From bottle rockets to tomahawks: the production of anti-ship missiles, land attack cruise missiles, and short-range ballistic missiles

Nolan Fahrenkopf
University at Albany, State University of New York, nolanfahrenkopf@gmail.com
From Bottle Rockets to Tomahawks: The Production of Anti-Ship Missiles, Land Attack Cruise Missiles, and Short-Range Ballistic Missiles.

By
Nolan Fahrenkopf

A Dissertation
Submitted to the University at Albany, State University of New York
In Partial Fulfilment of
The Requirements for the Degree of
Doctor of Philosophy

Rockefeller College of Public Affairs & Policy
Department of Political Science
December 2018
Abstract

What explains the variation in the sophistication of states military production capabilities? This dissertation analyzes this broader question by looking at the development of production capabilities of an arms sector that has required constant innovation—anti-ship missiles (ASMs), land attack cruise missiles (LACMs), and short-range ballistic missiles (SRBMs). I theorize that military innovation is driven by a combination of supply-side factors involving scientific and technical (S&T) human capital and demand-side factors including security, economic, and normative motives. This dissertation explores the factors associated with the proliferation of ASMs, LACMs, and SRBMs as part of a three-essay dissertation. The chapters on ASMs and LACMs relies on new data on cruise missile production capabilities and leverages a new measure of cruise missile sophistication as my dependent variable. Large-n analyses are used to explore the factors associated with acquiring missile production capabilities of different levels of sophistication for both ASMs and LACMs. The chapter on SRBMs explores how states innovate through reverse-engineering foreign purchased missile systems. Together, the inquiries find that states acquire ASM, LACM, and SRBM production capacities through fear and science. Demand for these capabilities is driven by security threats. The ability to produce these weapons is dependent on scientific and technical human capital. Finally, the sophistication of states' missile production capacities is fostered by the diffusion of missiles and related dual-use technology and equipment into the system.
My dissertation is dedicated to my parents. Your kindness and endless love, support, and patience continue to mean so much to me. I lucked out having you as parents. Thank you.

Acknowledgments

No projects come to fruition without amazing dedication and support from mentors, colleagues, friends, and family. Mine is no different. First, I would like to thank my committee, Bryan Early, Victor Asal, and David Rousseau. This dissertation was completed right at the last step before the submission deadline. Despite this, my committee provided extensive support, ideas, and revisions, without which this dissertation would not have been possible. David was my undergraduate advisor and helped develop my interest in this field and guide me as my focus developed. I have worked with Victor since my very first semester of graduate school. Victor’s dedication to students is well known throughout the University at Albany. My research and my teaching have significantly benefited from his guidance. Despite his hectic schedule, I could always count on Victor. I would particularly like to thank my dissertation chair and advisor, Bryan Early. I have worked with Bryan since his first semester as a UAlbany professor. After my first semester with Bryan, he decided to trust a quiet undergrad to work on the National Space and Ballistic Missile Dataset. This work captivated me and provided me with the rare opportunity to perform advanced research at the undergraduate level. Throughout graduate school, Bryan has never shied away from going above and beyond in helping me, even as I spent the first few years playing a little too much frisbee. The opportunities he afforded me as a member of PISCES helped introduce me to the policy realm of nonproliferation. This proved instrumental in developing the knowledge and expertise for my dissertation. It was an opportunity very few academics, let alone graduate students get to experience. I genuinely do not believe I would be the academic I am today if you did not come to UAlbany. I can’t convey my appreciation and thanks for your years of support.
I am much indebted to the efforts and support of Jim Walsh and Mike Horowitz. Your support and contributions to our National Cruise Missile Dataset made this dissertation possible. Your thoughts and advice on how to best utilize the NCM data for my dissertation were invaluable.

I would also like to thank the entire PISCES team; Ryan Cathie, Jay Nash, Lara Howe-Stenberg and Richard Young. I have learned so much from working with all of you through PISCES. On each project I have worked on, all of you have had the patience to help me develop the understanding and skills of the policy side of nonproliferation — every trip and project I continue to learn more from you. I could not have asked for a better team to help me develop on my first “real job” outside of academia. I would also like to thank Richard Young in my work with SECURUS Strategic Trade Solutions. The knowledge I gained on the intricacies of nonproliferation and strategic trade control policy I learned while working under you was critical to this dissertation. My experiences and the lessons I learned at SECURUS are priceless, and I highly value them. I cannot finish this section without thanking Matt Ingram. Comparative Judicial Politics was the first time I truly began to care about learning Stata because you helped us replicate the findings from the articles we read. More classes should do that; it always stuck with me. You also have always taken time out of your busy schedule to help me with methodological questions on my dissertation or for other projects, thank you.

Finally, I would like to thank my partner, Allyssa Phillips. You read way more about missiles than I think you ever imagined you would (or wanted to). Also, as a fellow academic, you always provided phenomenal feedback. You helped me with statistics more often than I would care to admit, and you always helped me edit. This is all in addition to being a caring and sensitive partner who always had my back. Even if you make me run more than I want. Thank you.
Contents
Chapter One: Introduction ............................................................................................................................ 1
Missiles and Military Power ......................................................................................................................... 8
The Military Utility of ASMs, LACMs, and SRBMs ..................................................................................... 9
Missiles for Sale ...................................................................................................................................... 12
Building the Web: Experience Driving Proliferation ............................................................................... 13
Scientific, Technical, and Organizational Knowledge: The Ties that Bind .............................................. 14
Trends in Missile Proliferation ................................................................................................................ 16
Horizontal and Vertical Proliferation of Missile Production .................................................................... 19
Research Methods .................................................................................................................................. 23
Contribution and Policy Implications .................................................................................................... 24
Chapter Two: Horizontal Proliferation ....................................................................................................... 28
The Horizontal Proliferation of ASM and LACM Production ................................................................. 29
Research Methods .................................................................................................................................. 40
Dependent Variable ................................................................................................................................ 40
The NCM ................................................................................................................................................. 41
Independent Variables ............................................................................................................................ 42
Results ..................................................................................................................................................... 46
LACMs and GPS ....................................................................................................................................... 52
Conclusion ............................................................................................................................................... 53
Chapter Three: Going From Buyers to Suppliers ..................................................................................... 55
A Failed Case: Egypt ................................................................................................................................ 59
The Proliferation of Strategic Weapons .................................................................................................. 62
Theory ..................................................................................................................................................... 68
Research Design ...................................................................................................................................... 74
Dependent Variable ................................................................................................................................ 77
Independent Variables ............................................................................................................................ 77
Results ..................................................................................................................................................... 82
Conclusion ............................................................................................................................................... 86
Chapter Four: Stealing from the Best: The Determinants of the Vertical Proliferation of Cruise Missile Production .................................................................................................................. 89
Introduction ............................................................................................................................................... 89
Buzz Bombs to Tomahawks The development of ASMs and LACMs ..................................................... 92
Chapter One: Introduction

October 21, 1967, less than five months out from two successful engagements during the Six Day War, the INS Eilat was engaging in a patrol near the Egyptian port of Said. Despite warnings from Israeli intelligence that the Egyptians were planning an attack, Lieutenant Colonel Yitzhak Shoshan was unconcerned by the presence of Egyptian Komar Missile boats (provided by the Soviet Union). He had already engaged and sunk, two such craft during the Six Day War. Egypt fired no missiles then; there was little reason to believe they would now.

The Egyptian missile boats, with the help of Russian advisors, had been tracking the Eilat all day. When the Russian's felt they had a clear shot, they allowed the Egyptians to fire. The Russian built P-15 A, or Styx missiles were early generation anti-ship missiles (ASMs). ASMs can be either air-breathing jet engine or rocket-powered missiles used to target naval vessels from a significant distance. They are autonomous and can be devastating to even large surface vessels. The Styx missiles had a range of roughly 25 nautical miles, a speed just under Mach 1, and a 480kg warhead. Shortly after 1700, an Eilat signalman spotted the distinctive burst of light and missile trail coming from Port Said. Shoshan immediately gave the order for evasive action. As the Eilat zigzagged, desperately trying to evade the missile, the Captain determined that the Eilat have succeeded. The Styx appeared to have shot right out into the Mediterranean. They were wrong. At six nautical miles out, the missile activated its active homing and immediately locked onto the Eilat. The missile quickly changed course, heading straight for the

---

1 Kahana 2006, 85
3 Global Security Eilat Destroyer
4 Friedman (2006)
helpless Israeli destroyer. Despite attempts to shoot it down with anti-aircraft weapons, the missile struck the Eilat astern. Egypt quickly launched a second missile, which landed midship. Hours later the Eilat was struck again, this time the missile hit ammunition and fuel stores, furthering the ship’s demise. The Eilat sank, and 47 Israeli sailors lost their lives. While the Arab world celebrated, naval planners both in Israel, and the world over began to realize that anti-ship missiles posed severe problems.

The sinking of the Eilat showed the world that anti-ship missiles, a relatively cheap stand-off weapon, could threaten superior surface ships, and were effective against Western naval technology and strategy. The effectiveness of French Exocet ASMs during the 1982 Falklands War against the UK only served to reinforce the usefulness of ASMs, even against a great power with a much more powerful surface fleet. Weaker states view ASMs as a "poor man’s navy," a cheap and effective way of countering great power surface fleets. ASMs are an equalizing weapon that weak states can use to help resist power projection by more powerful states. ASMs do this through anti-access (A2) and area-denial (AD) properties that make it difficult for foreign surface fleets to engage in combat and support operations off foreign coasts. ASMs are an essential counter to one of the main strategies that more powerful states rely on when intervening militarily against weaker powers. However, possession of these weapons is often only the first half of the story, despite their great benefits, there are limitations to mere possession.

The Eilat is not the last time Israel faced off against Arab missile boats. Israel, like many states, was quick to heed the lessons learned from the Eilat sinking. Israel hurriedly sought to develop their ASM, the Gabriel. By 1970, Israel was one of the first states to develop an anti-

---

5 Kojukharov 1997, 122.
6 Horowitz (2010), 83
ship missile. The Gabriel was a highly advanced missile, and one of the first sea skimming ASMs. It had a top speed of just under 500 mph, a 533 kg warhead and a range of 21 km. However, what truly separated the Gabriel from the Styx missiles in the arsenals of Syria and Egypt was its advanced sea skimming capabilities, which allowed it to fly a mere 5-10 meters off the surface. It also had resistance to electronic and other countermeasures. These made the Gabriel Mk-1, used in the Yom Kippur war of 1973, one of the first genuinely modern ASMs. Moreover, it showed.

While the SS-N-2 Styx ASMs used by Egypt in the attack on the Eilat were cutting edge at the time, they were difficult to set up and took much time to fire due to their reliance on gyroscopes. They also lacked effective resistance to countermeasures, sea skimming, and other survivability upgrades. These missiles were first generation weapons that quickly became useless against anything but defenseless ships. The 1973 Yom Kippur war demonstrated this point very clearly. Egypt and Syria were armed with the same ASMs that sunk the Eilat 6 years before. Israel was armed with vast quantities of the domestically produced and significantly more advanced Gabriel ASM. The Soviet Union had more advanced systems at the time of the war but had not delivered them to Egypt or Syria.

On October 6th, 1973 off the coast of Latakia, the Israeli and Syrian navies engaged in the first-ever naval combat between two ASM armed vessels. It was a one-sided affair. The Israeli Gabriel missile proved significantly more effective than the Egyptian and Syrian Styx. Eleven missiles sank 4 Syrian vessels. 8 Syrian Styx missiles failed to even hit an Israeli ship due

---

7 Carus 1992, 35
8 Sea skimming is an incredibly significant survivability upgrade for ASMs. Sea skimming allows the missile to fly incredibly close to the surface, often time only a few meters above. Missiles with sea-skimming capabilities are incredibly difficult to detect, spot, and shoot down.
9 Chant 2013, 511
10 Chant 2013, 511
to advancements in electronic chaff countermeasures.\textsuperscript{11} The Egyptians did not fare much better. At the battle of Baltim, the advanced range of the Styx missiles was meaningless for the Egyptian ships. They fired at the Israeli ships before Israel could return fire and then took a hasty retreat to the shore.\textsuperscript{12} Israeli forces closed the gap and fired 12 Gabriel missiles. Six missiles struck and sank 3 Egyptian ships. Egypt fired 16 Styx missiles, none hit.\textsuperscript{13} Israeli success was the norm for anti-ship missile combat during the Yom Kippur war. Compared to the success of the Gabriel, Egyptian and Syrian forces landed no hits out of 47-55 missiles fired.\textsuperscript{14} In 6 years, the Egyptian and Syrian anti-ship missiles were made obsolete against Israeli naval vessels.

Meanwhile, Israel's domestic production of the Gabriel anti-ship missile created a more modern and capable anti-ship missile than it would have been able to import at the time. Unable to import newer ASMs from the USSR, or produce their own, Egypt and Syria entered the Yom Kippur War with the same missiles from before. Israel, learning a hard lesson from the INS Eilat was able to jumpstart an ASM missile program from an \textit{entirely different} missile system, that led to the production of one of the first modern, sea-skimming ASMs. In six years, Israel designed, produced, and deployed the Gabriel ASM. The Gabriel ASM helped change the course of the war and demonstrate the power that ASMs could bring to bear in a military conflict. Egypt and Syria meanwhile were left empty-handed and on the losing side of another conflict with Israel, their inability to produce a more modern ASM partly to blame.

