is likely to be seriously impeded as the foreign input is very important at this stage. On the other hand, if the country is in an advanced stage, that is the accumulative stage, where the role of foreign input is less determinant, the export controls will be less influential. Therefore, the timing of controls on technology transfer and the stage of technological capability of a recipient country at a given time

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greatly influence the impacts of export controls. Also, the export controls, instead of hampering, could provide an incentive for a strong indigenous effort in building capabilities, eventually making a target country more independent of foreign technology than it might otherwise have been.

India's space programme makes an interesting case study of the effectiveness of export controls on building technological capabilities. India has been one of the primary targets of various export controls since it exploded a nuclear device in 1974. Its nuclear, space and missile programmes have been subjected to severe export controls by the Western countries. The timing of MTCR and the stage of India's technological capability when it came to force appear to have determined the extent MTCR could influence further competence building under the space or missile programme.

The technology development process in India's space programme also suggest that it is very likely that India would have continued to be dependent on imports for much longer but for the presence of export controls. In contrast to the expectations for the impact of policies leading to export controls, instead of slowing down or stopping technological accumulation under the space programme, the controls appears to have increased its pace.

2. Expected Impact of MTCR on 'target' Countries

Considerable numbers of works focus on the kind of impact the MTCR could have on the potential proliferators (e.g., Bailey and Rudney (ed), 1993; Jones, 1992; Fetter, 1991; Stanford University, 1991; Anthony (ed), 1991; Pullinger, 1991; Navias, 1990; Arnett et al. (ed), 1989; Karp, 1986 and 1988). They discuss how the restrictions imposed by the MTCR on transfer of dual-use goods and technologies would affect the 'target' countries in different ways. Most of them expect that the MTCR could only limit and slow down the spread of missile technologies in the developing world. They expect it to "stretch out the development cycle, increasing development costs and impeding qualitative improvements" of the technology development programmes in a 'target' country thereby forcing the country to abandon them (Stanford University, 1991, p. 6). In the words of a US policy maker:

> With something as complicated as missiles, where basically ten nations control the technology, those ten countries can increase the time, the cost, the unreliability... associated with the programs of missile proliferators, and by increasing all of those factors, you of necessity force any government to ask whether this program is worth the price (Arnett et al. (1989), p.269).

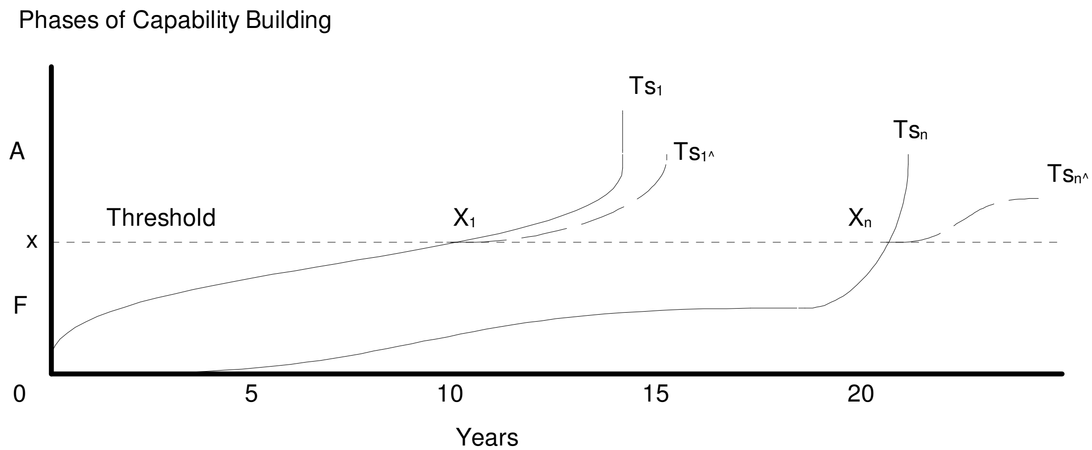
The literature suggests that the impact of MTCR on the technology development programmes in the 'target' countries could be the following: (a) slowing down or delaying the programmes; (b) increasing the cost of the programmes; (c) forcing states to abandon the programmes; and (d) may not affect the programmes significantly.

This paper will analyse the developments under India's space programme to find out the nature of impact of export controls. First, it will briefly discuss the relationship between different phases of technology accumulation and the impact of export control regime such as MTCR.

