The Contribution of Intangible Technology Controls in Controlling the Spread of Strategic Technologies

IAN J. STEWART[1]

Abstract

This paper seeks to understand the contribution of export controls on intangible technology transfer in limiting the spread of the manufacturing base of strategic dual-use technologies, particularly in the context of globalisation. A new model of capability acquisition is developed that has origins in the knowledge management discipline. This model is used to explore a case study related to Chinese efforts to indigenise production of carbon fibre, a strategic dual-use commodity with uses in civil, military and Weapons of Mass Destruction (WMD) programmes. The analysis reveals a complex picture. Capability indigenisation in a globalising world is not inevitable. Likewise, strategic trade controls are not without effect. However, export controls as currently implemented are poorly suited to the task of preventing the spread of intangible technology, which is one prerequisite to capability indigenisation. It is suggested that the Capability Acquisition Model has utility in understanding other technology transfer issues.

Keywords

Tacit knowledge, export controls, intangible technology transfers

Introduction

States utilise a variety of tools to control or restrict the transfer of technology where the transfer could otherwise jeopardise national or international peace and security. The main tools are export controls, which originated in the wars of the 20th century –if not before --and are now nearly ubiquitous in the international system. These measures restrict the transfer of single use technologies, such as guns, tanks, nuclear reactors, nuclear weapons, and long range missiles, as well as dual-use technologies including certain materials, machine tools, and other manufacturing capabilities. In controlling these dual-use technologies, the aim of the international community is not necessarily to prevent the transfer under all circumstances, but instead to provide individual states with the ability to both monitor the transfer of such technology and

[1] Ian J. Stewart is a senior researcher at King's College London where he also runs Project Alpha, which works to understand and counter illicit trade.

to prevent such transfers when the end use is deemed nefarious. Importantly for this paper, these controls typically include both the physical goods and the "intangible technology" associated with the controlled item and its use.

The challenge for the international community has long been to design controls on technology in general and on intangible technology in particular that prevent unsavoury transfers whilst not encumbering legitimate academic inquiry, business activity, personal expressive freedoms, or economic development. A debate on the merits and effectiveness of intangible technology controls has begun recently for a variety of reasons. These include the increasing availability of information via the internet, and the expansion of the use of i information and communication technology (ICT). Additionally, tensions between controllers and academics/researchers have also come to the fore recently through several individual cases, including the use of export control legislation to prevent the publication of bird flu data, the use of export controls to remove from the developers website plans for a "printed handgun", and the introduction in Australia of new measures to subject universities to export control legislation, among others.[2, 3, 4] These cases may have also resulted in a higher awareness of the controls in general, with broader awareness potentially equating to a broadening of the debate.

This paper seeks to understand the potential effect of intangible technology controls on the spread of the manufacturing base for strategic dual-use technologies. To enable this, a new Capability Acquisition Model, which has its conceptual groundings in the knowledge management discipline, is developed. This model is applied to recent Chinese efforts to indigenise carbon fibre production. This examination provides insight into the effects of intangible technology controls on the spread of the manufacturing base for certain proliferation-sensitive technologies.

This paper proceeds as follows. The next section sets out the various elements of the supply-side control framework. The "Capability Acquisition Model" is then presented. This model is used to examine Chinese efforts to indigenise carbon fibre production. The lessons identified from this examination are then presented and conclusions drawn.

Non-proliferation Controls

States adopted export controls during the First and Second World Wars for the purposes of protecting national security by, for example, stopping military technologies from reaching the enemy through neutral countries.[5] The tools were extended at the end of WW2 to serve as an instrument of the Cold War, with the founding of COCOM.[6] These tools were adapted further to counter the risk of further proliferation of nuclear weapons (and eventually chemical, biological and long range missile systems). It was in 2004 that the UN Security Council moved to universalise export controls within the international system in response to AQ Khan's activities in passing enrichment technology to Iran, Libya and North Korea through the adoption of UNSCR 1540 as well as the reaction to the events of 9/11.[7] More recently, the Security Council has also adopted "targeted" sanctions resolutions against Iran and North Korea, which prohibit any state from transferring technologies that could be used for nuclear and missile applications to these

---

[2] Greenfieldboyce, Nell. "Bird Flu Studies Mired in Export Control Law Limbo." *National Public Radio*. April 10, 2012. http://www.npr.org/blogs/health/2012/04/10/150311034/bird-flu-studies-mired-in-export-control-law-limbo.
[3] Holpuch, Amanda, MacAskill, E. & Arthur, C. "State Department orders firm to remove 3D-printed guns web blueprints." *The Guardian*. May 10, 2013., http://www.theguardian.com/technology/2013/may/09/3d-printed-guns-plans-state-department.
[4] Biercuk, Michael J. "Science and the Slammer: The Consequences of Australia's New Export Control Regime" *The Conversation*, October 15, 2012. http://theconversation.com/science-and-the-slammer-the-consequences-of-australias-new-export-control-regime-10127.
[5] Ritchie, H. "*The 'Navicert' System During the World War*," Washington, DC: Monograph Series ", Carnegie Endowment For International Peace, Division of International Law No. 2, 1938, Monograph. 2.
[6] COCOM (The Coordinating Committee for Multilateral Export Controls) was a Cold War era export control regime implemented by the US and its allies for the purpose of preventing Western technologies being used by the Soviet Union.
[7] United Nations Security Council 1540, S/RES/1540, New York, April 2004.

countries.[8]

At the inter-state level, there are four major export control regimes that aim to coordinate the control and the supply of technology that could contribute to proliferation. These are the Nuclear Suppliers Group, which seeks to prevent the spread of nuclear weapons, the Missile Technology Control Regime, which seeks to prevent the spread of long range missiles that could carry unconventional warheads, the Wassenaar Arrangement, which controls conventional military equipment and advanced dual-use technologies in order to prevent a "destabilising build-up of arms," and the Australia Group, which focuses on countering the proliferation of chemical and biological weapons.[9] Membership of these regimes includes most but not all states that have the capability to manufacture technologies required in the development of such weapons.[10] There is also another regime which is now largely defunct – the Zangger Committee – which was created in the 1970s to interpret article III.2 of the NPT but which does not control intangible technology associated with nuclear items.