\textsuperscript{11} Schulte 1994, 5-6  
\textsuperscript{12} Schulte 1994, 6  
\textsuperscript{13} Ibid  
\textsuperscript{14} Ibid, 8
ASMs are but one missile system upon which modern militaries are reliant upon to compete in the international system. Missiles have evolved to become one of the most important components of any modern fighting force. Modern militaries rely on missile systems for both offensive and defensive purposes, in the air, on the ground, and for surface and sub-surface naval forces.\textsuperscript{15} Despite this, policy makers and academics have given little thought to the wide variety of missile systems that greatly influence national power and military capabilities. Most policy and academic work have focused on advanced strategic missile systems, particularly long-range ballistic missiles (LRBMs). LRBMs are well deserving of the attention they receive given their strategic capabilities and balance of power altering potential.\textsuperscript{16}

Solely focusing on LRBMs misses the important tactical and proliferation role played by other missile systems. By focusing on what is often a strategic weapon and only one stage of a state’s proliferation, policymakers and academics are missing three critical components of understanding a states military power and capabilities. First, missile systems such as anti-ship missiles (ASMs), land attack cruise missiles (LACMs), and short-range ballistic missiles (SRBMs), provide states numerous tactical and strategic advantages, which have received little attention in the literature. Second, states that gain production capabilities become suppliers, increasing global proliferation, and can use the lessons from the scientific, technical, and production advances these programs bring to develop more advanced strategic missile and other related systems. If arms proliferation is a web, the ability to produce these systems are essential threads for any state with higher ambitions. Finally, proliferation does not end with acquisition.

\textsuperscript{15} Karp (1996); Gormley (2008); Gormley et al (2014); Mistry (2003); Early and Fahrenkopf (2017); Early et al (2017).

\textsuperscript{16} See Karp (1996); Mistry (2003); Nolan (1991).
Not all weapons, even nuclear weapons, are created equal. The vertical proliferation of weapons production within states is an equally important part of proliferation.

Just as there are spillover benefits from producing missiles, there are both costs and benefits for purchasing them. The most straightforward proliferation pathway for ASMs, LACMs, and SRBMs, is purchasing them. These systems are available from multiple producers along with a variety of levels of sophistication. For instance, France and the UK have sold their Storm Shadow missile to numerous states. The Storm Shadow is one of the most advanced LACMs available for purchase. France and the UK made these sales over loud protests from the United States that these missiles were too advanced to be available on the export market. Despite this, there are severe costs to relying on foreign providers. First, there is no guarantee that states can rely on foreign suppliers for weapons. Second, there are serious issues about the number of weapons available and access to a constant supply. This issue became all too apparent to Argentina during the Falkland War. Additionally, despite the export market having advanced missiles, they are often at least a generation below the most dominant weapons in the system. This issue plagued Egypt and Syria during the Yom Kippur War.

Given how the reliance on foreign suppliers can hurt states’ security environment, a simple solution would be to produce them domestically. This is no easy task. States’ seeking domestic production capacities face not only economic and industrial barriers to production but more importantly knowledge and experience barriers. Producing these weapons requires massive investment in scientific and industrial military complexes (SMICs) and scientific and technical human capital (S&T). These combined with the important role played by organization experience and knowledge make it incredibly difficult to produce these weapons domestically. States' may seek a shortcut toward domestic production by gradually reverse-engineering foreign
acquired weapons, this was the path taken by North Korea in its ballistic missile production efforts.

Israel’s success and Egypt and Syria’s failure leads to a broader question: *what explains the variation in the sophistication of states’ military production capabilities?* I analyze this question by looking at the development of production capabilities of a particular arms sector that has required constant innovation—anti-ship missiles (ASMs), land attack cruise missiles (LACMs), and short-range ballistic missiles (SRBMs). Undeniably, these weapons are in and of themselves important; I seek to also apply lessons from the production of these weapons to proliferation more broadly. Understanding these weapons, which are lower down the strategic ladder than nuclear weapons, chemical weapons, biological weapons, and LRBMs can help provide a broader understanding of the proliferation mechanics of all strategic weapons. Producing ASMs, LACMs, and SRBMs can be considered the first step states take in the proliferation process. These first steps and the connections between these programs and more advanced weapons is essential. Each of these missile systems has unique tactical and strategic roles, and resource demands. Their proliferation has distinct elements. Despite this, they share a common core of utility and production requirements with each other and other strategic weapons. This common core serves as the basis for developing a broader and interconnected understanding of proliferation.

The proliferation of literature and policymakers have struggled to integrate the difference between horizontal and vertical proliferation. By focusing only on horizontal proliferation, we are missing an essential part of proliferation and military power. What happens once states acquire a weapon system? Not all weapons are created equal, not in the resources required to build them or their power. North Korea's initial acquisition of LRBMs and nuclear weapon
production capabilities is incredibly essential. However, focusing on this first step in proliferation misses out on what is arguably more important, how North Korea utilizes this production capacity to develop more powerful and threatening weaponry. This dissertation tackles this question by looking at how states vertically proliferate once they acquire ASMs and LACMs. Given the spillover from different weapons programs, the determinants of the vertical proliferation of ASMs and LACMs may also influence the vertical proliferation of other systems.

**Missiles and Military Power**

While ASMs, LACMs, and SRBMs often lack the strategic punch of WMDs and LRBMs they possess three essential characteristics that demand further study. Compared to fighter and bomber aircraft they are often cheap and effective means to engage in anti-access (A2) and area-denial (AD) operations. A2 and AD weapons provide states with significant tactical and strategic capabilities. A2 weapons seek to target areas of deployment such as surface fleets, forward operating bases, and other key fixed targets that are critical to the logistical and support operations before combat takes place. AD is similar to A2, but instead of seeking to entirely prevent the free mobility of enemy forces outside of one's area of control, AD seeks to control the movement of enemy troops within states defended battlespace. Most AD weapons seek to maintain naval parity in areas under their control and strike enemy forces as they are entering the defender's battlespace before they can disperse.

---

17 Out of the three conventional systems of this dissertation LACMs have the most in common with more traditional strategic weapons. LACMs, in their initial forms within the US and USSR arsenals, were strategic nuclear delivery systems. They often still fill this role, but their more extensive proliferation and technological sophistication has also turned them into more commonly accepted conventional strike munitions.
18 Krepinevich et al. 2003, 4
19 Ibid, 5
ASMs, LACMs, and SRBMs are easily bought on the open market. Their inexpensive per unit cost as compared to weapons that do a similar job, and the ease of acquiring the requisite knowledge technical components for maintaining and deploying these weapons. This wide availability helps fuel the diffusion of more sophisticated variants and components throughout the system. This wide availability is like a Pandora's Box. The flow of advanced systems, components, and the requisite expertise that comes along with these weapons and their sales lead to technological diffusion, which in turn significantly decreases the costs associated with maintaining a closer level of technological parity.

Finally, proliferation is not one great leap; it's an interconnected web. States that pursue increasingly sophisticated weapons and production capabilities are reliant on the combined strength of their experience in the production of arms and their related technologies. The intangible benefits that experience in the field of arms production provides states can help them more quickly develop more advanced weapons. Israel's missile program, though not focused initially on ASMs, was able to quickly translate the scientific, technical, and organizational knowledge and experience into essential advances in its work on the Gabriel ASM. States that can successfully produce these mid-level missile systems will have a significant advantage in producing not only more advanced and threatening variants, but also more advanced missile systems, such a strategic WMD delivery systems.

The Military Utility of ASMs, LACMs, and SRBMs

A2 and AD are both incredibly important components of any military fighting force. A2 is the ability to limit an enemy force from entering a theater of operations. China has focused

20 Krepinevich et al. 2003, ii
extensively on this to counter the traditional dominance of US naval power, which allows the US to intervene nearly hassle-free across the world. By denying freedom of action, states make it significantly more difficult for would-be aggressors to conduct military operations. A2 weapons seek to target areas of deployment such as surface fleets, forward operating bases, and other key fixed targets that are critical to the logistical and support operations before combat takes place.\textsuperscript{21} AD is similar to A2, but instead of seeking to entirely prevent the free mobility of enemy forces outside of one's area of control, AD seeks to control the movement of enemy troops within states defended battlespace.\textsuperscript{22} Most AD weapons seek to maintain parity in areas under their control and strike enemy forces as they are entering the defender's battlespace before they can disperse. ASMs, LACMs, and SRBMs provide states deterrence by denial capabilities cheaply and quietly. States that can produce their missile systems are even better off.

The A2 and AD capabilities of these weapons have been proven effective time and time again. US forces in the First Persian Gulf War were so concerned with Iraqi Scud weapons that they were hesitant about an invasion, and the absorption of Iraqi Scud attacks eventually took roughly 25-30 percent of the entire allied war effort.\textsuperscript{23} A primitive Iraqi SCUD variant even killed 28 American soldiers in a successful strike on the Dhahran airbase in Saudi Arabia.\textsuperscript{24} SRBMs present states with a cheap and effective way to cut through air defenses and deliver conventional and WMD munitions, at a significantly smaller cost.\textsuperscript{25} Crude Iraqi ASMs converted into LACMs also played a role in affecting Coalition forces in the Persian Gulf War.\textsuperscript{26} Though no U.S. forces or equipment were lost in the 2003 invasion, U.S. military planners still

\begin{thebibliography}{9}
\bibitem{21} Krepinevich et al. 2003, 4
\bibitem{22} Ibid, 5
\bibitem{23} Karp 1996, 46
\bibitem{24} Gormley 2008, 117.
\bibitem{25} Nolan (1991) 71-73.
\bibitem{26} Gormley (2008), 19, 118.
\end{thebibliography}
considered SRBM and LACM forces a significant concern, and may have been fortunate that Iraq lacked a sophisticated production capacity for either at this point.\textsuperscript{27}

Iran is an excellent example of a state that has benefited from its efforts in conventional missile production. In the past twenty years, they have made significant strides in their missile production efforts.\textsuperscript{28} Part of Iran's success is due to the initial failure of the US and other proliferators to recognize the strategic implications that conventional missiles can have. Iran's use and growing expertise in missile production represent a legitimate strategic benefit for them against major powers that may attempt to intervene in their regional affairs. We are beginning to see the results of this process throughout the Middle East.

Iranian ASM and SRBM production have allowed them to export ASMs and SRBMs throughout the region. Houthi rebel groups in Yemen, Hezbollah, and Syria are some of the beneficiaries of Iranian missile production efforts. Houthi rebels have used Iranian ASMs to target U.S. and Saudi Coalition warships and shipping in the Gulf of Aden. Iranian missiles were used in at least two successful ship attacks.\textsuperscript{29} Houthis have also used SRBMs to target strategic and civilian targets deep in Saudi Arabia. Lacking an air force SRBMs provided by Iran or stolen from previous Yemeni military stores create a cheap form of strategic strike capability.\textsuperscript{30} Iranian made ASMs have also been provided to Hezbollah. These ASMs dealt severe damage to an Israeli naval frigate in 2006, demonstrating the continued power these weapons can bring to bear against more powerful foes.\textsuperscript{31}

\textsuperscript{27} Gormley (2008), 18-19, 117-118
\textsuperscript{28} Nuclear Threat Initiative, Iran (2017); The Iran Primer (2015).
\textsuperscript{29} Trevithick (2017); Schmitt (2018); Trevithick (2018).
\textsuperscript{30} HIS Janes Intelligence Review (2018); Human Rights Watch (2018).
\textsuperscript{31} Mazzetti and Shanker (2006).
Missiles for Sale

ASMs, LACMs, and SRBMs, while widely available are subject to controls, albeit many informal. There have been efforts to control the spread of these weapons systems. SRBMs, ASMs, and LACMs fall under the authority of the Missile Technology Control Regime (MTCR) and the Wassenaar Arrangement. Also, like ASMs, the problem of extensive proliferation by dominant powers undercuts the utility of the MTCR and other nonproliferation efforts. The United States, one of the leading proponents of the MTCR, is very active in the international arms market for SRBMs, ASMs, and LACMs. The United States widely exports the MGM-140 ATACMS SRBM. The United States, Russia, China, North Korea, Libya, Egypt, and many other states have all had active roles in the proliferation of SRBMs and their associated technologies. There are even more significant numbers of producers for ASMs and LACMs. A large number of suppliers and lack of a suitable regime or norm promoting/controlling the spread of ASMs, LACMs, and SRBMs has made these systems reasonably easy to acquire. It is estimated that a military budget of just 2.5 billion dollars if allocated consistently and adequately for many years, is enough to both acquire and produce SRBMs.32

My experiences at two arms expos The Air Sea and Space Expo, 2015 and the AUSA Annual Meeting and Exposition 2016, provided valuable insights into how missile producers market and sell their weapons systems. At these arms expos, timid compared to many others throughout the world, ASMs, LACMs, and SRBM systems were openly marketed for sale to thousands of participants from the armed forces and defense ministries of countless nations.33 As expected, the expos had numerous missile systems from the defense industries of the major industrialized nations. The top of which were responsible for over 60% of arms exports from

32 Karp (1996).
33 Author Research and Notes
There were also relative newcomers to the missile market, such as the Turkish SOM LACM and ASM, a joint venture between the Turkish Defense Industries Research and Development Institute, and Roketsan. The capabilities of these missile systems are becoming increasingly advanced, and continue to push the guidelines set by multilateral control regimes such as the Missile Technology Control Regime (MTCR). One industry official explained that the MTCR plays little to no role in sales decisions. This response was concerning considering the missile capabilities exceeded the MTCR category I guidelines.