3. Relationship between Two-Phase Model of Technological Accumulation and Impact of MTCR.

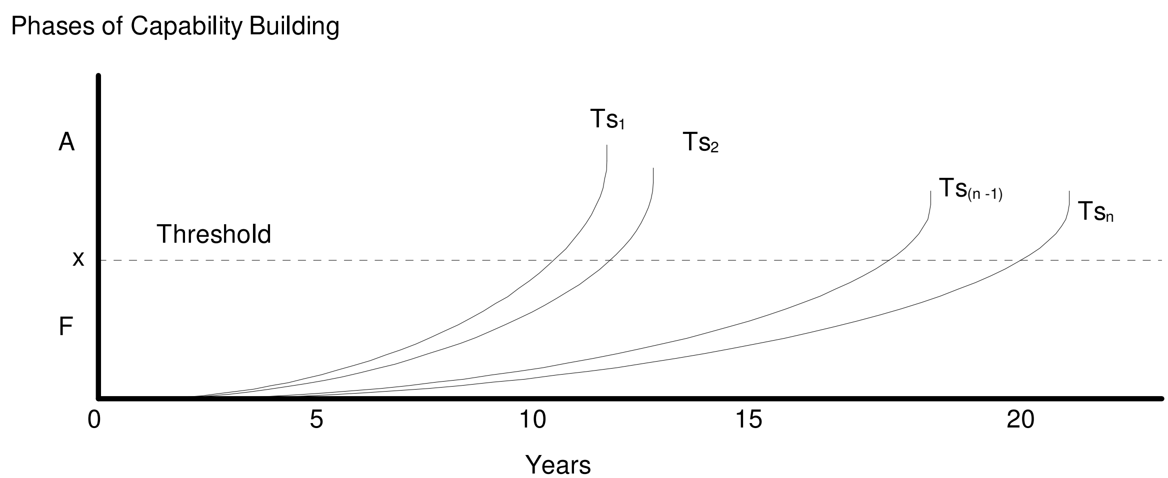
The impact of the export control regimes such as MTCR on a particular country may depend upon whether it is in the *formative* phase or in the *accumulative* phase of technological development. If it is in the formative phase, then the impact is likely to be greater to the point of crippling the growth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

Figure 2: Relationship Between MTCR and Technological Accumulation



F - Formative Phase
A - Accumulative Phase

Figure 1: The Space Technology Scenario in Different Countries



F - Formative Phase
A - Accumulative Phase

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. T_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-2 is used 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 the developing 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 Xn the other countries cross the threshold. As the need for foreign technological input is likely to be much greater in the formative phase than the accumulative phase, the space/missiles programmes of those countries which are in the zone X_1Xn will be affected to a maximum extent. It is possible that most 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 Xn. In these latter cases, the impact is likely to range from almost none to some significant level. For example the most efficient programme, Ts_1, may be affected to some extent, which might retard the process slightly. It is represented in the figure by the slight distortion $Ts_{1^\wedge}$. In the same way, the least efficient programme Ts_n may be affected to a considerable extent, which is represented in the figure by a very significant distortion $Ts_{n^\wedge}$.

4. Significance of Export controls to a Space programme

India is one of the few developing countries, which have been running an ambitious space programme with an objective of developing a launch vehicle capable of launching a 3-tonne satellite into the geo-synchronous orbit. It has been dependent on foreign supplies, especially for critical items listed under Category-II of the Equipment and Technology

Annex of MTCR, to implement various projects while making effort to develop indigenously most of these items. Therefore, restrictions imposed by the suppliers on export of these items and technologies could have an impact on the development projects of India's space programme as shown by Table-1

Table 1: Technologies Controlled by the MTCR and Their Significance in a Space Programme

Technologies Controlled	Significance in a Space Programme
CATEGORY I	
Item-1: **Complete rocket and unmanned air-vehicle systems with 500 kg payload and 300 km range.**	This will not affect a space programme significantly because already there have been very little transfer of complete rocket systems. However, it may affect a space programme which is in an early stage and dependent on imported rocket systems.
Item-2: **Complete sub-systems usable in Item-1:** 2 (a) individual rocket stages 2 (b) re-entry vehicles 2 (c) solid or liquid rocket engines 2 (d) guidance sets 2 (e) thrust vector controls 2 (f) arming, fusing and firing mechanisms and production facilities / equipment for the above items.	These are technologies which are involved in civil launch vehicles as well as missiles. Restrictions on the transfer of these technologies (except re-entry vehicles and certain mechanisms which have only military use) could affect seriously a launch vehicle programme in a 'target' country which is dependent on importing these items.
CATEGORY II	
Item-3: **Propulsion components usable in Item-1.** 3a: Light weight turbojet and turbofan engines; 3b: Ramjet / Scramjet / Pulse jet / Combined cycle engines and their components; 3c: Rocket motor cases, "interior lining", insulation and nozzles; 3d: Staging and separation mechanisms and interstages; 3e: Liquid and slurry propellant control systems and components therefor; 3f: Hybrid rocket motors and components therefor.	Many of these components are employed in the development of a satellite launch vehicle. Restriction on them can affect the development projects.