The export control regimes and UN measures mentioned above all require states to adopt control in intangible technologies as well as on physical items. The approach taken by export control regimes has largely been to control the intangibles associated with technologies that are otherwise controlled. The designs for missile propulsion systems, for example, are likely to be considered controlled and thus cannot be exported without a licence.[11]

Currently, intangible technology is defined by the Wassenaar Arrangement is:

"Specific information necessary for the development, production, or use of [controlled] goods or software" (where information may "take many forms including, but not limited to: blue prints, plans, diagrams, models, formulae, tables, source code, engineering designs and specifications, models and instructions, written or recorded on other media or devices"). where… "information takes the form of technical data or technical assistance." "Technical data may take forms such as blueprints, plans, diagrams, models, formulae, tables, engineering designs and specifications, manuals and instructions written or recorded on other media or devices such as disk, tape, read-only memories." "Technical assistance may take forms such as instruction, skills, training, working knowledge, consulting services." Technical assistance may involve transfer of 'technical data' as defined by the Wassenaar Arrangement.[12]

Figures from the US Department of Commerce demonstrate the extent to which these intangibles are controlled: From 2001-2012 the Department of Commerce refused almost 2500 licenses, of which around 150 were for intangibles technology as defined in US law. Of these 150, around half were destined to China and a quarter to India.[13] While these controls are usually coordinated at the international level, it is individual states that are responsible for their implementation. While the systemic measures outlined above control both tangible and intangible technologies, some states have also opted to adopt additional controls to specifically restrict proliferation through intangible

[8] United Nations Security Council 1718, S/RES/1718, New York, October 2006.
[9] For details of the Nuclear Suppliers Group, see: nuclearsuppliersgroup.org, for the Wassenaar Arrangement, see http://www.wassenaar.org/, for the Missile Technology Control Regime, see http://www.mtcr.info/ and for details of the Australia Group, See http://www.australiagroup.net/.
[10] For example, China did not join the Nuclear Suppliers Group until 2002 and has not yet joined the MTCR despite having a substantial missile manufacturing capability. (Note, however, that China did express interest in joining the MTCR in 2002).
[11] Export control laws typically prohibit an export unless a licence (sometimes known as an authorisation) has been granted by the competent national authority.
[12] 'The Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies." The Wassenaar Arrangement. (2013). Definitions and terms used in these lists, http://www.wassenaar.org/controllists/index.html.
[13] Stewart, Ian J. Author's Study of US Export Licensing Statistics. London: (Unpublished), 2012.

technology transfer. An increasingly ubiquitous measure in developed countries is student vetting.[14] Certain countries – notably the United States –imposes controls on "deemed exports" – that is, transfers where "technology or source code is released to a foreign national within the US" defined in EAR 734.2 (b).[15] At least one country – the United Kingdom – also maintains controls on the ability of foreign nationals to study certain subjects within the United Kingdom. The purpose of such student vetting schemes typically is to ensure that individuals coming from overseas to study a course with relevance to proliferation such as nuclear science and technology, have no known connections with activities of proliferation concern.

These frameworks are elaborate and multi-layered, though there are usually exceptions. "Basic scientific research" and "information already in the public domain" are typically exempt by export control regimes, for example.[16] These decontrols exempt the majority of activity undertaken by academia.

There are also other tools available to states in controlling technology transfer. States have, for example, long maintained official secrets legislation and related classification systems for information that, if released, could threaten national security. Some countries have also adopted legislation prohibiting the release of information on certain nuclear-sensitive activities, such as uranium enrichment. As this case study focuses on dual-use technology, these broader tools will be considered beyond the scope of this examination. However, the model presented below could be usefully applied to understand the contribution of such tools to non-proliferation efforts.

The question that is of interest to this paper is whether this system of 'supply-side controls' is capable of preventing proliferation when, as described below it is recognised that capability acquisition requires the coming together of equipment, material, and knowledge. To examine this question a "Capability Acquisition Model" is presented before being applied to a case study involving efforts to indigenise carbon fibre production. To inform the case study, several experts from the carbon fibre industry were interviewed. Each of the interviewed experts had knowledge of export control issues and had been involved with the export or carbon fibre and related production equipment and technology. Two were primarily based in the United Kingdom and one in the United States.

Framework for Analysis

The starting point for this analysis is the recognition that to manufacture any commodity three prerequisites must come together: equipment, materials, and knowledge. The knowledge management discipline, building from the work of Polanyi, may further divide knowledge into its "tacit" and "explicit forms".[17] Explicit knowledge is information that is easy to express and to transfer, such as through blue prints or instruction manuals or other written communications. Tacit knowledge is not as easy to express and cannot readily be transferred. This division will be used below when deriving the "Capability Acquisition Model".

While scholarship on knowledge management is relevant to this problem, it should nonetheless be recognised that the issue of proliferation is fundamentally different to the problem studied by most knowledge management scholars. For example, in their definitive book Nonaka and Takeuchi present a model for the use of knowledge in innovative businesses, which is presented below.[18] The creation of

---

[14] "Academic Technological Approval Scheme," Foreign and Commonwealth Office, London, March 25 2013. https://www.gov.uk/academic-technology-approval-scheme.

[15] "Export Administration Regulations, Code of Federal Regulations 734.2", Bureau of Industry and Security, Washington, DC: US Department of Commerce, July 22, 2015.

[16] "Dual-Use Controls," European Commission, 2014. http://ec.europa.eu/trade/import-and-export-rules/export-from-eu/dual-use-controls.