ASMs, LACMs, and SRBMs are widely proliferated and benefit from gaps in the non-proliferation regimes and easy access in the open market. Though these weapons fall under many multilateral control regimes, such as the Wassenaar Arrangement and the MTCR, they often fall below any presumption of denial transfer guidelines. ASMs, LACMs, and SRBMs have benefited from the dual-use nature of their technical components and Western arms companies' readiness to sell them. Transfer of dual-use technology and technical information, the flow of education and technical and scientific knowledge across borders, and the "synthesis of multiple weapons and systems" continue to provide a leg up to states seeking to produce or acquire these missile systems.

Building the Web: Experience Driving Proliferation

The interconnected nature of weapons proliferation is not a new concept. Weapons proliferation, particularly nuclear proliferation, has been thought of like a ladder. States climb a complex

---

34 Fleurant et al. (2016).
35 "SOM Stand-Off Missile," Roketsan,
36 Author Notes from The Air Sea and Space Expo, 2015.
37 Hoyt 2001, 46-47
ladder that entails scientific and technical advances, organizational development, experience, and lobbying, and ends with acquisition. Different states sit in different spots on the path to nuclear weapons. The concept of nuclear latency helped to underscore the concept that proliferation is not a binary concept, it is a complex and interconnected path.

I argue that proliferation is more linked than a ladder would imply. Proliferation is a web. States abilities and experiences in one field are connections that strengthen the proliferation capacity web altogether. Early and Way (2017) found support for this idea when they found that there is a positive spillover effect on a state’s ability to acquire nuclear weapons from the length of time, they had ongoing military rocketry R&D programs.38 This spillover makes sense considering the investments states need to make to produce strategic weapons. In addition to financial and industrial resources, states require SMICs and S&T human capital to design, develop, produce, and deploy weapons systems. S&T human capital is a stronger means to capture states capacities to embark on rigorous research and development projects successfully. S&T human capital captures the scientists, engineers, technicians, tacit knowledge, connections, and experience that states can bring to bear on large-scale research and development projects.39 Investments in SMICs and S&T and the organizational experience that comes with these programs is not zero-sum. They have a significant spill over into other fields.

Scientific, Technical, and Organizational Knowledge: The Ties that Bind

At the onset of the Falkland War between Argentina and the UK, Argentina had only five air-launched Exocet ASMs. Their ground-launched missiles were generally out of range of the

38 Early and Way (2017)
39 Bozeman and Mangematin (2004); Bozeman et al. (2001).
British naval fleet, though one ground-launched Exocet successfully struck the HMS Glamorgan.40 Argentina was struggling with properly deploying their Exocet missiles due to issues with the launch platform. Though France mostly observed the arms embargo,41 Dassault, the French producer of the Exocet, and 51 percent owned by the French government had a team in place that provided technical support to Argentina to help them successfully launch the Exocet missiles.42 While Argentina does not produce ASMs, this experience demonstrates the incredibly important role that technical capital plays in the operation of missile systems, and how the technical support that comes with missile sales helps to develop the technical and human capital of the recipient state.

The multilateral export control regimes have caught up to the critical role played by scientific and technical capital in proliferation. The Wassenaar Arrangement defines technology as a broad concept that covers much of these concerns. Technology is defined as:

Specific information necessary for the "development," "production" or "use" of a product. The 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 a disk, tape, read-only memories. 'Technical assistance' may take forms such as instruction, skills, training, working knowledge, consulting services. 'Technical assistance' may involve the transfer of 'technical data.'43

40 Cobain (2017).
41 There were, and still are, suspicions that France was intending to circumvent the embargo by delivering Exocets and super Etendard fighters to Peru, which would most likely transfer them to Argentina.
42 Thomson (2012); Tweedie (2012).
43 — the Wassenaar Arrangement Secretariat (2017).
This definition encompasses a wide range of things that help states foster their scientific and technical prowess. Scientific, technical, and organizational (STO) capital and the knowledge and experience that they provide are incredibly crucial to proliferation. Each attempt to climb toward more advanced weapons systems is strengthened by the level of knowledge and experience derived from these three intangible concepts.

Despite the vital role played by STO capital for advanced military projects, there is a little linkage in the literature between the role such experience plays in the broader proliferation universe. This dissertation will help provide the proliferation literature with an additional benchmark for measuring STO capital and displaying the link between different proliferation projects reliance on STO capital. If proliferation is a web, the ability of states to produce, and their level of production sophistication for LACMs, ASMs, and SRBMs should provide an important indication of their ability to bring STO capital to bear on other projects.

**Trends in Missile Proliferation**

Over 80 countries possess some variant of ASMs, though the levels of sophistication, range, and payload vary widely. Out of these 80, roughly 19 have some form of domestic production capacity. ASMs have numerous producers and, more so than the other weapons in this dissertation can be considered to be a "requirement" for modern militaries. Over the past twenty years, an increasing number of states have come to adopt ASMs, despite lacking a traditional security need. For example, Mexico has purchased numerous advanced U.S. Harpoon Block 2 ASMs. The weapons are viewed as critical for national security and to "combat criminal
organizations." A dubious explanation, given the Harpoon's primary application, is for use against larger modern warships.

Map 1.0

Though less so than ASMs, SRBMs are still widely proliferated. Today, roughly 26 states possess SRBMs. Out of these 26, roughly 14 have some form of domestic production capacity. At one time, though, this number was higher than 30.45

---

45 Early and Fahrenkopf (2017)
LACMs have not proliferated as broadly as ASMs. Part of this is likely due to their relatively new entry as a dual-role strategic and conventional system. Initially, due to wild inaccuracy and inconsistency, LACMs were viewed merely as an additional nuclear delivery system. As navigation technology advanced through the late 1970s and early 1980s, this attitude began to change. The introduction of GPS and discontinuation of required degradation for non-U.S. military systems in 2000 has spurred a dramatic increase in LACM systems. The introduction of GPS land-targeting systems has primarily driven this increase into existing ASM systems. Today, roughly 35 states possess LACM systems. Out of these 35, roughly 16 produce their variants.

---

Map 3.0

Horizontal and Vertical Proliferation of Missile Production

These proliferation stories are linked together by a common thread. To better understand this connection, this dissertation builds its foundations upon two interconnected questions for each stage:

- **Horizontal Proliferation**
  - What role does the security environment play in states initial acquisition of advanced conventional missiles?
  - Resources vs. Know How: In states' initial acquisition efforts, what plays a more important role: raw capabilities or specific scientific, organizational, and human capital?

- **Vertical Proliferation**
  - Once a state acquires a production capability for an advanced conventional missile system, what role does the initial security environment play in driving continued work in producing more advanced missiles?
  - Know How vs. Time: As time goes on what plays the most significant role in states increasing their missile production sophistication, technological diffusion over time, or specific scientific, organizational, and human capital?
Focusing on these two different aspects of proliferation reveals insights into understanding not only which countries acquire the ability to produce missiles but how sophisticated the missiles systems they gain the capacity to build. The dissertation is split into three separate essays. The theoretical foundation of each essay explicates the role that states’ security environment and national capabilities play in their ability to gain initial production capacities and to continue to develop more advanced ASMs, LACMs, and SRBMs.

Essay one, "The Horizontal Proliferation of Cruise Missiles," looks at the horizontal proliferation of LACM and ASM production. The findings for the first stage of the analysis, horizontal proliferation of ASMs, reflects the critical role that the security environment plays in a state's decision to develop an initial production capacity. Of additional importance is the size of a state's domestic defense industry. States with pertinent security concerns that have existing organizational and technical capacity in the field of weapons production are more likely to pursue and acquire ASM production capabilities. The horizontal proliferation of LACM production has similar empirical findings as their ASM counterparts. The security motivation driving LACM production is the acquisition of nuclear weapons. The vital role played by the acquisition of nuclear weapons presents an interesting duality to these results. Significant security concerns drive nuclear proliferation but also signals that a state most likely has a significantly advanced organizational, economic, scientific, and industrial capacity. The incredibly important role played by nuclear weapon possession in the horizontal proliferation of LACMs is most likely influenced by both points. Also, the horizontal production of LACMs is
also influenced by the organizational and technical capacity of states in the field of missile technology.

Essay two, *Going from Buyers to Suppliers: The Reverse Engineering of Short-Range Ballistic Missiles*, takes a different route and focuses exclusively on the horizontal proliferation of SRBM systems. The essay uses a form of medium n analysis known as qualitative comparative analysis (QCA) to determine which factors and pathways lead states to reverse engineer foreign acquired SRBM systems within a ten-year window. The horizontal proliferation of SRBMs through reverse engineering demonstrates the true duality between the supply and demand aspects of proliferation more clearly than ASMs or LACMs. For states to successfully reverse engineer SRBMs, they require *specific* scientific, technical, and organizational capital more so than traditional benchmarks of national capabilities such as economic size and industrial capacity. The security environment for the pursuit of SRBM production plays a more significant role than in the other two cases. Like the LACM case, nuclear weapons play an essential role in the horizontal proliferation of SRBMs as well. Nuclear weapon exploration rather than acquisition is influential in states that reverse engineer SRBM technology within a ten-year window.

Essay three, *Stealing from the Best: The Determinants of the Vertical Proliferation of Cruise Missile Production*, investigates the vertical proliferation of LACMs and ASMs. The vertical proliferation of ASM production presents a more complicated picture than the horizontal analysis. The Snark was a U.S. LACM that was notorious for poor accuracy. Many crashed in the ocean after unsuccessful tests, an inaccurate and early ancestor of modern LACMs. While security
motivations play an essential role in a state's first steps toward production, they are not pertinent in a state continuing to produce more advanced missiles. Instead, the most consistent driver of a states' missile production sophistication is time, and the continued diffusion of more advanced ASMs and LACMs throughout the international system. There is also limited support for the benefits of organizational and scientific and human capital in the field of weapons production. This finding paints a grim portrait for nonproliferation policies. Once states cross the initial production threshold, the ability to prevent continued advances becomes increasingly difficult. The vertical proliferation of LACMs deviates partially from ASMs. While security concerns seemingly play little role in the vertical proliferation of ASM systems within states, security concerns, in the form of states with nuclear weapons seeking additional delivery systems, plays a continued role in states continuing to produce more advanced LACMs. Curiously, for LACM vertical proliferation specific scientific, technical, and organizational capital take a backseat to a traditional measure of national capabilities, economic size. The one constant between ASM and LACM vertical proliferation remains time and the diffusion of more advanced LACMs into the international system.

Together, the cumulative findings in these three essays support the broader proliferation literature’s increasing acceptance of the importance of specific and relevant scientific and technical knowledge and organizational capacity as a vital determinate of proliferation capabilities.48 Despite this, the ability to produce these weapons alone is not enough to push states to accept the costs associated with their production, security concerns, and for ASMs, potentially economic motivations, are required for states to take this step.

**Research Methods**

This dissertation employs a mixed-method approach, relying on large n quantitative analysis for the ASM and LACM essays and medium n quantitative comparative analysis (QCA) for the SRBM essay. The quantitative analysis utilizes data on approximately 200 countries from 1950-2008. The data for the SRBM essay relies on data compiled by the National Space and Ballistic Missile Dataset.\(^49\) Data for the ASM and LACM essays were compiled in part for this dissertation and in part for the National Cruise Missile Dataset.\(^50\) This data collection effort compiled data on the ASM and LACM possession and production capabilities of all states in the international system. Data was collected on the universe of different ASM and LACM systems, where they have proliferated too, who produces them, and some different capabilities for each missile system. The data from this dissertation represents the first dataset to collect the universe of ASM and LACM missile systems, their producers, possessors, and technical capabilities. This data was used for both the horizontal and vertical proliferation models for the essays. For the vertical proliferation models, missile capability data was used to create a sophistication index for each missile to broadly measure each missile systems level of technological sophistication and military value. Data was acquired through some interviews with defense industry employees, experts, and military personnel at two arms expos, The Air Sea and Space Expo, Washington D.C. 2015 and the AUSA Annual Meeting and Exposition 2016. This data contributed partially to the broader datasets and provided valuable insights into how these weapons systems operate, are developed, and proliferate.

---

\(^{49}\) Early and Fahrenkopf (2017).
\(^{50}\) Early et al. (2017).
Contribution and Policy Implications

This dissertation makes both theoretical and empirical contributions to the literature on proliferation, the role of technology in international security, and military power. The general findings help to explain the complicated relationship between states demand for and ability to supply the required resources to produce advanced military technology. Supply-side explanations for proliferation have traditionally focused on a state's national capabilities. Unfortunately, the theoretical and empirical employment of national capabilities has often employed too broad of a brush. Such imprecision misses the nuances required to understand the complex requirements that different advanced weapon systems require. This failure prevents academics and policymakers from having a proper understanding of how states that possess a clear demand for a weapons system successfully proliferate.

These findings further support the developing notion that states outside of the most developed nations can focus on the specific scientific, technical, and organizational requirements that these weapons demand and make great strides in horizontal and vertical proliferation.\(^{51}\) This experience can be leveraged to extract technological advances with little resources. The successful proliferation stories of traditionally "weak" states such as Iran and North Korea demonstrate this concept. This dissertation reinforces the academic and policy shift toward focusing on the role of scientific and technical capital, tacit knowledge, and ideas play in the proliferation of weapons and technology.