Technologies Controlled	Significance in a Space Programme
Item-4: **Propellants and chemicals for propellants.** 4a: Propulsive substances - MMH, UDMH, Ammonium perchlorate, spherical aluminium powder, metal fuels in particle sizes less than 500 microns, HMX and RDX, perchlorates, chlorates or chromates mixed with powdered metals, carboranes, decorboranes, pentaboranes, liquid oxidisers such as N_2O_4 and IRFNA; 4b: Polymeric substances - CTPB, HTPB, GAP, PBAA and PBAN; 4c: Composite propellants;4d: Other high energy density propellants such as Boron slurry; 4e: Propellant additives and agents such as bonding agents, curing agents, burning rate modifiers, nitrate esters and nitrato plasticizers and stabilisers.	These items are related to solid and liquid propellants for the rocket motors and engines. Most of the developing countries which run civil space programmes are dependent on importing them. Very few countries can supply these items. Therefore, multilateral controls on these items could have a serious impact on development projects of a space programme.
Item-5: **Propellant production technology and equipment.** 5a: Production, handling or acceptance testing of liquid propellants; 5b: Production, handling, mixing, curing, casting or acceptance testing of solid propellants.	Propellant production technology and equipment are very important to develop large rockets to launch satellites. Particularly, the know-how related to equipment and handling of liquid propellants are not easy to master locally. Restriction on these items could severely affect the process of the accumulation of local capabilities.
Item-6: **Production technology and equipment for structural composites usable in systems in Item-1**	This involves very high technology and even the advanced developing countries are dependent on imports. Export controls will create serious problems for development projects under a space programme.
Item-7: **Pyrolytic deposition / densification technology and equipment.**	This is a production technology. Export restrictions will create problems for a space programme.
Item-8: **Structural materials usable in the systems in Item-1.**	These are mainly used to fabricate rocket motor casings. Most developing countries are mainly dependent on imports. Restrictions on their export will create serious problems.
Item-9: **Instrumentation, navigation and direction finding equipment and systems and production and test equipment.**	These involve very high precision technologies. Most of the developing countries are largely dependent on imports. Export controls will affect them seriously.
Item-10: **Flight control systems and the related 'technology'.**	These are advanced systems and very important for launch vehicles. Restriction on export can have a severe impact.

Technology Controlled	Significance in a Space Programme
Item-11: **Avionics equipment and related 'technology' and components.**	This involves space electronics which are very important for launch vehicles and to some extent satellites. Export controls can have serious impact on a space programme.
Item-12: **Launch support equipment, facilities and software for the systems in Item-1.**	These are relatively less complex and export controls may not have significant impact on a space programme.
Item-13: **Analog and digital computers usable in systems in Item-1.**	Very advanced technology. Export controls can create serious problems for a space programme.
Item-14: **Analog-to-digital converters usable in the systems in Item-1.**	This is also a complex technology and restrictions on export will have serious impact on a space programme.
Item-15: **Test facilities and test equipment usable for the systems in Item-1 and Item-2.**	Most of the developing countries are dependent on foreign imports for test facilities and equipment, particularly during the initial period of development. Export controls could create serious problems.
Item-16: **Specially designed software with specially designed hybrid computers for modelling, simulation, or design, integration of systems in Items-1 and 2.**	This is an advanced area of technology where the impact of export controls could be severe for development projects of a space programme.
Item-17: **Reduced observables technology, materials and devices.**	These involve mostly military applications. The restrictions over them may not affect a space programme.
Item-18: **Devices for use in protecting rocket systems and unmanned air vehicles against nuclear effects.**	This also involve mainly military technologies. Export controls on them will not affect a space programme. However, as satellites employ some radiation hardened devices, the restriction may have some impact on a space programme.
Item-19: **Complete rocket systems and unmanned vehicles not covered in Item-1 with the range of 300 km and above.**	Until the early 1990s, these were freely exported to many developing countries. Export controls may not have serious impact on a space programme.
Item-20: **Complete sub-systems usable in systems in Item-19.**	It appears that many developing countries have already acquired these subsystems. Export controls may not have a serious impact on a space programme.

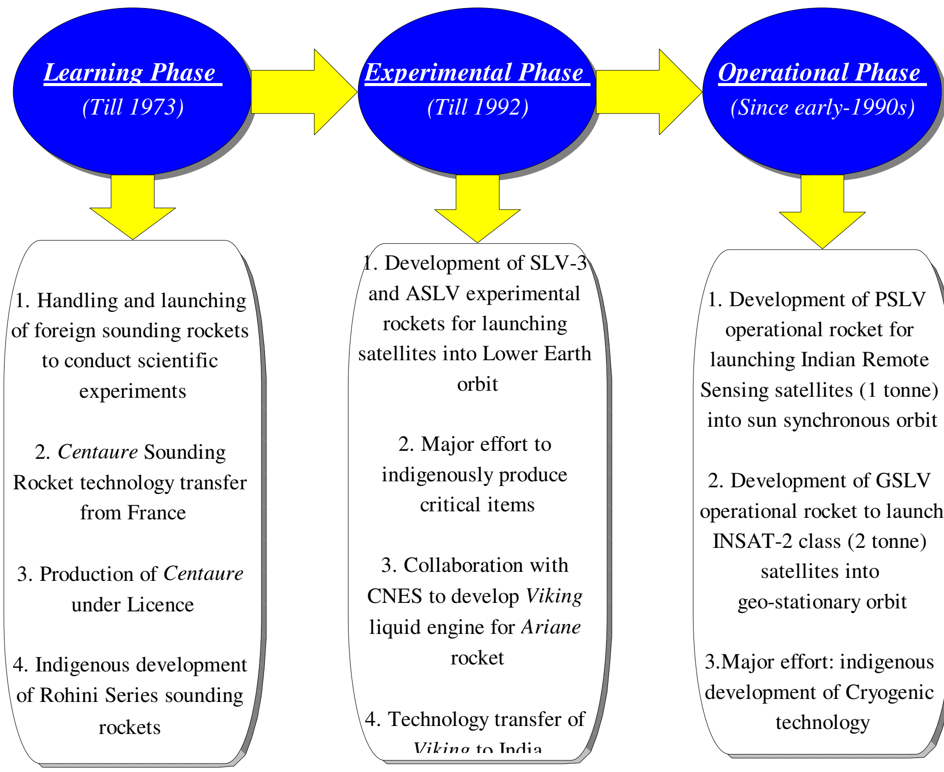
The following sections will discuss the impact of MTCR in different areas of space technology, that is, rockets, satellites and rocket launching and spacecraft control facilities.