[17] Polanyi, Michael. *The Tacit Dimension* (Chicago: University of Chicago Press, 1966).

[18] Nonaka, Ikujiro, and Hirotaka, Takeuchi., H. *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation* (New York: Oxford University Press, Inc., 1995).

innovative designs and products differ substantially from what in effect is the reverse engineering task faced by those who would acquire a proven capability. i.e. the task is not to invent a new technology or process, but is instead to acquire something that someone else has previously mastered. Additionally, unlike in business where more codification of tacit knowledge could be undertaken if it was in the financial interest of the business to do so, for proliferators, cost could perhaps be expected to be a secondary or tertiary consideration after success and secrecy.

Capability Acquisition and Proliferation

Export controls have been adopted for the purposes of preventing the proliferation of weapons of mass destruction and for preventing the transfer of other technologies that could be a threat to national security or international peace and security. Export controls cover most military technologies, such as guns, fighter aircraft, and even satellites.

Importantly, however, export controls have also been extended to manufacturing technologies associated with key components, including manufacturing equipment. This extension occurred after states that were unable to acquire military or WMD products outright instead opted to procure manufacturing capabilities so that these technologies could be produced indigenously. Inevitably, the manufacturing equipment in question is dual-use in nature: it could be used to manufacture the technology of concern or it could be used to manufacture other technologies with which there are no sensitivities. The study of the indigenisation of the ability to manufacture strategic technologies is thus integrally linked to the study of proliferation.

A variety of approaches have either been or could be taken by states to indigenise the manufacturing capability of an item. These may include reverse engineering acquired technologies, or acquisition of designs, materials and equipment through procurement or theft.

Current Literature on Knowledge Transfer

The framework put forward in this paper has roots in the work of Nonaka and in the earlier conceptual grounding provided by Polanyi, who is credited with coining the phrase "tacit knowledge".[19] He summed up his insight by stating, "Individuals can know more than they can say". This observation is an oversimplification of the concept he developed which in its full form can perhaps be better demonstrated by considering the impossibility of transferring the entire knowledge and experience of one person to another.

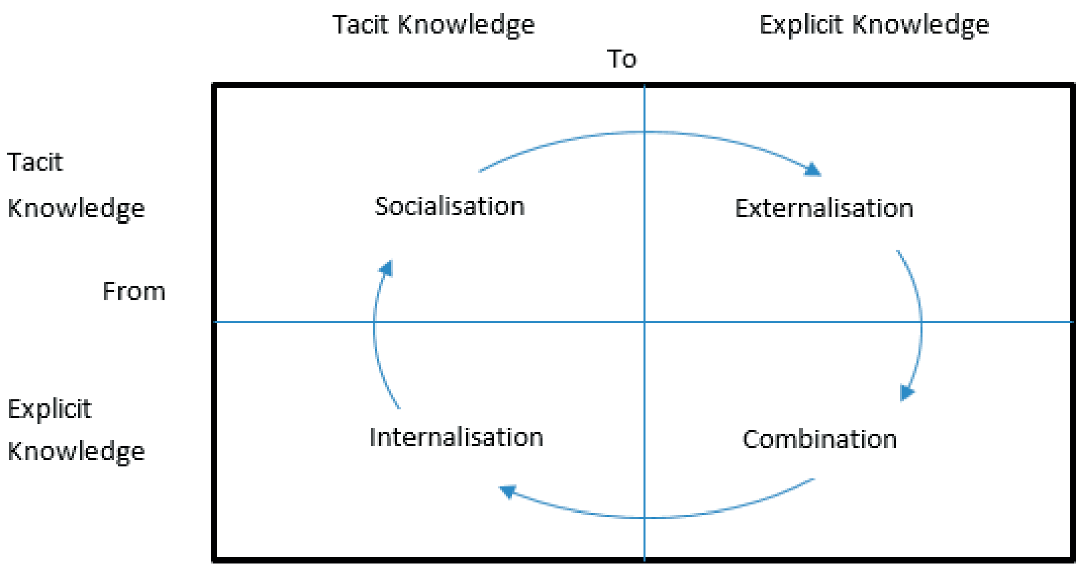
Based upon Polanyi's definitions, explicit knowledge is easily communicable information usually in the form or writing, diagrams and so forth. Tacit knowledge on the other hand is personal and difficult to communicate. It is nonetheless apparent that explicit knowledge is often usable only when combined with tacit knowledge. For example, to read a blueprint it is necessary for the individual to read the diagram, understand its meaning, and visualise the underpinning data – all tasks that require some degree of tacit knowledge gained through formal or informal education. The exact nature of the knowledge required evidently varies from task to task, but would at least include an understanding of the material properties, a visualisation of what is to be manufactured, and an expertise in utilising the equipment for the task at hand.

Know-how, a form of tacit knowledge, evidently differs from information since know-how is held not in a physical form but in the minds of individuals. Know-how is gained through education, training, and doing. The key to know-how is usually experience. Having done something before or something which

[19] Ibid.

is comparable, the individual can utilise judgement to anticipate what will happen the next time around. Experience is, of course, context-specific but it may be possible to extrapolate from one task to another. It is apparent that while know-how can exist within a collective community, it cannot readily be passed onto a new member of the community. This principle is embedded in most societies: The length of an undergraduate degree is typically not governed by the amount of information that has to be assimilated, but the amount of experience that is required for the individual to have an understanding of the subject. Likewise, technical apprenticeships often last for a number of years so that skills can be acquired, where acquiring skill is comparable to understanding as the prerequisite is typically experience.
Nonaka went on to define a circle model of knowledge creation in which he suggested that only individuals can create knowledge and that it is the role of the organisation to exploit the tacit knowledge held and generated by such individuals.