These results are directly relevant to the non-proliferation policy-making community. Policy makers need to account for the increasingly important role that intangible resources play in both horizontal and vertical proliferation. Such controls have begun to make their way into the

control lists of major multilateral export control regimes and national control lists. The findings within this dissertation validate the evolution of these policies and should encourage policymakers to develop such policies further and assist in their universal implementation and enforcement.

One of the primary contributions of this dissertation project was the collection of the universe of LACM and ASM systems. This collection effort was part of the National Cruise Missile Dataset project.52 Before this dissertation and the NCM, there was no universal database of states ASM and LACM capabilities. This dissertation project also sought to expand upon the cataloged technical capabilities of each missile system to provide a complete portrait of the capabilities of each system and the proliferation of individual missile capabilities. This will provide academics and policymakers an important tool for understanding the proliferation of these systems as well as the proliferation of individual technological capabilities that make these systems more advanced.

Developing a sophistication score that captures the sophistication of individual missiles and states production capacities is an important contribution to the proliferation and military power literature. Much of the proliferation literature considers proliferation to be binary variables. States possess a given system, or they do no. By capturing how powerful individual weapon systems are, the vertical chapter makes two important contributions. First, by capturing the sophistication of states missile production capacities, we capture the second stage of proliferation. The findings on diffusion playing a large role in vertical proliferation highlight how access to missile systems and related dual-use technology and knowledge fuel proliferation. This supports the increasing policy focus on controls on dual-use goods and intangible technology and knowledge.

---

52 Early et al (2017)
Finally, the ability to catalog and empirically measure the level of sophistication of these missile systems allows policymakers and academics to have a more realistic understanding of the role these weapons play in the international system. Political and military leaders do not think of their weapons capabilities in binary terms. Iran’s ability to produce ASMs, LACMs, and SRBMs is a major concern for U.S. political and military leaders. The wars in Iraq demonstrated the utility of even unsophisticated LACMs and SRBMs. Despite this, Iranian weapons are not nearly as powerful as U.S. weapons. U.S. ASMs and LACMs grant American strategists significantly more freedom and power than their Iranian counterparts. Being able to capture how states think about their and adversaries weapon capabilities is an important part for understanding conflict and military power.

This dissertation will explore the factors and processes associated with the proliferation of ASMs, LACMs, and SRBMs as part of a three-essay dissertation. The first two chapters split proliferation into two stages, horizontal and vertical. Horizontal proliferation looks at the diffusion of production of ASMs and LACMs throughout the system. This first chapter seeks to explain how and why states gain an initial production capacity. The vertical proliferation chapter seeks to explain the level of sophistication of states production capabilities for ASMs and LACMs. The data for ASMs and LACMs will rely on new data on cruise missile production capabilities and leverage a new measure of cruise missile sophistication as my dependent variable. A large-n analysis is conducted to explore the factors associated with acquiring missile production capabilities of differing levels of sophistication for both ASMs and LACMs. The chapter on SRBMs will explore how states innovate through reverse-engineering foreign purchased missile systems using Qualitative Comparative Analysis (QCA). Together, the inquiries in this dissertation have shown the important role that the security environment,

scientific, technical, and organizational capital, and technological diffusion over time, have played in both horizontal and vertical proliferation. These explain why certain states' arms industries have been far more successful in both mastering the production of missile technology and pushing the envelope forward regarding producing increasingly sophisticated variants.

The proliferation of advanced conventional weapons has been overshadowed by a focus on weapons of mass destruction and long-range ballistic missiles. ASMs, LACMs, and SRBMs deserve the attention of academics interested in international security and power, and policymakers seeking to curb proliferation or better understand their uses on the battlefield. These weapons are essential and have game-changing capabilities. The security environment driving states to seek domestic production of these weapons is not entirely different from those driving WMD and LRBMs proliferation. This raises interesting questions regarding both the complementary nature between advanced conventional weapons with A2 AD capabilities and more powerful strategic weapons. The success of states that nurture their specific forms of intangible resources in proliferating across a wide variety of weapons is a critical contribution of this dissertation to the study of proliferation. These insights help to highlight further the role that specific scientific, technical, and organizational capacities play in strengthening the ability for states to strengthen their web of proliferation capacity. Overall, this dissertation provides essential contributions to understanding the linkages between different forms of successful state proliferation, in addition to providing insights into the proliferation of understudied, yet significant advanced conventional missile systems.
Chapter Two: Horizontal Proliferation

Anti-ship missiles (ASMs) and land-attack cruise missiles (LACMs) are weapons that are receiving increased attention as they continue to proliferate throughout the system and their strategic utility becomes increasingly apparent. I theorize that in addition to the security environment states face, it is S&T human capital and investments in and experience with SMICs that best determine the ability for states to produce ASMs and LACMs. I theorize that states' investments in their domestic defense industry produces S&T human capital and strengthens their SMICs and that this enhances states abilities to develop ASMs and LACMs. States' investment and experience in defense-related fields help create significant intangible resources, such as organizational, scientific, technical, and engineering knowledge, organizational experience, and even tacit knowledge. These resources cannot be replicated with money or industrial might alone. These pools of S&T human capital create positive spill over into other proliferation efforts.

I conduct a quantitative analysis of the effects of states' S&T human capital and SMIC experience on the proliferation of production capacities for ASMs and LACMs. I find consistent evidence that the security environment, like other strategic weapons, plays a vital role in states proliferation decisions. I also find that S&T human capital and defense-related SMICs have a statistically significant and positive effect on states developing domestic production capacities for ASMs and LACMs. This chapter contributes to the growing work that incorporates the importance of knowledge and S&T human capital in the supply side of proliferation.54 It also

---

54 Singh and Way (2004); Early and Way (2017); Jo and Gartzke (2007); Bell (2016); Fuhrmann (2009); Kroenig (2009); Brown and Kaplow (2014); Horowitz and Narang (2014); Early (2014); Horowitz (2010); Fuhrmann and Horowitz (2015)
contributes to recent work on the diffusion of military technology and implications for international security and power. ASMs and LACMs are important yet understudied weapons. These weapons provide states with significant stand-off strike and anti-access and area-denial capabilities, making them cheap, effective, and dangerous weapons, even for hegemons. In addition to the vital contribution to the supply side literature on weapons proliferation, this chapter highlights how and why states are producing weapon systems that are growing in importance and availability throughout the international system.

This chapter proceeds as follows. First, I situate myself within the literature and draw upon it to develop my theory on security and S&T human capital driving states' production of ASMs and LACMs. Next, I present my research design and quantitative analysis. I conclude by discussing the findings and their contribution to our theoretical understanding of the growing role of S&T human capital in proliferation.

The Horizontal Proliferation of ASM and LACM Production

The nature of strategic weapons has led security considerations to play an important role in states’ proliferation decisions. Involvement in international conflicts, interstate rivalry, great power rivals, and conventional imbalances have all been shown to play a role in states nuclear proliferation decisions.55 Similar security considerations have also been shown to play a role in long-range missile-related proliferation decisions.56

---

55 Singh and Way (2004); Early and Way (2017); Jo and Gartzke (2007); Bell (2016); Betts (1993); Freedman (1994)
The proliferation of ASMs and LACMs splits from the rest of the strategic literature along a significant chasm. Generally, the literature on the proliferation of strategic weapons only considers the production of said weapons. Long range ballistic missiles and nuclear weapons are not available on the open market. The acquisition of ASMs and LACMs is not the same as producing them. We should not expect the determinants of nuclear or LRBM proliferation to play an outsized role in the proliferation of ASMs and LACMs. Just about any state can purchase ASMs and LACMs, whereas LRBM and nuclear possession are reliant on wholly domestic sources.

Explanations for the proliferation of possession of these weapons may best be explained by ideas of what it means to be a “modern” military or simple mimicry. Sagan has argued that “nuclear symbolism” plays a role in a state’s decision to pursue or not pursue the bomb. This sociological, institutional perspective can also be applied to conventional weapons. Proponents of this approach argue as a certain weapon system becomes widely proliferated, with numerous producers, state militaries tend to mimic one another, believing that such a weapon is required to be considered a "legitimate" state. This norm is further developed by the "powerful" states in the system, who are also often the primary producers of these weapons. Due to the low cost of the

---

57 Saudi Arabia’s purchase of Chinese MRBMs a singular notable exception
58 Sagan 1997, 73
weapon, supply-side variables have little effect on the proliferation of ASMs, and increasingly LACMs as well. Instead, the attitude that states hold toward the weapon, and states perceptions of security threats may have the most explanatory power for why states seek to acquire ASMs and LACMs. The systemic level of proliferation of ASMs and LACMs may not be about an explicit security threat, but rather the perception that the weapon has in the international system.

However, the production of ASMs and LACMs has more in common with the broader literature on strategic proliferation. Producing ASMs and LACMs is not nearly as difficult as producing LRBMs or nuclear weapons. Despite this, their wide availability on the open market drives up the security demand needed to invest in the production of these weapons. The strategic utility these weapons can provide states in a hostile security environment provides for a significant degree of crossover from the security perspectives on the proliferation of more traditional strategic weapons.

ASMs and LACMs provide states with cheap and effective anti-access and area denial capabilities. The experience of the UK against the French made Exocet ASMs wielded by Argentina during the Falkland war is an excellent example of both the security benefits ASMs provide and the limitations states face when they lack a production capacity for these weapons. Though Argentina did manage to use its shore-based MM-38 Exocets against the HMS Glamorgan effectively, it was the advanced AM-39 air-launched Exocets that were the most dangerous. The AM-39 increased the anti-access (A2) capabilities of the Argentine Air Force and were the only genuine chance the Argentines had to prevent UK naval supremacy. France

---

60 Thomson (2012); Anderson (2002), 9
61 Anderson (2002), 11
had provided Argentina with the advanced AM-39 Exocets and their launch platform, the Etendard fighters. Unfortunately for Argentina, France abided by the NATO embargo on the country and halted deliveries. This left Argentina with only 5 Etendard’s and AM-39 Exocets.\textsuperscript{62} Despite only having five missiles, Argentina was able to sink the HMS Sheffield, a British destroyer, and the Atlantic Conveyor, a supply ship. This was done with technical support from French specialists in Argentina working for Dassault during the war.\textsuperscript{63} If Argentina had access to more of the advanced AM-39 Exocets, it would have had a much greater A2 capability against the more powerful British naval task force. This would have made the reclaiming of the Falklands significantly more difficult and bloody for the British, despite their overwhelming naval superiority. All of this could have been possible with a relatively cheap yet effective conventional weapon.

Originally LACMs were solely in the operational realm of the great powers. LACMs, compared to LRBMs, were inaccurate, expensive, and difficult to operate. Their utility was limited to nuclear strikes. This was the niche LACMs originally filled. The technological advances in jet propulsion technology, computing power, and guidance technology began to transform the operational potential of LACMs. Starting in the 1980s, LACMs began to be fitted for conventional roles by the U.S. and USSR.

Additionally, as their use by the U.S. as a cheap, effective, stand-off strike weapon began to become more commonplace, the security advantage of LACMs started to become increasingly apparent. Gormley argued that the Persian Gulf War and the 2003 Iraq war was a turning point for attitudes toward the security benefits of LACMs. Iraqi LACMs and other light aircraft posed serious concerns for U.S. missile defenses. Modern air defense focuses on ballistic missiles and

\textsuperscript{62} Corum (2002)
\textsuperscript{63} Thomson (2012) and Corum (2002)
traditional manned fighter and bomber aircraft, ignoring low flying and slower targets. This creates an opening for LACMs (and drones) to provide cheap and effective area denial capabilities for weaker states. U.S. air defense failed to detect and intercept five crude Iraqi LACMs that were converted from ASMs. LACMs provide states not only with stand-off precision strike capabilities that can allude air defenses but also with the ability to engage in strategic bombing without establishing air superiority. The experience of both U.S. and Iraqi LACM use during the war highlighted the numerous benefits the weapons provided and helped fuel the proliferation of LACM production in states such as Iran, Pakistan, India, South Korea, and even Japan.

States that produce their own ASMs and LACMs increase their ability to not only cut their reliance on foreign suppliers but also to develop more advanced versions. Argentina had significant interests in advanced domestically produced conventional missiles but lacked the capabilities required to do so. The ability to produce ASMs and LACMs can guarantee states access to cheap and effective A2 and AD capabilities. Brazil has been one state that has increasingly sought to produce its missile production capabilities. To avoid being "Iraqed," Brazil argued that if no single tactic proves to be effective against a more powerful force, states should instead focus on a few effective and cheap high technology conventional weapons that will prove the most effective at complicating any military operations of an advanced power. My theory argues that the heightened costs that come with producing these weapons bear

---

64 Gormley (2008), 108, 111, 117.
65 Gormley (2008), 117.
66 Gormley (2008), 50.
68 Early and Fahrenkopf (2017); Early et al (2017)
69 Garrity in Roberts (1995), 51-52
similarities to the security motivations that drive the proliferation decisions states have made regarding nuclear weapons and LRBMs.

**Hypothesis 1: Security threats will increase the likelihood of a state producing ASMs and LACMs**

Threats alone though did not drive states to produce LACMs and ASMs. States had to first learn of the effectiveness that these weapons could bring to bear. At the end of the Cold War, the U.S. had the most dominant navy on the planet. The U.S. through sheer financial strength and organizational capacity and flexibility was able to not only produce significant numbers of aircraft carriers but develop and employ the complicated shifts in naval tactics required to use them properly.\(^70\) The USSR, knowing it could not make up the conventional imbalance presented by U.S. carrier dominance, invested heavily in ASMs.\(^71\) By 1965, six years after the introduction of its first ASM, the USSR had produced no less than six different ASMs. These missiles also increased in sophistication to further attempt to counter U.S. carrier dominance.\(^72\) The Soviets were the first movers in the production and integration of ASMs out of strategic necessity, while other states had to learn.