5. Impact of Export Controls on Rocket Technology Development

Figure-3 illustrates the competence building activities in the area of rocket technology during different phases. During the leaning phase, that is, between mid-1960s and early-1970s, India developed different types of sounding rockets. Between the mid-1970s and early-1990s, India has developed three launch vehicles, that is, SLV-3, Augmented satellite launch vehicle (ASLV), and Polar Satellite launch vehicle (PSLV). The first two were experimental launchers and the PSLV was an operational launcher. During the 1990s, India was developing the Geo-stationary satellite launch vehicle (GSLV) that would be capable of launching a 3-tonne class satellite. Table-2 provides the salient features of these launchers. Until the late 1970s, that is, before the launch of the SLV-3, India did not experience stringent export controls in this area, although there were restrictions. During this period there were two important technology transfers from France, that is, the *Centaure* sounding rocket technology and the *Viking* liquid engine technology for PSLV. Further, India was able to import most of the critical items. However, since the early-1980s India started facing increasing difficulties from export controls.

Since the late-1970s, that is, long before the MTCR came into force, there has been a rapid growth in the volume and the complexity of the indigenous technology development under the space programme. The major catalyst behind this appears to be the pressure from export controls. At the time India was facing severe difficulties with its nuclear programme because of the problems created by the export controls. The space establishment in India could hardly ignore this turn of events, which would have implications for its programme in the future.[1] This concern, more than anything else, appears to have forced Indian Space Research Organisation (ISRO) to undertake a planned and organised indigenous programme with the main aim of overcoming export control problems.[2]

Figure 3: Different Phases of Rocket Technology Development in India



In the mid-1970s, the planners in ISRO formulated a programme to develop indigenously certain critical items needed by the launch vehicle programme such as titanium alloy forging and the production of maraging steel, ammonium perchlorate, hydroxyl terminated polybutadiene (HTPB), unsymmetrical dimethyl hydrazine (UDMH) and nitrogen tetroxide. Some of these items were not required until several years later. This programme had achieved good results and a large number of items (for launch vehicles) were developed indigenously long before the MTCR came into force. This suggests that both the expectations about export controls and their imposition provided incentives to develop capabilities internally. These occurred because the MTCR prevented a 'target' country from acquiring these capabilities through technology transfer. It appears from the evidence to be quite likely that India would have followed a different approach towards competence building in the absence of export controls, and, as a result, it is likely to have remained dependent on others for much longer time.

Table 2: Salient Features of ISRO's Launch Vehicles

Feature	SLV-3	ASLV	PSLV	GSLV
Gross Lift-off Weight	17 t	39 t	275 t	400 t
Maximum Diameter	1.0 m	1.0 m	2.8 m	2.8 m
Height	22.0 m	23.5 m	44.0 m	51.0 m
Number of Stages	4	5	4	3
Propellants	Solid	Solid	Solid & Liquid	Solid, Liquid & Cryogenic
Guidance	Open-Loop Inertial	Closed-Loop Inertial	Closed-Loop Inertial	Closed-Loop Inertial
Orbit Injection	Spin Stabilised	Spin Stabilised	3-Axis Stabilised	3-Axis Stabilised
Orbit	Low Earth Orbit	Low Earth Orbit	Sun Synchronous Orbit	Geo-stationary Transit Orbit
Main Payload	ROHINI 40 kg	SROSS 150 kg	IRS 1000 kg	INSAT 2000-2500 kg
Primary Mission	Space Science & Technology	Space Science & Technology	Remote Sensing	Communication & Meteorology
Development Period	1972-1983	1982-1994	1982-1997	1991-98

Source: S. C. Gupta, "Growth of Capabilities of India's Launch Vehicles", Current Science, Vol. 68., no. 7., 10 April 1995.

Particularly, the analysis of the PSLV project suggests that ISRO had to depend primarily on internal effort to execute the project in the face of increasingly stringent export controls. This had caused some delays to the project. However, ISRO appears to have succeeded in building threshold capabilities in both liquid and solid propulsion systems. In the case of GSLV, initially ISRO did not make much effort indigenously to develop cryogenic technology, as it was trying to import it as in the case of the *Viking*. However, India was forced to develop it indigenously after a technology transfer deal with Russia was cancelled because the US argued that the deal had violated the MTCR. It also banned ISRO for two years from importing any relevant goods. India's response to this action suggests that, instead of affecting its programme adversely, the MTCR enforcement seems to have provided more incentives to develop the cryogenic technology locally. Also, the US ban on ISRO made the Indian population aware of the difficulties imposed export controls and generated a consensus on supporting the space and missile programmes. The denial of cryogenic technology also made India to become more determined to develop technologies denied by the West with little if any regard to the cost.

By the 1990s, capability building in India was predominantly being determined by local effort than by the technological imports. In other words, the importance of technological 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. 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 evidence points to the fact that the timing of the introduction and enforcement of export controls is a very important factor if there is to be a positive impact on the capability building and learning process in a 'target' country. The positive impact can 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.