Image 1: Nonaka's Innovation Cycle Model[20]



The dichotomy provided by Nonaka provides a foundation for describing knowledge transfer and will serve as the basis of this analysis:[21]

- *Socialisation:* Transfer tacit knowledge from person to person. For example, during an apprenticeship a learner gains experience under the tutorage of his master. Generally, this requires person-to-person contact. As such, knowledge transfer to second countries via this route requires one party to spend significant periods of time in the others country.
- *Externalisation:* Creating explicit knowledge from tacit knowledge for the purposes of passing it on. For example the current moratorium on nuclear weapons testing has resulted in western nuclear weapons laboratories introducing knowledge retention programmes that include oral interviews with retired engineers. Such efforts cannot capture all the individual's tacit knowledge, however, and there is likely to be a diminishing rate of return.
- *Combination:* Transfer explicit knowledge from explicit knowledge. This is a straight forward transfer from one information holder to another. For example, emailing a design or sending a blue print from one company to another.
- *Integration:* Transforming explicit knowledge into tacit knowledge. This could be achieved, for example, by rehearsal.

In addition to work such as this that has explored how tacit and explicit knowledge can be transferred (or otherwise), the expansive literature on tacit and explicit knowledge has explored also what constitutes

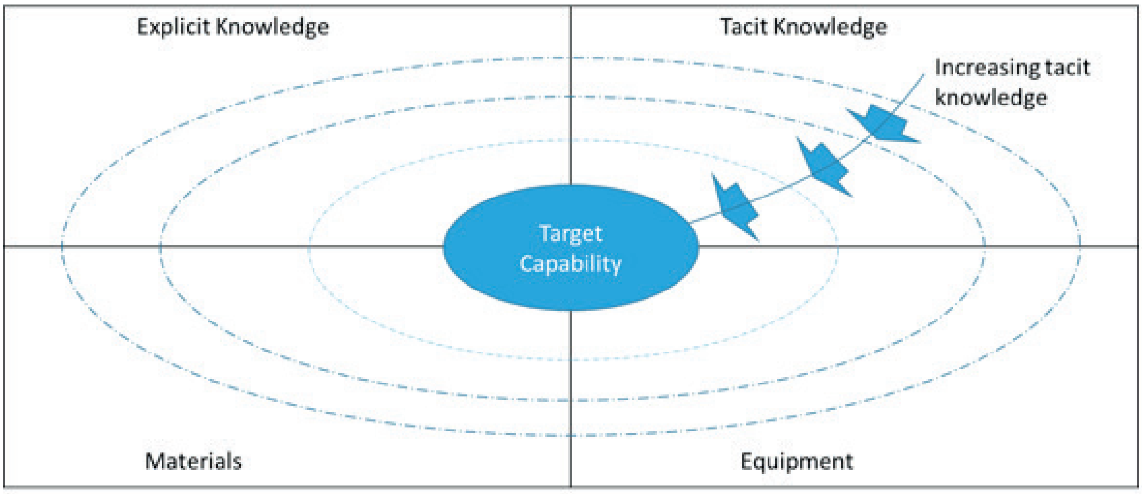
[20] Ibid.
[21] Ibid.

tacit and explicit knowledge to more nuanced levels. For example, Gorman identified several types of knowledge, including declarative (what), procedural (how), judgement (when) and wisdom (why), suggesting that each type of knowledge had both tacit and explicit elements.[22]

As discussed above, the process of capability indigenisation, which is a prerequisite to proliferation, may be fundamentally different from that of creating and exploiting new ideas. It is not necessarily the case that indigenisation requires the creation of original knowledge. As will be demonstrated below, indigenisation more often involves the acquisition or emulation of a capability that already exists elsewhere in the world. In such circumstances the task for the acquirer is to develop the capability to achieve a known goal. The task for the acquirer is to acquire the information (explicit knowledge), materials, and equipment, and importantly the tacit knowledge required to make use of these in order to achieve a target capability.

In order to visualise this, the following "Capability Acquisition Model" was derived by the author. Through the model, it is suggested that in order to achieve the target capability, the acquirer can progress iteratively inwards as their possession of tacit knowledge increases. This inward progression allows them to utilise explicit knowledge, materials, and equipment more fully in reaching their target capability.

Image 2: Capability Acquisition Model



The indigenisation of capability requires three elements. The first two are the availability of equipment and materials. The purpose of the most well-established non-proliferation controls (export controls) has traditionally been to control the transfer of such physical goods. The third is knowledge. Utilising the framework outlined in the previous section it is apparent that both tacit and explicit knowledge are required for capability acquisition to be successful. A more nuanced model could further categorise the tacit and explicit knowledge requirement into the categories identified by Gorman, although for the purposes of this analysis, the differentiation between tacit and explicit knowledge is helpful as it more directly maps to the definitions of technical data (i.e. explicit knowledge) and technical assistance (i.e. tacit knowledge) mentioned above.

Technology Transfer and Export Controls

Drawing the distinction between explicit information and know-how is helpful when conceptualising how intangible controls may contribute to efforts to prevent proliferation. There has long been a concern that a nation-state or terrorist could use a "blueprint" for a nuclear weapon as a shortcut to obtaining a

[22] Gorman, Michael E. "Types of Knowledge and Their Roles in Technology Transfer." *Journal of Technology Transfer* 27:3, (2002): p. 219-231.

functioning device. On the other hand, Montgomery, for example, has highlighted that a lack of access to tacit knowledge impeded the nuclear weapons programmes of several countries that received information and technology from overseas.[23]

Explicit knowledge, such as a product's blueprints and instructions on how to operate the equipment is increasingly likely to be available through open sources. Such information could be procured not only from books and through taught education, but also increasingly from the internet. It can be emailed or otherwise transferred across international borders with ease. This rising availability of explicit knowledge (i.e. information) makes considering whether national laws can effectively police such transfers important. The instinctive answer at first would appear to be 'no': The sheer volume of information flowing around the world would make detection of such technology transfer for illicit purposes difficult. It may, however, be possible to police some information transfers for single-use technologies, such as designs for nuclear weapons by constraining supply – that is, preventing such information from reaching the public domain or to manage its removal if it does.