Despite increasing concerns regarding Soviet ASMs, the U.S. failed to take significant action to produce its ASMs until the sinking of the INS Eilat in 1967. Chief of Naval Operations, Admiral Elmo Zumwalt argued that the Navy’s hierarchy of naval aviators stagnated the U.S.’s ability to

\(^{70}\) For a detailed explanation of the U.S. development of carrier, warfare see Horowitz 2010.  
\(^{71}\) Horowitz (2010); 201, 92.  
\(^{72}\) Early et al (2017).
adopt this crucial weapon system. Admiral Zumwalt was not alone in the view of the U.S. suffering a critical organizational failure. Others have pointed to the “union” of naval aviators as being hostile to ASMs. Many within the U.S. Navy were threatened by the potential for ASMs to be a more advanced or even complimentary form of standoff strike capabilities. The Egyptian sinking of the INS Eilat was the wake-up call to the potency of ASMs.

Rogers’ work on diffusion can help explain how important the sinking of the INS Eilat was to the proliferation of ASM production. Early adopters of ASMs, such as the USSR and their client states were the only states to adopt this innovation. These early movers had an advantage in naval combat that was demonstrated when the INS Eilat was sunk. This is termed a "demonstration point," and represents when the diffusion of innovations generally "take off." As Rogers' notes, the newness of innovation is not merely about knowledge of the innovation, but about the development of favorable attitudes towards it. Thus, the diffusion of innovations relies on a demonstration point that can trigger a takeoff event, where those who have not yet adopted an innovation begin to see the benefits it can provide.

ASMs demonstrated their relative advantage in naval combat against larger more powerful surface ships and fleets was due to their standoff capabilities. ASMs original development was meant to give the significantly weaker Soviet Navy a strategic response to US Carrier based warfare. Shortly after the sinking of the INS Eilat, states began producing ASMs; Israel produced the Gabriel, The U.S. produced the Harpoon, and France the Exocet. My theory argues that demonstration points are vital for states too with significant security concerns.

---

74 Rogers (2003), 8
75 Ibid 11
recognize the benefits of ASMs and LCMS, leading to them adding them to their arsenals, and ultimately to produce them

*Hypothesis 2: Demonstration points of LACMs and ASMs will increase the likelihood of a state producing ASMs and LACMs*

The original role that LACMs filled in the arsenals of the nuclear powers was as an additional nuclear delivery system. The Soviets, Americans, and in the 1980s, the French originally produced LACMs to deliver nuclear weapons by ground, air, and sea. The same reason LACMs are attractive for conventional strikes applies to nuclear strikes as well. LACMs have long ranges, fly at low altitudes to avoid air defenses, and provide states with stand-off launch capability from air and sea. My theory predicts that states that have acquired nuclear weapons will also pursue a domestic LACM program to increase their nuclear deterrent capabilities.

*Hypothesis 3 Nuclear acquisition will increase the likelihood of a state producing LACMs*

Both the academic and policy realm has paid increasing attention to how states acquire strategic weapons. Much of the literature has focused extensively on raw industrial and economic resources. Given the significant resource demand that nuclear weapons, LRBMs, and other strategic weapons require, this approach should be expected. The strategic proliferation literature has found that raw national capabilities, such as financial power and industrial power, play
significant roles in explaining how strategic weapons have proliferated.\textsuperscript{76} ASM and LACM production does not require the same resources as other strategic weapons. First, these weapons, and the associated technology are readily available. Much of the technology that is important for the research, manufacture, and deployment of these weapons are dual-use.\textsuperscript{77} The weapons themselves are readily available on the open market as opposed to more strategic weapons, which bear significant barriers to the acquisition of the weapons themselves, but also the associated technology. ASMs and LACMs are also merely cheaper. A Single Minuteman 3 ICBM cost the U.S. $7 Million to produce in 1970. The cost for the U.S. to even upgrade its ICBM arsenal has run as high as $7 billion over the past 15 years. A total replacement of the arsenal will cost upwards of $238 billion.

Meanwhile, one of the most advanced ASMs, the Harpoon Block 2, currently costs roughly $1.2 million per unit.\textsuperscript{78} This is no measly sum, but ASMs and LACMs are cheaper and easier to build than ballistic missiles, nuclear weapons, and other strategic weapons. The materials to build them are more widely and readily available this along with their lesser capabilities compared to other strategic weapons makes their production a less financially and industrial demanding enterprise.

\textit{Hypothesis 4: Traditional benchmarks for national capacity such as industrial and economic power will have no significance on ASM and LACM production}

If ASMs and LACMs are the "poor man's air force," cheap, readily available, and easier to build, what stands in the way of states producing them?\textsuperscript{79} The academic and policy communities have begun focusing increasingly on knowledge as one of the most important

\textsuperscript{76} For instance see: Horowitz (2010); Mistry (2003); Singh and Way (2004); Jo and Gartzke (2007); Bell (2016)
\textsuperscript{77} Dual-use goods are goods or technology that have both legitimate civilian and military applications.
\textsuperscript{78} FAS Minuteman 3 (2016); U.S. Navy Fact File Harpoon Missile (2017).
\textsuperscript{79} Gormley (2008) 50-51.
mechanisms of proliferation. Major powers are increasingly developing and promoting intangible technology controls — these attempt to control the spread of both explicit knowledge such as blueprints and designs as well as intangible and tacit knowledge. These controls reflect the increasingly important role scientific, technical, and organizational capital play in proliferation. States seeking to develop strategic weapons need to go through arduous research, design, development, production, and deployment efforts to produce and field strategic weapons adequately. This requires significantly more than the raw materials and equipment states can bring to bear through domestic industrial and economic power. It requires having individuals with extensive scientific, technical, engineering, and organizational skills, and a government with a history of successfully running large programs that translate these and more traditional resources into scientific, technical, and production advances. The proliferation literature has begun to incorporate these concerns into understanding how states proliferate. These "intangible" assets have been shown to contribute to strategic proliferation through mechanisms such as organizational capacity, technological capabilities, foreign assistance, technical cooperation, leader assistance, and experience with similar programs.  

Success and experience within one realm of strategic proliferation can often help support efforts in other areas. Investing in one program, whether it’s nuclear weapons or the production of conventional weapons, is an investment in states’ scientific and technical (S&T) human capital, as well as its organizational capabilities. As noted by Early and Way (2017), this investment in scientific-military-industrial complexes (SMICs), regardless of the specific program, is still an investment in scientists, engineers, and technicians that can have positive

---

80 Singh and Way (2004); Early and Way (2017); Jo and Gartzke (2007); Bell (2016); Fuhrmann (2009); Kroenig (2009); Brown and Kaplow (2014); Horowitz and Narang (2014); Early (2014); Horowitz (2010); Brown and Kaplow (2014); Fuhrmann and Horowitz (2015)
States that have well-developed weapons programs can utilize the resources from those sectors to advance other arms programs. The investments in one type of military arms program are not incompatible with others. They often require very similar experience and knowledge in design, material and component acquisition and production, testing, and deployment. Advanced arms projects, such as military rocketry programs, require a systems level approach to be successful. Project managers must manage and combine several different scientific and technical fields. The tacit knowledge and experiences that scientists, engineers, and project managers can bring from one project to another have also been shown to benefit nuclear and other strategic weapons programs. Some of the nuclear literature has argued that tacit knowledge is so vital that foreign assistance is often useless if it does not include the transfer of tacit knowledge, and that without tacit knowledge the world could "forget" how to build nuclear weapons after a few generations. New empirical work has shown that there is indeed a connection between success and experiences in one realm of strategic proliferation transferring to other programs. Space launch programs have been shown to benefit greatly from a domestic missile and rocketry program, and even nuclear weapons programs benefit from a state’s experience in the production of advanced ballistic missiles. Arms production programs do not exist in a vacuum. Nor are they simply getting the right parts and putting them together. The experience, knowledge and expertise states develop in one realm can, and have, been translated into other programs. My theory argues that this "intangible" realm of supply-side proliferation will play an outsized role in the production of ASMs and LACMs.

---

81 Early and Way (2017), 368.
82 Karp (1996), Chapter 4; Gormley (2008)
83 Karp (1996); Montgomery (2005); Johnson-Freese (2007); Hymans (2011)
84 Hymans (2011); MacKenzie and Spinardi (1995)
85 Early (2014); Early and Way (2017)
Hypothesis 5 Scientific, technical, and organizational capacity will have a positive impact on ASM and LACM production

Research Methods

To test my hypotheses, I conduct a quantitative analysis utilizing a rare events model on data drawn from the National Cruise Missile Dataset. This data includes the LACM and ASM possession and production data for roughly 168 countries from 1950-2007. The unit of analysis is the country year, and the data are structured in an event history format. Observations are included up until the first year they gain a domestic production capacity, at which point they exit the dataset. States gaining a production capacity for ASMs and LACMs suffer from a common problem among quantitative studies for proliferation, they are rare events. Rare event bias is a significant issue for maximum likelihood estimators. I account for rare event bias on the dependent variable by using the firth-logit command. Firth-logit utilizes a penalized likelihood estimator to account for the rare event bias that maximum likelihood estimations are known to suffer. This model has been employed in previous studies of proliferation. To control for the small number of total observations I also run multiple models in addition to my primary model. The additional models add relevant control variables one at a time to the main model to help alleviate issues related to degrees of freedom.

Dependent Variable

The dependent variable in my analysis is the first-year states crossed the threshold into successfully producing ASMs and LACMs from 1950-2007. My analysis relies on data compiled

---

86 Early et al, (2017)
87 King and Zeng, 2001; Williams, 2018
88 Way and Weeks (2014); Early and Way (2017); Bleek and Lorber (2014).
by the National Cruise Missile Dataset.\textsuperscript{89} For ASMs I control for landlocked states, which would
not need ASMs.

\textbf{The NCM}

Much of the data for this dissertation is drawn from the National Cruise Missile Dataset. The NCM dataset codes the worldwide efforts to develop and possess cruise missile capabilities from the end of the Second World War until 2015. This dataset collects information on states' possession of strategic, ASM, and conventional LACM arsenals, how those capabilities were acquired, and whether states have the capability of producing them. The NCM has three separate datasets. The first breaks both land attack and anti-ship missiles up into categories based on their technological and strategic capabilities. The second dataset is a complete missile list. This list details, country by country, every missile that has ever been deployed in a state's arsenal and is available in the open source. The third dataset is a time series cross-section of the most technically advanced missile in a state's arsenal based on range and broken up by mission and launch platform.\textsuperscript{90}

The NCM uses a definition of cruise missile that is similar to Seth Carus’ in \textit{“Cruise Missile Proliferation in the 1990s”}. We, like Carus, use the broad definition as laid out in the INF treaty to capture a more wide, and accurate array of the large variety of cruise missiles that exist in global arsenals. A cruise missile is: “an unmanned, self-propelled, vehicle that sustains flight through the use of aerodynamic lift over most of its flight.”\textsuperscript{91} This definition, as Carus

\textsuperscript{89} Early et al (2017)
\textsuperscript{90} Early et al (2017).
\textsuperscript{91} Carus (1992), 7-9.
points out, considers a broader array of tactical and strategic cruise missile weapons, such as rocket-powered anti-ship cruise missiles and cruise missiles within the loop terminal guidance.\textsuperscript{92}

**Independent Variables**

*The frequency of dispute involvement.* States security environment has been shown to play an essential role in their proliferation decisions. To account for this, I include a measure of conflict propensity that utilizes that number of interstate disputes using a five-year moving average number of militarized interstate disputes. This approach is commonly used in the proliferation literature.\textsuperscript{93} I employ data from Version 4.0 of the updated MIDs data set.\textsuperscript{94}

*Military rocketry R&D programs.* To account for states experience with military missile and rocketry programs I include a count variable of the years since initiation of a military rocketry R&D program. This approach has been shown to be positively associated with states’ nuclear programs, SRBM programs, and space launch programs.\textsuperscript{95} Data for this is drawn from the national space and ballistic missile dataset.\textsuperscript{96}

*Demonstration point.* To account for states learning the effectiveness of ASMs and LACMs I include a variable for the demonstration point events for both ASMs and LACMs. After coding this variable in multiple ways, I determined that a 5-year lag in addition to the year the event occurred granted states adequate time to pursue domestic production capacity for ASMs and LACMs. This variable was coded specially for this analysis. Data for this variable was drawn from multiple sources; a demonstration point is deemed to have occurred when the weapon was used successfully in combat.