6. Impact of Export Controls on Satellite Technology Development

Starting with a simple spinning satellite, *Aryabhata* in 1975, ISRO had built 25 satellites by the early-2000 (see Table-3). Over 25 years, it has acquired capabilities to build very complex, world class operational IRS (1-tonne) and INSAT-2 (2-tonne) satellites for remote sensing and communications, respectively. The process of satellite technology accumulation is illustrated by Figure-4.

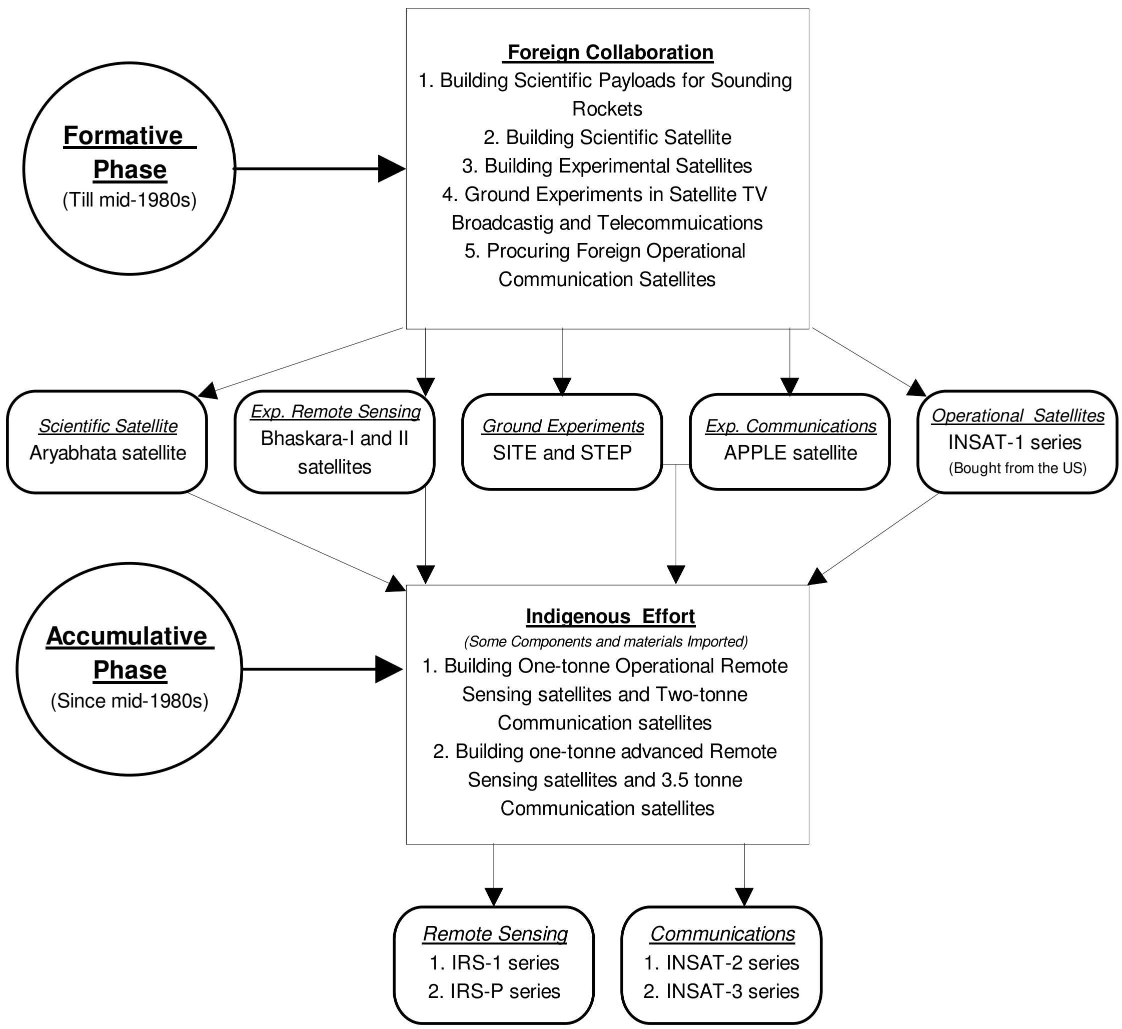
Table 3: Satellites Built by ISRO Since 1970s

Satellite	*Weight (Kg)*	*Date of Launch*	*Launched By*
Aryabhata	360	April 1975	Intercosmos (USSR)^
Bhaskara I	444	June 1979	Intercosmos (USSR)^
Rohini	35	August 1979	SLV-3 (India)*
Rohini-I	35	July 1980	SLV-3
Rohini-D1	32	May 1981	SLV-3
APPLE	650	June 1981	Ariane Test Launch (ESA)^
Bhaskara II	436	November 1981	Intercosmos (USSR)^
Rohini-D2	41.5	April 1983	SLV-3 (India)
SROSS-1	150	March 1987	ASLV-D (India)*
IRS-1A	975	March 1988	Vostok (USSR)
SROSS-2	150	July 1988	ASLV-D2 (India)*
IRS-1B	975	August 1991	Vostok (USSR)
SROSS-C1	106	May 1992	ASLV-D3 (India)
INSAT-2A	1906	July 1992	Ariane (ESA)
INSAT-2B	1906	July 1993	Ariane (ESA)
IRS-1E	846	September 1993	PSLV-D1 (India)*
SROSS-C2	113	May 1994	ASLV-D4 (India)
IRS-P2	804	October 1994	PSLV-D2 (India)
IRS-1C	1250^+	December 1995	Molniya (Russia)
INSAT-2C	2050^+	December 1995	Ariane (ESA)
IRS-P3	922	March 1996	PSLV-D3 (India)
INSAT-2D	2500	June 1997	Ariane (ESA)*
IRS-1D	1200	September 1997	PSLV-C1 (India)
IRS-P4	1050	May 1999	PSLV-C2 (India)
INSAT-3B	2070	March 2000	Ariane-5 (ESA)