For dual-use technologies it is clearly more difficult to police transfers of explicit knowledge. The approach taken by the export control regimes is to control intangibles only when associated with technologies that are otherwise controlled. This approach is perhaps on the assumption that those who hold tangible technology can also be held accountable on a related intangible transfer. Beyond the formal rules that govern the transfer of intangible technology, those who hold such technology may, for their own reasons, opt to restrict its availability, perhaps to protect intellectual property for example. It is apparent that any restriction on intangible technology may be vulnerable to theft be it via physical or cyber-attack. Additionally, as demonstrated by the speed with which designs for 3d guns were mirrored by hosts around the world after their designer uploaded them to his own website, hopes that specific pieces of information can be removed from the internet are perhaps unrealistic. (Although steps could be taken to make such information more difficult to find, by co-opting search providers to exclude certain content, for example).

Tacit knowledge, such as competence, skills, and experience, on the other hand does not become increasingly available through the progression of modern communications technology. It continues to be the case that to gain tacit knowledge an amount of effort must be invested undertaking an activity from which tacit knowledge can be socialised or developed. Such acquisition is aided when under the tutorship of someone more experienced – "a master." The knowledge required for proliferation to succeed again falls into multiple categories including single-use and dual-use.

How Important is Tacit Knowledge Transfer?

In the Capability Acquisition Model presented above it was suggested that tacit knowledge acquisition is a prerequisite to capability acquisition. It is suggested in the model that it is the progression of tacit knowledge that allows progress to be made towards realising a capability, thus implying that acquisition of equipment or materials and availability of explicit information alone would not result in successful capability acquisition. Of relevance to this paper is therefore whether supply-side controls could affect the acquisition of tacit knowledge.

Case Study: China's Efforts to Indigenise Carbon Fibre

Carbon fibre is a strategic commodity that can be used in many different applications. Legitimate applications include use as a structural material for motorsports, aerospace, and the leisure industry. Potentially prohibited end uses include use as a structural material in missiles, uranium enrichment centrifuge rotors, and military satellites. Perhaps the most significant market for carbon fibre is the aerospace industry, which has both civil and military elements. China identified carbon fibre as a high-

[23] Hsu, Nina. "Developing Advanced Carbon Fiber in India: Process Technology Advancements for the Future," Harper International. http://www.simco-groups.com/wp-content/uploads/2014/07/developing-Advanced-Carbon-Fiber-in-india.pdf.

priority sector for indigenous development in its 12th strategic 5 year investment plan of 2011.[24] It is unclear exactly why China chose carbon fibre for prioritised development, but there are likely several contributing factors. First, carbon fibre has uses in many programmes with national security ramifications that were also featured in the development plan, such as the aerospace industry and in the defence sector. Second, although licences for exports of carbon fibre to China have usually been granted, the fact that the supply of a strategic commodity like carbon fibre was subject to control by all of the small number of manufacturing states was likely a driver for indigenisation. This focused development of these key technologies takes place in the context of a broader systematic effort by the Chinese authorities to acquire capability through technology transfer.[25]

Because of the uses of carbon fibre in programmes of concern, its export is controlled by two export control regimes: the Nuclear Suppliers Group and the Wassenaar Arrangement. Not all countries are members of these regimes, but all countries with a substantial capability to manufacture carbon fibre are a member of at least one regime as shown in table 1 below. Additionally, UN sanctions prohibit the export of controlled carbon fibre and related equipment from any destination to Iran and North Korea. The geographical coverage of export controls with regards to carbon fibre manufacture is therefore relatively good.

Table 1: Headquarter location of all major carbon fibre producers

Name	Country (Ownership)
Toray	Japan
Toho Tenax	Japan
Mitsubushi Rayon	Japan
Hexcel	USA
Cytec	USA
Formosa	Taiwan, China
AKSA	Turkey
SGL Group	USA
Zoltek	USA
Hyosung Corp	South Korea
Nippon Graphite	Japan
Mitsubushi Plastics	Japan

China is a member of the NSG but this affords China no favour with regards to the licensing decisions of other states. Exporting governments usually state that licences are judged on a case-by-case basis, with proposed exports being judged on grounds related to declared end use and the risk of onward diversion.[26] While China has actively worked to improve its implementation of export controls in recent years, it is known to be a diversion point for goods destined to Iran and North Korea in breach of sanctions.[27] China has also been subject to a western arms embargo since the Tiananmen Square protests in 1989, though this embargo does not prohibit export of dual-use material to China.[28] Nonetheless, this combination of concerns likely explains why several licences to export carbon fibre and carbon fibre production equipment have been refused to entities in China in recent years.

---

[24] British Chamber of Commerce in China, *China's Twelfth Five Year Plan (2011-2015)*, as translated by the Delegation of the European Union in China, http://www.britishchamber.cn/content/chinas-twelfth-five-year-plan-2011-2015-full-english-version.
[25] Gross, Clifford M. "The Growth of China's Technology Transfer Industry Over the Next Decade: Implications for Global Markets," *Journal of Technology Transfer 38:5*, (October 2013), p. 716-747.
[26] Department for Business Innovation and Skills. "Assessment of Export Licence Applications: Criteria and Policy." September 10, 2012. https://www.gov.uk/assessment-of-export-licence-applications-criteria-and-policy. Accessed 11 August 2013.
[27] Stewart, Ian J., Andrea Stricker, A., and Albright, D. "Chinese Citizen's Involvement in the Supply of MKS Pressure Transducers to Iran: Preventing a Reoccurrence," *Institute for Science and International Security* and *Project Alpha,* April 30, 2014. ISIS reports, http://www.isisnucleariran.org/assets/pdf/MKS_China_30Apr2014-final.pdf.
[28] "Dual-Use Controls," European Commission. 2014. http://ec.europa.eu/trade/import-and-export-rules/export-from-eu/dual-use-controls/.