\textsuperscript{92} Ibid, 8.
\textsuperscript{93} Early and Way (2017); Singh and Way (2004).
\textsuperscript{94} Ghosn et al. (2004); Palmer et al (2015)
\textsuperscript{95} Early (2014); Early and Way (2017); Early and Fahrenkopf (2017)
\textsuperscript{96} Early and Fahrenkopf (2017)
Domestic defense industry. To account for the size of states’ domestic defense industries, I include a variable which accounts for states’ total defense exports each year. This measure is based on the total military value of the exports, rather than simple GDP total.\textsuperscript{97}

Economic Size. To capture economic power, I control for countries’ level of economic development using the squared term for GDP per capita.\textsuperscript{98}

Great Power Defense Pacts. To control for the security guarantees provided by defense pacts with great powers, I include a binary variable for whether the state has a defense pact with either the U.S. or the USSR.\textsuperscript{99}

Non-great power and great power strategic rivalry. To account for the security threat posed by great powers, I include a measure of great power rivalry. I also include non-great power rivalries as well.\textsuperscript{100}

Domestic SRBM production. This variable captures an additional measure a states military rocketry S&T and R&D human capital. This is a binary variable that captures whether states’ produce SRBMns. Data for this variable is drawn from the NSBM.\textsuperscript{101}

Composite index of national capabilities. To control for countries’ national industrial and military capabilities, I use the Composite Index of National Capability index. This variable is a composite measure of states’ military, industrial, and population capabilities as a proportion of the total global pool of those capabilities.\textsuperscript{102}

\textsuperscript{97} SIPRI (2017)  
\textsuperscript{98} Gleditsch (2002).  
\textsuperscript{99} Gibler (2009)  
\textsuperscript{100} Thompson et al. (2001)  
\textsuperscript{101} Early and Fahrenkopf (2018)  
\textsuperscript{102} Singer (1987)
The sophistication of possessed ASM/LACM. This variable utilizes a sophistication score created by the author for measuring the technological sophistication and capabilities of missiles. Sophistication scores range from 1-25 and are determined based on a point system that ranks the sophistication that particularly missile capabilities require. For a more detailed explanation of this variable see the vertical proliferation chapter.

Most sophisticated ASM/LACM in the system. This variable utilizes the sophistication score to determine the most sophisticated missile currently developed. This variable seeks to capture the concept of technological diffusion. As technology advances, it becomes easier and easier to produce a less advanced version of weapons.

Total Missile Technology Control Regime members. This variable captures the number of MTCR members in the system each year.

Domestic education levels. Despite how important capturing the tacit knowledge and scientific and technical capabilities of a populace is to proliferation studies, it is incredibly hard to capture. The best relative measure for S&T human capital for which direct data exists is countries' education levels. To capture this, I use Barro and Lee's (2010) educational attainment data set. This dataset contains estimates of education levels at five- year intervals for 150 countries from 1950 to 2010. Using these data, my higher education variable codes the proportion of a country’s population 25 and over that have completed higher education programs. To account for the five-year interval of the data, I code the five year estimates forward and backward two years. This was done by Early (2014) in his work on space launch capabilities.

---

103 Barro and Lee (2010)
104 Early (2014).
Polity. I also include the Polity2 variable from Marshall and Jaggers.\textsuperscript{105} This variable code states based on how democratic they are. Scores can range from -10 to 10.

Nuclear possession (LACM test only). This variable includes states that possess nuclear weapons. Nuclear possession is coded using a one-year lead.\textsuperscript{106}

Nuclear pursuit (LACM test only). This variable includes states that are (or were) actively pursuing nuclear weapons.\textsuperscript{107}

Time. To control for temporal effects, I control the number of years before states acquire production capacities for ASMs and LACM. This includes the squared and cubed values as per the recommendation of Carter and Signorino (2010).\textsuperscript{108}

GPS. GPS provides cheap and highly accurate satellite-based guidance. It has extensive dual-use and military applications. GPS is coded as becoming "Available" in 2000 after the U.S. removed the selective availability element of its publicly available GPS. Selective availability degraded the accuracy of the publicly available system.\textsuperscript{109} With its removal, it became possible to develop highly accurate missiles for significantly less.

Landlocked. For ASMs I control for states that are landlocked. States with no ocean access have no strategic use for ASMs.\textsuperscript{110}

\textsuperscript{105} Marshall and Jaggers (2004)
\textsuperscript{106} Early and Way (2017)
\textsuperscript{107} Early and Way (2017).
\textsuperscript{108} Carter and Signorino (2010)
\textsuperscript{109} “Selective Availability” GPS.gov (2018).
\textsuperscript{110} Early (2008).
## Results

### Table 1.0 ASM Production

<table>
<thead>
<tr>
<th>Model</th>
<th>Demonstration Point</th>
<th>Rocket R&amp;D Years</th>
<th>Log of Defense Exports</th>
<th>Log of Real GDP</th>
<th>Time</th>
<th>Time 2</th>
<th>Time 3</th>
<th>Great Power Defense Pact</th>
<th>Great Power Strategic Rival</th>
<th>SRBM Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.107**</td>
</tr>
<tr>
<td>2</td>
<td>0.789</td>
<td>0.0426</td>
<td>0.263*</td>
<td>0.192</td>
<td>0.651</td>
<td>-2.209</td>
<td>0.0222</td>
<td>0.307</td>
<td>-0.542</td>
<td>2.107**</td>
</tr>
<tr>
<td>2</td>
<td>(0.70)</td>
<td>(1.96)</td>
<td>(2.01)</td>
<td>(0.67)</td>
<td>(1.31)</td>
<td>(-1.36)</td>
<td>(1.40)</td>
<td></td>
<td>(-0.86)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.675</td>
<td>0.0411</td>
<td>0.278*</td>
<td>0.185</td>
<td>0.655</td>
<td>-2.238</td>
<td>0.0226</td>
<td>0.307</td>
<td></td>
<td>2.107**</td>
</tr>
<tr>
<td>3</td>
<td>(1.08)</td>
<td>(1.91)</td>
<td>(2.10)</td>
<td>(0.85)</td>
<td>(1.43)</td>
<td>(-1.50)</td>
<td>(1.54)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.896</td>
<td>0.0406</td>
<td>0.264*</td>
<td>0.241</td>
<td>0.623</td>
<td>-2.181</td>
<td>0.0223</td>
<td></td>
<td></td>
<td>2.107**</td>
</tr>
<tr>
<td>4</td>
<td>(1.37)</td>
<td>(1.82)</td>
<td>(1.97)</td>
<td>(0.32)</td>
<td>(1.50)</td>
<td>(-1.59)</td>
<td>(1.64)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.819</td>
<td>0.0399</td>
<td>0.262*</td>
<td>0.0844</td>
<td>0.799</td>
<td>-2.633</td>
<td>0.0255</td>
<td></td>
<td></td>
<td>2.107**</td>
</tr>
<tr>
<td>5</td>
<td>(1.23)</td>
<td>(1.69)</td>
<td>(2.00)</td>
<td>(0.33)</td>
<td>(1.79)</td>
<td>(-1.84)</td>
<td>(1.84)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.568</td>
<td>0.0316</td>
<td>0.265*</td>
<td>0.158</td>
<td>0.630</td>
<td>-2.127</td>
<td>0.0214</td>
<td></td>
<td></td>
<td>2.107**</td>
</tr>
<tr>
<td>6</td>
<td>(0.93)</td>
<td>(1.98)</td>
<td>(1.97)</td>
<td>(0.54)</td>
<td>(1.30)</td>
<td>(-1.36)</td>
<td>(1.40)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.604</td>
<td>0.0326</td>
<td>0.265*</td>
<td>0.216</td>
<td>0.519</td>
<td>-2.211</td>
<td>0.0239</td>
<td></td>
<td></td>
<td>2.107**</td>
</tr>
<tr>
<td>7</td>
<td>(1.00)</td>
<td>(1.49)</td>
<td>(1.97)</td>
<td>(0.66)</td>
<td>(1.23)</td>
<td>(-1.59)</td>
<td>(1.75)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.623</td>
<td>0.0326</td>
<td>0.249</td>
<td>0.227</td>
<td>1.425**</td>
<td>(2.63)</td>
<td>(2.06)</td>
<td></td>
<td></td>
<td>2.107**</td>
</tr>
<tr>
<td>8</td>
<td>(0.94)</td>
<td>(1.54)</td>
<td>(1.94)</td>
<td>(0.76)</td>
<td>(1.16)</td>
<td>(1.15)</td>
<td>(1.33)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1.044</td>
<td>0.0427**</td>
<td>0.249</td>
<td>0.147</td>
<td>0.579</td>
<td>-1.976</td>
<td>0.0210</td>
<td></td>
<td></td>
<td>2.107**</td>
</tr>
<tr>
<td>9</td>
<td>(1.28)</td>
<td>(0.99)</td>
<td>(2.03)</td>
<td>(0.53)</td>
<td>(0.72)</td>
<td>(-1.20)</td>
<td>(1.17)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Sophistication of ASM in the system</th>
<th>Total MTCR Members</th>
<th>Higher Education</th>
<th>_cons</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-0.366</td>
<td>-0.0486</td>
<td>-0.0119</td>
<td>-15.27**</td>
<td>6093</td>
</tr>
<tr>
<td>2</td>
<td>(-1.53)</td>
<td>(-0.58)</td>
<td>(-0.17)</td>
<td>(-2.98)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-0.206</td>
<td>-15.27**</td>
<td>-15.32***</td>
<td>-15.55**</td>
<td>6093</td>
</tr>
<tr>
<td>3</td>
<td>(-1.20)</td>
<td>(-3.17)</td>
<td>(-3.37)</td>
<td>(-3.25)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-0.200</td>
<td>-14.75**</td>
<td>-11.92*</td>
<td>15.27**</td>
<td>6093</td>
</tr>
<tr>
<td>4</td>
<td>(-2.65)</td>
<td>(-2.97)</td>
<td>(-2.40)</td>
<td>(-2.58)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-0.219</td>
<td>15.27**</td>
<td>-21.92**</td>
<td>-13.97**</td>
<td>6093</td>
</tr>
<tr>
<td>5</td>
<td>(-2.65)</td>
<td>(-2.25)</td>
<td>(-2.79)</td>
<td>(-2.73)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-0.208</td>
<td>15.55**</td>
<td>-13.97**</td>
<td>-17.52**</td>
<td>6093</td>
</tr>
<tr>
<td>6</td>
<td>(-2.25)</td>
<td>(-2.53)</td>
<td>(-2.79)</td>
<td>(-2.68)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>-0.213</td>
<td>-11.92*</td>
<td>-21.92**</td>
<td>-13.97**</td>
<td>6093</td>
</tr>
<tr>
<td>7</td>
<td>(-1.53)</td>
<td>(-2.40)</td>
<td>(-2.79)</td>
<td>(-2.73)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>-0.210</td>
<td>13.97**</td>
<td>-17.52**</td>
<td>-13.97**</td>
<td>6093</td>
</tr>
<tr>
<td>8</td>
<td>(-1.53)</td>
<td>(-2.79)</td>
<td>(-2.79)</td>
<td>(-2.73)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>-0.201</td>
<td>17.52**</td>
<td>-17.52**</td>
<td>-17.52**</td>
<td>6093</td>
</tr>
<tr>
<td>9</td>
<td>(-1.53)</td>
<td>(-2.79)</td>
<td>(-2.79)</td>
<td>(-2.73)</td>
<td></td>
</tr>
</tbody>
</table>

* t statistics in parentheses
** *p<0.05 ** *p<0.01 *** *p<0.001"
Table 2.0 LACM Production

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstration Point</td>
<td>-0.166</td>
<td>-0.178</td>
<td>-0.135</td>
<td>-0.152</td>
<td>-0.151</td>
<td>-0.194</td>
</tr>
<tr>
<td></td>
<td>(-0.18)</td>
<td>(-0.20)</td>
<td>(-0.15)</td>
<td>(-0.16)</td>
<td>(-0.16)</td>
<td>(-0.23)</td>
</tr>
<tr>
<td>disputes</td>
<td>-0.223</td>
<td>-0.235</td>
<td>-0.243</td>
<td>-0.349</td>
<td>-0.212</td>
<td>-0.320</td>
</tr>
<tr>
<td></td>
<td>(-0.56)</td>
<td>(-0.60)</td>
<td>(-0.61)</td>
<td>(-0.82)</td>
<td>(-0.51)</td>
<td>(-0.89)</td>
</tr>
<tr>
<td>Nuclear Possession</td>
<td>2.550**</td>
<td>2.438**</td>
<td>2.144*</td>
<td>2.425**</td>
<td>2.957**</td>
<td>2.668**</td>
</tr>
<tr>
<td></td>
<td>(2.91)</td>
<td>(2.79)</td>
<td>(2.12)</td>
<td>(2.77)</td>
<td>(2.88)</td>
<td>(2.97)</td>
</tr>
<tr>
<td>Rocket R&amp;D Years</td>
<td>0.0614*</td>
<td>0.0743*</td>
<td>0.0673*</td>
<td>0.0729*</td>
<td>0.0529*</td>
<td>0.0721**</td>
</tr>
<tr>
<td></td>
<td>(2.48)</td>
<td>(2.36)</td>
<td>(2.52)</td>
<td>(2.54)</td>
<td>(2.10)</td>
<td>(2.79)</td>
</tr>
<tr>
<td>Log of Real GDP</td>
<td>0.379</td>
<td>0.317</td>
<td>0.351</td>
<td>0.121</td>
<td>0.290</td>
<td>0.236</td>
</tr>
<tr>
<td></td>
<td>(1.13)</td>
<td>(0.98)</td>
<td>(1.05)</td>
<td>(0.31)</td>
<td>(0.79)</td>
<td>(0.73)</td>
</tr>
<tr>
<td>Time</td>
<td>-0.232</td>
<td>-0.222</td>
<td>-0.212</td>
<td>-0.127</td>
<td>-0.207</td>
<td>-0.170</td>
</tr>
<tr>
<td></td>
<td>(-1.08)</td>
<td>(-1.15)</td>
<td>(-1.03)</td>
<td>(-0.52)</td>
<td>(-0.90)</td>
<td>(-1.02)</td>
</tr>
<tr>
<td>Time 2</td>
<td>0.159</td>
<td>0.0923</td>
<td>0.103</td>
<td>-0.148</td>
<td>0.0303</td>
<td>-0.0517</td>
</tr>
<tr>
<td></td>
<td>(0.17)</td>
<td>(0.11)</td>
<td>(0.11)</td>
<td>(-0.15)</td>
<td>(0.03)</td>
<td>(-0.07)</td>
</tr>
<tr>
<td>Time 3</td>
<td>0.00411</td>
<td>0.00468</td>
<td>0.00435</td>
<td>0.00674</td>
<td>0.00566</td>
<td>0.00605</td>
</tr>
<tr>
<td></td>
<td>(0.38)</td>
<td>(0.48)</td>
<td>(0.43)</td>
<td>(0.60)</td>
<td>(0.48)</td>
<td>(0.76)</td>
</tr>
<tr>
<td>Great Power Defense Pact</td>
<td>-0.668</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-0.87)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRBM Production</td>
<td>0.611</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.75)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Capabilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.177</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.94)</td>
</tr>
<tr>
<td>Higher Education</td>
<td>0.0623</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.88)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Power Strategic Rival</td>
<td>1.221</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.93)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-2.63)</td>
<td>(-2.42)</td>
<td>(-2.64)</td>
<td>(-2.09)</td>
<td>(-2.19)</td>
<td>(-2.47)</td>
</tr>
<tr>
<td>N</td>
<td>7770</td>
<td>7770</td>
<td>7770</td>
<td>7770</td>
<td>6365</td>
<td>7720</td>
</tr>
</tbody>
</table>