* Launch Failed; ^ Cost Free Launch; + Weighed at lift-off.

Foreign collaboration appears to have played a very significant role during the *formative* phase, that is, until the mid-1980s, in competence building under the satellite programme in India. Until the mid-1980s, India did not seem to have any problem with export controls. It was able to import almost anything needed for its programme without hindrance. Therefore, in the case of the satellite technology there appears to have been no attempt to manage indigenous technology development process in an organised and planned manner as we have seen in the case of rocket technology. There was no strategic planning for the development of critical items that might come under export controls in the future. It was likely that India preferred to depend on foreign imports for many critical items because they were easily available and cheaper compared to the development cost at home.

Figure 4: Formative and Accumulative Phases of Competence Building in Satellite Technology in India



In the second half of 1980s, when the IRS-1 and INSAT-2 projects were executed, India increasingly felt the pressure of export controls. The developments under these projects suggest that the presence of export controls has significantly changed the approach towards indigenous technology development under the satellite programme. It seems that India started planning and managing its indigenous effort in a manner so as to reduce dependence on foreign countries. Particularly, it appears to have accorded priority to the most critical items to avoid the problems created by the export controls as it had already done with its launch vehicle programme.

7. Impact of Export Controls on Development of Ground Facilities

Between the mid-1960s and mid-1980s, ISRO built a network of earth stations, rocket launching facilities and satellite tracking and control facilities in different parts of the country (see Figure-5). This was the first area to benefit from a major indigenisation effort under the space programme since the technology was not very complex and the industry was confident of taking up the challenge. It appears that India did not face many problems with export controls in this area as the technology was a low security risk to other countries. This enabled India to forge foreign collaboration and international co-operation. ISRO developed most of the ground equipment with the help of other R&D organisations in the country and the industry. This effort was helped significantly by liberal imports of those items that could not be made locally. This trend continued through each new project until the mid-1980s. By then, when the MTCR was in place, India had already achieved extensive capabilities. The MTCR was too late to affect India in a significant way in the area of ground facilities such as rocket launch support. It is likely that India's effort to build capabilities in this area would have been affected adversely, if there had been problems with export controls in the 1970s. The developments in this area suggest that India did not feel it necessary to follow a strategic approach towards indigenous technology development because of the absence of export controls. Instead, it appears to have followed a 'scientific' approach whereby it chose to develop whatever technology was possible within its existing capabilities and to import the rest from other countries. It appears that export controls had little if any influence on this policy. Instead, the main influential factors for this decision appear to have been the lower level of complexity of technologies involved, the existing capacity of the local industry, the economies of scale and financial constraints affecting decisions to opt for foreign imports.