China's investment in carbon fibre includes regional investment in Jilin City and investment in numerous facilities and university research centres. In all there are also up to 20 entities working to produce carbon fibre in China.[29] Nonetheless, official industry statistics and knowledgeable experts point to a failure to date of Chinese producers to master carbon fibre production. A key indicator of performance is the grade of carbon fibre produced – Chinese producers currently manufacture high volumes of comparatively low grade "T300" equivalent carbon fibre but almost no higher grade materials such as "T700" or "intermediate modulus" carbon fibres.[30] A survey of manufacturing data by the author reveals that actual output of higher grade carbon fibre by commercial producers in China continues to be in the kilogram range compared to the tonnes of lower grade material produced by these same firms.[31] Given the substantial level of investment this leads to the question of what is the barrier to Chinese mastery of carbon fibre production?

When asked, industry experts identified the primary issue as a lack of precursor.[32] Precursor is effectively a textile and is not controlled by the export control regimes. Precursor must be processed to turn it into carbon fibre by heating ("carbonisation"), stretching, and surface treatment. Carbon fibre in turn must be combined with resin for the material to be usable as a structural material. This process of combination can be either automated by laying sheets of resin on top of sheets of carbon fibre or through a winding process in which one continuous strand of carbon fibre is weaved (usually around a mandrel) into the required shape before being baked in an oven. Controlling the resin to carbon fibre ratio is usually important for high-performance applications. There are several producers of precursor worldwide but production of precursor is generally scaled with and integrated to carbon fibre manufacture. Such producers therefore have little incentive to supply to Chinese carbon fibre producers who would become competitors. Whilst not driven by non-proliferation controls, this lack of access to precursor has effectively constrained Chinese production of carbon fibre. Overcoming this lack of access to high-grade precursor has led China to adopt a range of approaches to master carbon fibre production indigenously.

China's Capability Acquisition Strategy[33]

Acquisition of technology from overseas has been a key aspect of China's investment plan. Industry experts highlighted that there are effectively no producers of carbon fibre manufacturing equipment such as spinning equipment and furnaces of the appropriate type in China. Chinese producers have instead turned to overseas suppliers of manufacturing equipment. However, industry experts have highlighted that US producers have been unable to supply to China because export licences were denied. European producers on the other hand were known to have fulfilled these contracts, highlighting inconsistent approaches to export licensing decision-making around the world.[34]

Chinese producers have thus acquired production equipment from overseas. Technology controls on tangible exports alone, therefore, cannot explain the failure of Chinese producers to master carbon fibre production.[35] That said, production of certain grades of carbon fibre requires the use of a very high temperature furnace and it is unclear whether licences for such furnaces have been sought or would be granted. Attention must therefore turn to how the technology is used.

---

[29] Authors survey taken by author of Chinese producers of Carbon Fibre, (unpublished), 2013.
[30] Carbon Fibre Expert 1, Interview by author, London, United Kingdom, 2013.
[31] Author's Survey taken by author of Chinese producers of Carbon Fibre, (unpublished), 2013.
[32] Carbon Fibre Expert 2, Telephone Interview by author, London United Kingdom, 2013.
[33] The use of the term acquisition strategy should not be taken to mean that there is anything inherently untoward about Chinese acquisition of carbon fibre manufacturing capability. Indeed, China as a member of the Nuclear Suppliers Group applies export controls on its own exports of carbon fibre in order to curb proliferation. Of interest to this paper is not the fact that China is seeking a carbon fibre production capability, but instead lies in the routes China has pursued and the resulting success, or otherwise, of these activities.
[34] Ibid, Expert 1.
[35] Carbon Fibre Eexpert 3, Interview taken by author, United States, 2014.

When asked what constrains the use of equipment to produce carbon fibre, industry experts were clear that expertise is the vital prerequisite. One western expert stated explicitly that carbon fibre production is a “black art” and that those with the knowledge could practically get any production line to produce carbon fibre even without instruction manuals, although this may mean working from “first principles.”[36] The same individual went on to clarify that effective operation of carbon fibre production equipment required “black magic” that could not be learned in a class room or read in a book. Another expert also described the process as being like art, going on to clarify that to operate a plant successfully, the operator would have to touch and “practically smell” the fibre.[37] Expertise had to be gained through operating (and ideally problem solving) a live production line with an expert alongside.[38] The first individual went on to clarify that on many occasions carbon fibre production lines were run efficiently in the presence of such outside experts who could “tweak” conditions, but after someone with experience left, the line would inevitably fall in efficiency as the local staff had not mastered every problem that could arise. Perhaps in an attempt to overcome this very issue, Chinese producers were known to have recruited (as opposed to the common practice of hiring) western specialists to reside on the operators site and oversee operations.[39]

Companies that sell capability for the production of carbon fibre also recommend that procurers begin with a pilot plant, primarily to build expertise, before attempting to upgrade to a commercial-scale plant.[40] This accounts for the small batch quantities of high-specification materials that Chinese officials claim to have produced. However, two of the interviewees expressed doubts about these claims.[41]

In addition to these efforts to acquire this direct knowledge for specific facilities, there are a variety of other mechanisms that have been used to less directly transfer knowledge to China. One relates to Chinese nationals studying overseas. There are several university-affiliated research institutes outside China where expertise in carbon fibre production rests. One expert suggested that such centres typically include lab-scale carbon fibre production facilities.[42] Experts highlight that while knowledge available in books could not teach an individual how to operate a production line, association with such a research centre could allow individuals to build expertise which could aid in operating commercial scale production lines in China.[43] It was highlighted however that such knowledge could not be directly extrapolated because of the differences in process conditions and equipment from a lab-scale setup to a commercial plant, thus highlighting the context-specific nature of tacit knowledge.