t statistics in parentheses

* p<0.05  ** p<0.01  *** p<0.001
<table>
<thead>
<tr>
<th></th>
<th>Model 7</th>
<th>Model 8</th>
<th>Model 9</th>
<th>Model 10</th>
<th>Model 11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demonstration Point</strong></td>
<td>-0.142 <strong>(-0.13)</strong></td>
<td>-1.525 <strong>(-1.43)</strong></td>
<td>-0.173 <strong>(-0.18)</strong></td>
<td>-0.0501 <strong>(-0.06)</strong></td>
<td>-0.162 <strong>(-0.18)</strong></td>
</tr>
<tr>
<td><strong>disputes</strong></td>
<td>-0.0291 <strong>(-0.06)</strong></td>
<td>0.401** <strong>(2.71)</strong></td>
<td>-0.199 <strong>(-0.48)</strong></td>
<td>-0.224 <strong>(-0.55)</strong></td>
<td>-0.219 <strong>(-0.55)</strong></td>
</tr>
<tr>
<td><strong>Nuclear Possession</strong></td>
<td><strong>2.608</strong> <strong>(2.80)</strong></td>
<td>-0.279 <strong>(-0.32)</strong></td>
<td><strong>2.490</strong> <strong>(2.79)</strong></td>
<td><strong>2.165</strong> <strong>(2.12)</strong></td>
<td><strong>2.535</strong> <strong>(2.91)</strong></td>
</tr>
<tr>
<td><strong>Rocket R&amp;D Years</strong></td>
<td>0.0576** <strong>(2.29)</strong></td>
<td>0.0571 <strong>(1.86)</strong></td>
<td>0.0612** <strong>(2.49)</strong></td>
<td>0.0556** <strong>(2.31)</strong></td>
<td>0.0612** <strong>(2.50)</strong></td>
</tr>
<tr>
<td><strong>Log of Real GDP</strong></td>
<td>0.234 <strong>(0.64)</strong></td>
<td>0.535 <strong>(1.38)</strong></td>
<td>0.371 <strong>(1.10)</strong></td>
<td>0.209 <strong>(0.63)</strong></td>
<td>0.376 <strong>(1.14)</strong></td>
</tr>
<tr>
<td><strong>Polity Score</strong></td>
<td>0.0572 <strong>(1.13)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>-0.263 <strong>(-0.88)</strong></td>
<td>-0.350 <strong>(-1.36)</strong></td>
<td>-0.232 <strong>(-1.03)</strong></td>
<td>-0.218 <strong>(-1.15)</strong></td>
<td>-0.242 <strong>(-1.25)</strong></td>
</tr>
<tr>
<td><strong>Time 2</strong></td>
<td>0.259 <strong>(0.19)</strong></td>
<td>0.955 <strong>(0.87)</strong></td>
<td>0.166 <strong>(0.17)</strong></td>
<td>0.104 <strong>(0.13)</strong></td>
<td>0.222 <strong>(0.26)</strong></td>
</tr>
<tr>
<td><strong>Time 3</strong></td>
<td>0.00326 <strong>(0.21)</strong></td>
<td>-0.00811 <strong>(-0.66)</strong></td>
<td>0.00396 <strong>(0.35)</strong></td>
<td>0.00538 <strong>(0.58)</strong></td>
<td>0.00327 <strong>(0.32)</strong></td>
</tr>
<tr>
<td><strong>Possessed LACM</strong></td>
<td><strong>0.305</strong>* <strong>(4.60)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sophistication Score</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pursuit of Nuclear Weapons</strong></td>
<td></td>
<td></td>
<td></td>
<td>1.297 <strong>(0.81)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Log of Defense Exports</strong></td>
<td></td>
<td></td>
<td></td>
<td>0.294 <strong>(1.85)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>GPS</strong></td>
<td></td>
<td></td>
<td></td>
<td>0.0251 <strong>(0.02)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>_cons</strong></td>
<td>-8.496* <strong>(-2.02)</strong></td>
<td>-11.57* <strong>(-2.43)</strong></td>
<td>-9.998** <strong>(-2.60)</strong></td>
<td>-9.563* <strong>(-2.54)</strong></td>
<td>-10.03** <strong>(-2.65)</strong></td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>7040</td>
<td>7770</td>
<td>7770</td>
<td>7770</td>
<td>7770</td>
</tr>
</tbody>
</table>

*t statistics in parentheses

*= p<0.05  **= p<0.01  ***= p<0.001"
Tables 1, 2, and 3 above contain the primary results from the ASM and LACM tests. The tables include the models that control for additional variables. These initial models allow me to show the effects of key variables before addressing issues related to omitted variable bias. The results show strong support for hypothesis 1 and 3 that states' security environment will be positively associated with the production of ASMs and LACMs. Across 8 of the nine models for ASM production, the disputes variable is positive and statistically significant. Across 10 of the 11 models, nuclear weapons possession is positive and statistically significant. These findings are in line with much of the strategic proliferation literature on the importance of security threats driving proliferation decisions. I would not expect security threats to be a primary driver of possession for ASMs and LACMs. Given the increased cost that production requires, the security threats states' face should be expected to be more in line with those that also pursue nuclear weapons and LRBMs. Indeed, this is what we see.

The security guarantees of great powers, the U.S. and the USSR in this analysis, raises interesting questions. Defense pacts with the US and USSR are not statistically significant. This runs counter to the expectation that great power alliances would lessen the security demands on states to produce ASMs and LACMs. The history of the North Korean missile program may shine a light on explaining this finding. The USSR often provided significant military assistance to its allies. Part of this involved significant ASM exports, military-technical assistance, and even nuclear and missile assistance and technical support. This support in and of itself has been credited with and continues to support the North Korean missile program. Despite this, security guarantees do not alleviate the concern over supply to weapons deemed necessary to a

---

111 t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001
112 Warrick (2017); Nuclear Threat Initiative (2017); Pinkston (2008)
state's security. North Korea had long pursued a path of Chuch’e or self-reliance. Soviet acquiescence during the Cuban Missile Crisis pushed North Korea to double down on this policy. North Korea did not feel the USSR would risk a war with the US to defend them. They no longer felt their weapons pipeline from great power allies, be it USSR or China, could be relied upon.\textsuperscript{113} This highlights the critical role of state leaders' perceptions of their security environment as an essential determinate of state proliferation decisions. Such an approach has been applied to nuclear proliferation and should be increasingly used in other areas of strategic proliferation.\textsuperscript{114}

Despite the importance of states' security demands, an important driver of the narrative surrounding the utility ASMs and LACMs provide insecure states; demonstration point does not draw any support from this analysis. Demonstration points are not significant in any of the models. This finding erodes quantitative support for hypothesis 2. I think there are two explanations for why demonstration points were not significant to this study. In his research review of nuclear proliferation literature, Bell notes the complicated nature of quantitative findings in the realm of proliferation. Given the relatively rare nature of proliferation, quantitative models sometimes do not capture the importance of variables in certain cases. Bell confronts this by utilizing random forests, extreme bounds, and cross-validation analysis of nuclear proliferation. Bell’s argument that treating variables as homogenous over time, and that variables may cause proliferation without being correlated with it may apply to the demonstration point.\textsuperscript{115}

\begin{flushleft}
\textsuperscript{113} Pinkston (2003); Pinkston (2008)
\textsuperscript{114} O’Reilly (2012)
\textsuperscript{115} Bell (2016), 526-527
\end{flushleft}
Demonstration points for ASMs and LACMs may have triggered the adoption of possession rather than production. Additionally, states that adopted production capabilities for ASMs and LACMs may have been driven by demonstration points to pursue production capabilities but could not produce them within the five-year window used in this analysis. Demonstration points may only push major powers (such as the U.S. and France after the sinking of the INS Eilat) and states’ with pertinent security threats (such as Israel after the INS Eilat) to quickly pursue production capacities. The narrative and normative appeal of producing these weapons for other states may take longer to be adopted or diffuse in different ways, such as seen in the conventional proliferation literature. The treatment of the demonstration point as a homogenous variable capturing the narrative of the security utility of producing ASMs and LACMs may not be the best way to measure or consider demonstration points’ role in proliferation.

Given that there are significantly fewer resources required to produce ASMs and LACMs compared to other strategic weapons, it is not surprising to see support for Hypothesis 4. Across all models, the results show there is no indication that traditional benchmarks for economic and industrial power play a role in the production of ASMs and LACMs. Instead, we see strong support for Hypothesis 5 across the board. For ASMs, the size of a states domestic defense industry is statistically significant in 6 of the 9 models. Additionally, model 4 of the ASM results shows that states' domestic SRBM production capabilities exercise positive and statistically significant effects on ASM production. LACMs show strong support for hypothesis 5 as well. The Rocketry R&D variable is positive and statistically significant for LACM production in 10 of the 11 LACM models. The nuclear possession variable could also be
considered an indication of states' scientific and technical human capital. These findings add to the literature and policy realms increasing focus on the crucial role S&T human capital provides proliferant states and the symbiotic nature between different weapons programs.116

**LACMs and GPS**

The data for this dissertation struggle to capture a growing trend in the proliferation of production for LACMs. The introduction of cheap, simple, and effective GPS guidance for missiles has dramatically increased the ability for states to produce pure, yet effective LACMs. The primary trend driving this is the conversion of ASMs into LACMs by adding GPS guidance. Converting ASMs into LACMs is not a new phenomenon. Gormley notes that this is a difficult, but feasible route. Older ASMs have larger bodies which provide states more room to add needed parts and equipment.

Additionally, making previously heavier ASMs lighter can increase the range. Iraq modified Chinese Styx ASM variants into LACMs to be used against U.S. forces during the 2003 Iraq War. This was an experience which helped fuel the demand for LACMs.117 There are serious concerns, particularly given the extensive proliferation of ASMs, of states converting existing ASM stockpiles into LACMs. Despite this, Gormley notes this is a difficult task.118 More concerning is prominent ASM producers entering the LACM market by simply adding GPS systems to existing advanced ASMs. Since 2000 the market for cheap and effective LACMs has expanded significantly, as some of the highest profile and most widely sought ASMs have

---

117 Gormley (2008), 62-64.
118 Gormley (2008), 64.
introduced land-attack capabilities. New sales and marketing materials for these ASMs prominently display these new precision land-attack capabilities with high payload and often ranges near or exceeding 300km raises serious proliferation concerns.\textsuperscript{119} The next wave of LACM proliferation will be more difficult to distinguish from ASM proliferation as these missiles increasingly serve dual roles.

**Conclusion**

ASMs and LACMs are an important, yet understudied part of proliferation and military power. The interconnected nature of proliferation programs and the effects these, and other related weapons have on international security demand that we broaden our focus beyond the simply nuclear proliferation. ASMs and LACMs are dangerous weapons with system altering dynamics, and efforts to produce them can have positive externalities on other more powerful strategic weapons. This chapter shows that states' security environment plays a role in driving the proliferation decisions states to make for ASMs and LACMs, which are further down the strategic weapons ladder. More importantly, this chapter has shown that not only is S&T human capital and (SMICs) an understudied and essential resource in proliferation capabilities, but that military production programs are interconnected. Investing in one SMIC has positive externalities onto other production efforts.

My findings reinforce recent work on moving supply-side aspects of weapons proliferation away from traditional notions of state capabilities, and toward a focus on S&T human capital.\textsuperscript{120} The scientific, technical, production and organizational know-how for the entire defense field are linked. State efforts in one area will have positive externalities in other

\textsuperscript{119} NCM (2018); Author Interviews.