Figure 5: Ground Infrastructure Developed under the Indian Space Programme

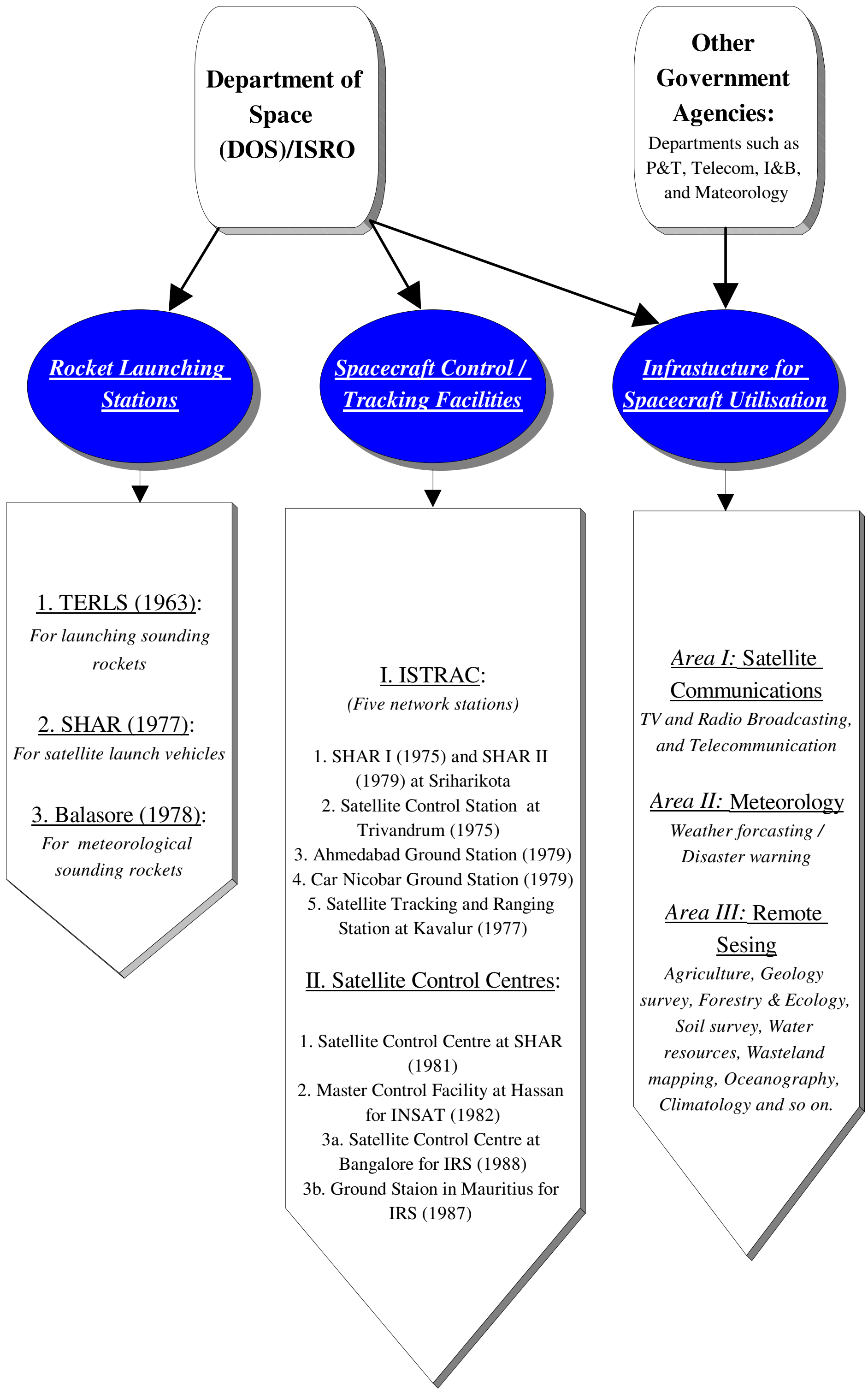


Table 4: Comparison of the Impact of Export Controls On Competence Building in Different Areas of Space Technology

Area of Technology	***Rockets***	***Satellites***	***Rocket Launching and Spacecraft Control Facilities***
Degree of Complexity	Highly Complex	Complex, but relatively less than the rockets	Less complex
Presence of Export Controls:			
(a) Until Early 1980s	Generally strict controls even before the MTCR (because of India's nuclear programme), particularly on transfer of technologies. But, imports of critical items were possible and alternate sources were available.	A much weaker controls. It was possible to import most of the critical items.	Almost no controls. It was possible to import freely, including technology transfers.
(b) From mid 1980s	Very stringent multilateral controls, formalised by MTCR.	Stringent controls. It became difficult to import some of the critical items which could be imported freely in the past.	Very few controls. Occasional denials.
Balance between Local and Imported Supplies*:*			
(a) Until early 1980s	Strong indigenous effort. But, critical dependence on imports. Significant foreign technological assistance, i.e., international collaborations, technology transfers, and supply of critical items.	Strong local effort. But, predominantly dependent on imports. Very significant foreign technological assistance, i.e., 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.	Very strong indigenous effort accompanied by imports of large amounts of equipment that was critical and could not be made locally.
(b) From mid 1980s	Very strong indigenous capabilities in almost all areas except a few such as materials and cryogenic technology. Very limited imports due to export controls.	Very high indigenous capabilities in all aspects except space electronics and materials. Foreign imports still significant.	Almost completely indigenous capability. Much less imports.

Area of Technology	*Rockets*	*Satellites*	*Rocket Launching and Spacecraft Control Facilities*
Impact of Export Controls:			
(a) Until early 1980s	Strict controls even before the MTCR and the experience of the nuclear programme forced India to follow a strategic approach towards achieving technological independence. Development of critical items was undertaken to overcome possible export controls in the future. Although export controls caused problems, they did not affect the programme seriously.	Export controls did not cause serious problems. Although India was making strong indigenous effort, It did not follow a strategic approach towards technology development as in the case of rocket technology. It was able to import almost all critical items without many problems. It was not seriously concerned by this dependence.	The influence of export controls was the least strong. The absence of export controls allowed free imports. However, India made very strong efforts from the beginning to create local capabilities. It was not content to remain dependent on imports. Factors other than export controls seem to have played a role in this approach.
(b) From mid 1980s	Export controls caused some delays to projects such as PSLV and GSLV. However, the long term impact appears to have been insignificant. Export controls seem to have provided incentives to develop local capabilities irrespective of cost.	Export controls caused problems for the projects such as IRS-1 and INSAT-2 satellites. The pressure from export controls forced India to strategically plan and manage indigenous technology development to overcome dependence on imports for critical items.	Problems of export controls were insignificant. By this time India had already created very strong local capabilities. From the beginning, because of the absence of export controls, India appears to have followed a 'scientific' approach to competence building in contrast to the case of rocket technology.