Controls on Carbon Fibre

As highlighted earlier, there are three primary state-led tools that could restrict the transfer of any technology. These are export controls, deemed export controls and student vetting schemes. The effect of each of these on the transfer of carbon fibre technology is considered.

Export Controls

Since 2004 when the UN Security Council adopted resolution 1540, all states have been required to adopt domestic export control systems, although there continues to be considerable variation in regard to the completeness and effectiveness of national implementation even amongst like-minded states.[5] For example, while the US makes extensive use of «deemed export controls» (see below), these do not appear in the relevant EU regulations. As highlighted above, there is also variation in national decision-making.

---

[36] Ibid, Expert 1.
[37] Ibid, Expert 3.
[38] Ibid, Expert 1.
[39] Carbon Fibre Eexpert 4, Interview taken by author, United Kingdom, 2013.
[40] Ibid, Hsu. “Developing Advanced Carbon Fiber in India: Process Technology Advancements for the Future,” Harper International. http://www.simco-groups.com/learning-center/carbon-fiber/developing-Advanced-Carbon-Fiber-in-india.pdf
[41] Ibid, Expert 1, Eexpert 3.
[42] Ibid, Expert 3
[43] Ibid, Expert 2.

While some countries such as the UK publish both licensing criteria and licensing statistics, most do not, and it is therefore difficult to know whether different national authorities approach the same cases in a comparable way. Certain cases such as the difference between US and EU approvals of licenses noted above, suggests there are differences. While this could be justified based upon different levels of risk tolerance in different capitals, clearly such variation between technology holders calls into question the effectiveness and legitimacy of the controls. How export controls affect carbon fibre indigenisation in China is explored below.

<u>Export of manufacturing equipment:</u> some, but not all equipment required for carbon fibre production is controlled and can only be exported to China with a licence issued by an appropriate national authority. The fact that manufacturing equipment from some counties has been authorised for export to China, whereas from others it has not, calls into question the effectiveness of these controls - certainly it can be concluded that these controls alone would not be sufficient to prevent Chinese acquisition of carbon fibre manufacturing capability. One interviewee highlighted attempts within China to produce manufacturing equipment indigenously, but stated that this equipment was deficient in capability and quality.[44]

<u>Export of intangibles technology:</u> The definition of technology used by the export control regimes means that the transfer of information from the exporting state to the recipient state via electronic means (i.e. via email or during a telephone exchange) in relation to otherwise controlled technologies could be considered controlled. One interviewee suggested that the licences issued by the US typically prohibit even the discussion of technology assistance, for example.[45] As such, a licence may be required before the transfer could take place. However, as has been highlighted, such explicit knowledge is insufficient to operate a carbon fibre production line in an efficient manner.

<u>Deemed exports:</u> (The transfer of knowledge to foreign nationals within the territory originating (no export actually takes place). Such 'deemed export controls' are a notable feature of US export laws but feature in the national laws of few other territories. Deemed exports potentially provide a transmission route for both tangible and intangible technology as the foreign national could become an integral part of an engineering team. Nonetheless, enforcement of deemed exports raises an immediate problem – is it proportionate to restrict the employment opportunities of foreign nationals through deemed export controls when any national could equally opt to move overseas after holding the same role? For this reason, outside the US, few countries operate deemed export controls on dual-use technologies.

<u>Technological assistance:</u> (by nationals provided via on-site consultation at the overseas facility[46].) Controls on technological assistance in most jurisdictions appear to be much less established than that of the other export control tools mentioned above. Technological assistance provides a clear route through which tacit knowledge can be transferred – indeed, in the Chinese carbon fibre case technological transfer appears to be one of the primary routes through which China could overcome that country's lack of mastery of carbon fibre. During interviews, it was revealed that there are only a handful of established companies (four) that provide such on-site services. This very limited supply base could lend itself to effective control, but this would require the governments in the territories in which those companies are based to adopt extraterritorial controls on the provision of technological assistance. There are limitations to the practicality of such controls, however. For example, it is unlikely that such controls could prohibit the right of individuals to take up foreign citizenship before conducting such technology transfer. Nonetheless, both individuals who provide this service and equipment manufacturers commented to the author that there is a great deal of 'self-policing' in this area, with consultants opting not to provide assistance with plants where it is apparent that a higher-performance (military grade) fibre is being sought.[47]

---

[44] Ibid, Expert 1.
[45] Ibid, Expert 3.
[46] For the purposes of this paper the term "nationals" has been used where the individual is a national of an exporting state whereas the term foreign national has been used where the individual is a national of the importing or acquiring state.
[47] Ibid, Expert 1, Expert 3.

Student vetting: Each year hundreds of thousands of students study undergraduate degrees in China and tens of thousands of Chinese students study engineering and science degrees outside China. The sheer scale of this highlights the broad availability of staff with the potential to work in support of carbon fibre production. Nonetheless, undergraduate engineering and science degrees intend usually to prepare individuals for a future career in a profession rather than to produce graduates who can immediately take on specific technical roles without further development and on-the-job training. It is perhaps for this reason that it typically takes a number of years to become a chartered engineer or scientist.

Postgraduate education and research, however, is often more focused or applied than undergraduate research and there is thus the potential for the researcher to assimilate tacit knowledge related to processes, techniques, materials, and equipment. Two points are worth noting here. The first is that applied research tends to focus on very specific issues rather than on broader technical issues like 'how to manufacture carbon fibre. The second, as suggested above, is that such research is often not readily transferable to a production environment.

Student vetting schemes provide a mechanism to review the course selections and backgrounds of international students. As implemented in the UK, student vetting is aimed at post graduate students who may be gaining applied rather than general knowledge in potentially sensitive fields.