8. Comparison of Impact of Export Controls on Different Areas of Space Programme

One method that can be employed to analyse the impact of export controls on competence building under the space programme is to compare the developments under different areas of space technology, that is, rocket technology, satellite technology, and rocket launching and spacecraft control facilities. Table-4 illustrates these developments at different time periods, that is, until the early 1980s and after the 1980s. Table-4 also shows the importance of the timing of export controls. Until the early 1980s, despite the presence of export controls to varying degrees in different areas of space technology, India was able to import most of its requirements. This was possible mainly because of the availability of alternate sources of suppliers and the absence of a co-ordinated multilateral approach towards enforcing these controls. As a result, India was able to build strong capabilities in all the areas of space technology. The role of foreign imports for competence building during this period appears to have been very important. If export controls had been enforced very stringently during this period, the competence building process under Indian space programme is likely to have been affected very seriously.

By the time these controls became stringent due to the multilateral approach in mid 1980s, India had already accumulated threshold capabilities in most of the critical areas as shown in Table-4. This helped the country to reduce dependence on foreign imports and to overcome most of the problems created by export controls. This shows that the timing of export controls has a very strong impact on a target country.

Table-4 suggests that the presence or absence of export controls has influenced the decisions regarding the way indigenous technology development was undertaken in the Indian space programme. It depicts three different illustrations of this pattern. First, it shows an area, that is, rocket technology, where export controls were present long before the MTCR came into force. Second, it illustrates an area, that is, satellite technology, where there were fewer controls until the mid-1980s and relatively more controls after the MTCR. Third, it shows an area, that is, ground support facilities, where there was almost no export control. In the first case, that is, rocket technology, even in the early 1970s, ISRO anticipated problems with the import of items for its launch vehicle programme because of the experience of India's nuclear energy programme. The presence of export controls during the 1970s appears to have influenced the decision-makers to follow a strategic approach towards indigenous technology development.

Table-4 also shows that India had made strong indigenous efforts in all areas of space technology both before and after the mid 1980s, that is, before and after the MTCR. Because of the indigenous effort during the 1970s and early 1980s, the country was able to accumulate strong local capabilities which eventually helped it to overcome stringent export controls after mid-1980s. India appears to have accumulated a high level of indigenous capabilities in at least 18 out of 20 items proscribed by MTCR. India attained this level of capabilities in some of these items long before export controls became very stringent in mid 1980s. Further, Table-4 suggests that indigenous effort played a predominant role in capability building from mid-1980s when export controls became stringent. This suggests that export controls might provide incentive for indigenous technology development. However, Table-4 also shows the important role of foreign technological inputs in building capabilities in all the areas, particularly until the early 1980s. This suggests that, in the absence of foreign technological inputs during this period, it is likely that the pace of capability building in all areas would have been relatively slower. Particularly, the impact would have been more severe in the areas of rocket and satellite technology because of the complexity involved. This suggests that timing of export controls and the stage of technological capability of a target country at the time mostly determine the impact of export controls.

9. Conclusions

The evidence suggests that foreign technological inputs played a major role in competence building under India's space programme until the early 1980s, that is, during the formative period. The absence of these inputs is likely to have seriously affected competence building at the time. This shows that export controls could have serious impact on a target country during the formative phase of capability building. By the time the MTCR came into force in the mid 1980s, India's dependence on foreign imports had been reduced to a limited number of areas such as microelectronics and advanced materials. The impact of export controls such as the MTCR on the space programme appears to have been limited to causing some short term delays to its projects.

The comparison of technology developments under different areas of space technology such as rockets, satellites, and ground support facilities shows that, instead of adversely affecting competence building in India, export controls such as the MTCR forced the country to develop independence from foreign sources of technology. The presence and fear of export controls appears to have forced ISRO to follow a strategic approach towards competence building in critical areas to avoid dependence on foreign countries. This happened first in the area of rockets and then in the area of satellites.

In the case of rocket technology, ISRO appears to have anticipated stringent export controls because of the experience of India's nuclear energy programme. The fear of these controls forced it to manage its R&D strategically from the mid-1970s with the aim of avoiding future problems created by export controls. In the case of satellite technology, there were considerably fewer export controls before mid 1980s and ISRO appears to have followed a 'scientific' approach towards competence building. There were no planned R&D activities to create capabilities aimed at circumventing future export controls. However, increasingly stringent export controls from mid 1980s appear to have forced ISRO to follow a strategic approach to technology development. In the area of ground support facilities, the near absence of export controls enabled ISRO to take a 'scientific' approach towards R&D management throughout the period examined in the study as it was possible to import all its requirements. Nevertheless, the absence of export controls did not lead the country to become completely dependent on imports. ISRO made strong indigenous efforts towards competence building in this area as it had done in the areas of rockets and satellites. The approach and the motivation appear to have been different in these two cases, but the outcome was similar. The developments in rocket and satellite technology suggest that export controls might have provided an incentive for building indigenous capabilities. However, the analysis of competence building in ground support facilities suggests that the absence of export controls does not necessarily lead to a developing country like India remaining dependent on foreign imports.

Notes

[1] It should be kept in mind that the space programme was run by the nuclear establishment for nearly a decade before it became separated. Also, most of the scientists and engineers of ISRO originally came from the nuclear establishment and had a very good understanding of its problems.

[2] Interview with Prof. Satish Dhawan (Former Chairman of ISRO) and a former ISRO engineer involved in planning the programme.

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