Assessing the Capability Acquisition Model and Controls on Carbon Fibre

Before turning to address the effectiveness of technology controls on carbon fibre production technology, it is important to reiterate that it is not the purpose of the export control regimes to prevent a country like China from acquiring a capability. The regimes exist to prevent the proliferation of WMD and the destabilising accumulation of armaments. Licensing decisions are matters for individual states rather than the regimes, and it is possible that different countries could assess the risks associated with exports to China in different ways. Of interest to this study is not whether countries share an

assessment of the risks posed by China in this regard: licences have been both issued and refused, perhaps suggesting that they do not. Instead, the purpose of this analysis is to understand whether non-proliferation controls could be effective at constraining the acquisition of technology in the context of the Capability Acquisition Model set out above.

The case study reveals a complex picture. First, it appears that the Capability Acquisition Model does provide useful insight when understanding what is required to indigenise a capability, such as the production of carbon fibre. Interviewees highlighted the key constraint as being access to precursor materials, access to know-how, and access to equipment. Information, in the form of instruction manuals etc. was seen as of less importance. The need to progress from the use of pilot production plants to commercial-sized plants and the gradual improvement in fibre properties that can be gained over time as know-how increased also supports the inward spiral layers of the Capability Acquisition Model.
Having established that the Capability Acquisition Model is a useful tool for understanding the prerequisites to indigenisation, consideration can next be given to the potential effectiveness of controls on preventing acquisition in the context of the indigenisation of carbon fibre manufacturing technology. Export controls can, in theory, control, materials, equipment, information and know-how – the four elements of the Capability Acquisition Model. However, with regards to carbon fibre, there are no controls on precursor, which was identified by the interviewees as the single biggest constraint to production of high-quality carbon fibre. Controls on equipment appear to be well-standardised across the main supplier countries, although it is clear that different licensing authorities have reached different decisions on the same exports, which potentially undermines the controls.

To utilise Nonaka's framework that was presented above, it appears that controls are not well designed to control the transfer of intangibles. The controlling of 'technology' associated with the export of physical goods tends to mean that externalised information, such as instruction manuals and documentation are controlled even when the value of such 'combination' is less than the value of know-how, primarily because integration of explicit knowledge related to carbon fibre production is, at best, difficult. At the same time, control on know-how appears to be inadequate, allowing knowledge to be socialised. Presently, it appears that there are experts that are providing assistance to indigenisation efforts without the relative merits of this having been adequately considered by licensing authorities. While it would be difficult for a government to enforce rules on what information is transferred by a national while they are overseas, especially if the information is 'in their head' as opposed to in documents that they take with them, this nonetheless represents a weakness in the controls.

Overall, it is clear that carbon fibre is a particularly tacit-knowledge intense production process. While supply-side controls have had little effect in constraining the transfer of carbon fibre manufacturing capabilities, other factors have heavily constrained this transfer. Unfortunately it seems that controls are least suited to restricting tacit knowledge transfer even though tacit knowledge transfers offer perhaps the best supply-side control to prevent carbon fibre transfer. Given this, the apparent inequality in applying export licensing criteria should be considered. There are several sources of tacit knowledge that over a period of time will likely allow China to master carbon fibre production, albeit less quickly than officials would desire. It was perhaps with this in mind that one interviewee speculated that it would be only a matter of time (5-10 years) before Chinese producers mastered the technology.[48]

Conclusions: The Capability Acquisition Model and Supply Side Controls

Examination of the Capability Acquisition Model presented earlier highlights that for capability indigenisation to occur, three components would be required: equipment, materials and knowledge, where knowledge can be further divided into its explicit and tacit components. The framework then postulated that to realise a capability it would be necessary to iterate efforts. i.e. so that more knowledge would lead to better use of equipment which would result in better selection, understanding, and use of materials. And so on.

It may not matter where in this cycle one begins, be it with an idea, a piece of equipment, an understanding of a problem, or the material. Mastery of each is required to succeed. The carbon fibre experts prided themselves, after all, on being able to "get any production equipment to operate"; although this may require that they "revert to first principles." What is clear is that it is only with the coming together of knowledge, materials, and equipment that a capability can be realised. More than this, however, it is the acquisition of tacit knowledge that allows these assets to be utilised to achieve the desired capability.

This said, as the case study demonstrated, export controls as currently constituted, appear to have a limited ability to affect the transfer of manufacturing capabilities, even when supplier states wish to intervene. In particular, the controls are not well suited to control the transfer of tacit knowledge. While they currently do restrict the transfer of explicit knowledge, it is unclear whether controls on explicit knowledge are truly effective since companies for their own reasons do not publish 'cook-books', and even if they did, they would be of little use without the tacit knowledge required to tweak operating conditions.

More generally, the case study highlights that the effectiveness of export controls is fundamentally challenged by variance in national implementation. While the US appears to take the toughest line on the export of carbon fibre technology to China, not all countries have the same controls on technological

[48] Ibid, Expert 1.

assistance, for example; this would appear to fundamentally undermine the effectiveness of the unilateral US measures. This would suggest a rationale for limiting the application of controls to measures agreed by the various export control regimes, to which all major carbon fibre produces subscribe.

Broader Implications of the Capability Knowledge Model

This research helps to understand the implications of globalisation on the spread of technology. While it could be assumed that the advancement of mass communications associated with globalisation will result in technology becoming ubiquitous, the current research suggests that this may not be the case. There are substantial barriers to the indigenisation of capability, even if equipment, materials, and explicit information are available on how to manufacture a product. These barriers cannot be overcome by information available on the internet or via other communications media alone.

While information and communications may not short-cut the spread of know-how, it should nonetheless be recognised that the movement of people can do so. In the case of carbon fibre, the example of a plant operator moving to China is a case in point: this individual takes with him the know-how he had accumulated in his previous roles.

Future Research

This paper has developed a new Capability Acquisition Model which has proven useful in analysing the effect of supply-side controls on the spread of technology. Future work could usefully apply this model to other technological acquisition efforts. Of particular interest would be the fields of synthetic biology and precision metal parts, where automated processes such as additives manufacture (3d printing) are gradually displacing the need for skilled operators.