\textsuperscript{120} Such as Fuhrmann (2009); (2012); Kroenig (2009)a; (2009)b; Horowitz (2010); Early (2014); Early and Way (2017); Early and Fahrenkopf (2017); Fuhrmann and Horowitz (2017).
realms. Historically the DPRK has pursued this route with significant success. The DPRK has been able to leverage significantly limited resources by focusing on building domestic sources of S&T human capital through investing broadly in SMICs. States' investments in the defense realm play an outsized role in their ability to acquire strategic weapons production capacities.

Future research should focus on two paths. The first is to develop better conceptual understandings on what S&T human capital and SMICs are, how they can be measured, and how spillover occurs. Second, policymakers and academics focus on what triggers states to move from the possession of ASMs, LACMs, and similar weapons to producing them. And more importantly, is there a link between demand and the pursuit of production capacities for lower level strategic weapons and LRBMs and nuclear weapons. In other words, is the ability to produce ASMs and LACMs one step toward more advanced capabilities? If not, why do some states stop here, and others continue. This question demands a more intimate understanding of the demand side forces that push states to proliferate. Finally, proliferators recognize the importance of the spillover effect that SMICs can have on broader proliferation efforts. The DPRK has leveraged its limited resources to make focused investments in scientific and technical fields relevant to its proliferation programs, and have become a competent missile producer, nuclear power, and illicit nuclear and missile proliferator.
Chapter Three: Going From Buyers to Suppliers

In 1974, Syria acquired numerous Scud B systems from the Soviet Union.\textsuperscript{121} Hafez al-Assad, bruised from two disastrous wars against Israel, sought strategic parity and asymmetric deterrence through chemical weapons and ballistic missiles. Short Range Ballistic Missiles (SRBMs) provided Syria with two very important advantages. First, they offered Syria an asymmetric strategic deterrent capability based on chemical weapons. Second, they allowed Syria to strike deep into Israel, despite the large disparity between the Syrian and Israeli air forces. Despite the clear need and early access, Syria was unable to engage in even modest reverse engineering and domestic production until the late 1990s. Meanwhile, Iran, gaining SRBMs in 1985 during the Iran-Iraq War, was able to begin modest reverse engineering and domestic production by 1988.\textsuperscript{122} Both states had similar capabilities and security concerns, but Iran was able to reverse engineer SRBMs in a relatively short window while Syria took almost twenty years.

SRBMs are a unique and understudied facet of international security. With their own strategic and tactical uses, SRBMs can provide states wide-ranging security benefits. In some theaters, such as the Middle East, SRBMs can be considered strategic weapons systems because of the shorter distances between major population centers. The distance between Tel Aviv and Damascus is around 200 km, well within the range of even crude SRBMs. For states in these regions, this makes SRBMs coupled with WMDs no different than LRBMs. SRBMs can also be

\textsuperscript{121} Early and Fahrenkopf (2017)
\textsuperscript{122} Ibid
used to engage in A2 and AD operations even when states’ lack air superiority. Iraqi SRBMs complicated the U.S. invasion during the Gulf War.\textsuperscript{123}

The wide proliferation of SRBMs makes them the perfect basis for advanced missile development programs. In this way, states treat SRBM acquisition and production as a gateway to LRBMs. It is very rare for states to be able to import long-range nuclear capable ballistic missiles.\textsuperscript{124} Due to this, if states truly seek a nuclear or WMD capability, they need to be able to develop their delivery systems, of which ballistic missiles make up an important part. States can, however, import SRBMs and they widely do so. The Missile Technology Control Regime (MTCR) permits member states to export any missile that falls below the 300km/500kg range/payload threshold. This allows for the export of many whole missile systems that can, and have been, used as the foundation to produce more advanced missiles. This path has been the route taken by numerous states. The original nuclear powers were incredibly dependent on German hardware and scientists for their ballistic missile programs.\textsuperscript{125} If the domestic production of SRBMs is the first step in developing more advanced missiles or space launch systems, it is important to understand how and why states develop a domestic production capacity through reverse engineering foreign-acquired missiles.

This paper engages in an analysis of 18 historical cases to develop a theory of why certain states develop indigenous SRBM production capabilities after receiving foreign missiles. I employ qualitative comparative analysis (QCA) to identify the explicit proliferation pathways that led states to reverse engineer the SRBMs they received. QCA is particularly well-suited for analyzing medium-sized samples of data and evaluating whether independent variables serve as

\textsuperscript{123} Karp (1996), 49.
\textsuperscript{124} There are few exceptions, of which Saudi Arabia is one.
\textsuperscript{125} Van Riper (2004), 56
necessary and or sufficient conditions for the occurrence of a dependent variable. QCA can also help identify different causal pathways that can lead to the dependent variable (i.e., equifinality). This is important in that it shows that there can be multiple causal mechanisms that lead to the expected outcome.\textsuperscript{126} One of the strengths of QCA is that it offers the means to develop more generalizable insights than case studies alone could offer while taking into account that there are many causally distinct routes by which a phenomenon can occur. Following the QCA analysis, I will examine the Egyptian path toward reverse engineering SRBMs.

Reverse engineering foreign-acquired weapons have always affected international power and security. The Romans reverse engineered a Carthaginian ship to challenge them for dominance in the Mediterranean. The U.S. and Soviet missile programs were based on Nazi missiles, and the Soviet Union used an unexploded sidewinder missile launched during the 1958 Taiwan Strait crisis to build their air-to-air missiles.\textsuperscript{127} SRBM proliferation is following this same path, with the bonus that SRBMs form the basis for system altering weapons and civil space launch capabilities.

The results of the QCA analysis support the growing academic and policy focus on the importance of S&T human capital. States that invest in SMICs and S&T human capital in the field of defense technology and missile production benefit from the spillover benefits such expertise can provide. States that seek to develop their SRBM production capacity are no longer faced with daunting scientific, technical, and engineering milestones to break. These have already been done. Instead, my analysis shows that the proliferation literature’s increasing focus

\textsuperscript{126} Chan (2003), 58.
\textsuperscript{127} O'Connell (2011), 277.
on understanding the organizational, scientific, and technical aspects of strategic proliferation and the connection between different types of proliferation capacities is well founded.128

This paper contributes to the supply side literature on strategic proliferation.129 Whether it is space, missile, or nuclear capabilities, supply-side constraints are shifting from traditional benchmarks such as industrial and economic strength and military budgets to the realm of scientific and human capital and tacit knowledge. This shift highlights the increasing connection between different forms of weapons proliferation. SRBMs, given their wide proliferation and relative simplicity, are the first to see these changes. This will help to expand what we already understand about the proliferation of advanced weapons and technology as well as the connections between the two. This study is also the first to systematically explore how and why states reverse engineer and attempt to acquire SRBMs from imported sources. By better understanding which states are most likely to engage in reverse engineering, states can better predict who may become proliferation threats in the future. This can be used to help guide policymakers’ decisions in the export of advanced weaponry, such as SRBMs.

To account for temporal issues, this study focuses on states that reverse engineer SRBMs within a ten-year window after acquisition. This window is long enough to give states adequate time to produce the weapons, but not so long that the measures of the initial acquisition are no longer relevant. This window also has significant policy relevance. There is significant concern amongst policymakers of states that can develop or are in the process of developing ballistic missile production capabilities in the short term. The Rumsfeld Commission found that ballistic missile activities represent a significant threat to U.S. national security. The Commission found

129 See: Early (2014); Early and Way (2017); Mistry (2003); Horowitz (2010); Singh and Way (2004); Karp (1996); Gormley (2008); Jo and Gartzke (2007)
that there are serious short-term risks posed by the reverse engineering of ballistic missile production capabilities.\textsuperscript{130}

Policymakers concerned with the proliferation of ballistic missile production should have a better understanding of what leads states to reverse engineer ballistic missiles. Just as the U.S. has serious concern on the proliferation of ballistic missile production capacities, arms companies could benefit from having a better understanding of states that are likely to reverse engineer missiles they acquire. Reverse engineering has been the basis for even the U.S. and Soviet missiles programs; it provides states a significant advantage in their pursuit of missile development capacities. By focusing on states that reverse engineer foreign acquired missiles within ten years, this chapter provides policymakers and arms companies with an important tool for better understanding the potential repercussions of arms deals involving ballistic missiles.

I proceed as follows. The first section will discuss the current proliferation literature and how it relates to my theoretical framework for understanding SRBM reverse engineering and production. I will then provide a brief overview of my research design employing QCA and conduct the QCA analysis. These results are examined and used to guide a comparative analysis of select paths that lead or did not lead to states reverse engineering SRBMs within the designated ten-year window. This will help explicate the logic and story behind the paths, as well as explore how they are connected to the broader literature of proliferation.

**A Failed Case: Egypt**

These findings are also useful in understanding states that acquired SRBMs and were either perfectly content with the off the shelf models they purchased or sought to reverse

\textsuperscript{130} Rumsfeld Commission (1998)
engineer them and failed for years before eventually succeeding. Egypt had nuclear and WMD ambitions, acquired SRBMs in the early 1970s and yet, took almost 20 years to reverse engineer the technology successfully.

Egypt acquired SRBM’s in 1973 from the USSR, and their Military Rocketry Program goes back all the way to 1953.\textsuperscript{131} Egypt’s Military Rocketry Program was aimed at developing domestically designed and produced SRBMs; this failed miserably. The long-standing Military Rocketry Program, should have played a beneficial role in Egypt’s likelihood of success, and later it did, but early projects, whether they were artillery rockets or early SRBMs, were plagued by institutional patronage, and “bureaucratic ineptitude.”\textsuperscript{132} The Foreign Assistance Egypt was able to secure while pushing its SRBM production program from the design phase to testing, was also plagued by corruption and Israeli diplomatic and direct interference.\textsuperscript{133} Additionally, this assistance was illicit from West German firms, and easily shut down once discovered. By 1967 it was clear an indigenously designed and produced SRBM was a pipedream, and the program was scratched.\textsuperscript{134}

Following closer relations with the USSR after the disastrous 1967 war with Israel and the Yom Kippur War, Egypt managed to convince the USSR to deliver numerous Scud-B systems.\textsuperscript{135} Despite a clear lack of Soviet assistance, these missiles would restart the Egyptian program, which from then on would revolve around reverse engineering these Scud-B systems in a close partnership with North Korea.\textsuperscript{136} Though Egypt also engaged in the Condor Missile

\textsuperscript{131} Early and Fahrenkopf (2017).
\textsuperscript{132} Nuclear Threat Initiative, Egypt (2015); Sirrs (2006).
\textsuperscript{133} Nuclear Threat Initiative, Egypt (2015)
\textsuperscript{134} Cordesman (2004).
\textsuperscript{135} Early and Fahrenkopf (2017).
\textsuperscript{136} Nuclear Threat Initiative, Egypt (2015); Sullivan and Jones (2008).
project with Argentina and Iraq, this produced negligible gains compared to its reverse engineering program and cooperation with North Korea.

By the mid-1990s Egypt had finally been able to engage in modest gains in reverse engineering its SRBMs. So what drove this change? In 1975 Egypt delivered Scud B systems to North Korea. This was the spark that the North Korean program needed to develop. It only took North Korea nine years, despite its miserable education and economic condition, to reverse engineer and make significant strides with its SRBM systems. North Korea returned this favor by providing Egypt with significant, and long-lasting, foreign assistance. This foreign assistance provided Egypt with the tacit knowledge, experience, technology, and designs, that it’s previous program and firm based foreign assistance simply could not.

Additionally, it’s collaboration with North Korea, Argentina, and Iraq on the Condor project created the basis for a Military Rocketry Program that was better connected abroad, better funded and supplied, and more importantly, better organized. Egypt’s desire to domestically produce SRBMs did not change in the mid-1990s. What changed was Egypt’s ability to leverage the scientific and human capital benefits that sustained Foreign Assistance and a more developed and better run Military Rocketry Program. The development of domestic S&T human capital capabilities was critical to Egypt’s success.

---

137 Early and Fahrenkopf (2017).
138 Ibid.
139 Nuclear Threat Initiative, Egypt (2015); Sullivan and Jones (2008).
140 Ibid
The Proliferation of Strategic Weapons

Egypt’s ballistic missile program provides an excellent guide for applying findings from the proliferation literature to a case of SRBM reverse engineering. Why did it take Egypt so long to acquire a domestic SRBM production capability? One conclusion is that Egypt, for a very long time, simply lacked the raw capabilities to have such a demanding technological breakthrough no matter how bad they wanted it. It may be easy for any determined state to purchase missiles but being able to reverse engineer them and build more sophisticated variants cannot be attained with money alone. 141 We see this in nuclear proliferation literature. Singh and Way find that a state’s industrial capacity plays a major role in their ability to acquire nuclear weapons. 142 In a similar vein, Dong-Joon and Gartzke find that opportunity variables such as diffusion, (a play on the concept of technological determinism) economic capacity, and industrial capacity play one of the more dominant roles in explaining states that have acquired nuclear weapons. 143 Meanwhile, ballistic missile proliferation scholars follow a similar path to their nuclear counterparts. Karp focuses on financial resources and technical capital, while Mistry keys in on a spectrum of national capabilities more similar to the nuclear realm, such as industrial production and high technology production. 144

Despite the importance of raw capabilities in the proliferation of advanced missiles and nuclear programs, sheer financial cost, while heavy, is not necessarily a limiting factor for SRBMs. Karp argues that cost is only a minor barrier to the first step of ballistic missile proliferation. 145 Ballistic missiles, while costly, “are not beyond the budgets of almost any

141 Karp (1996), 88.
143 Jo and Gartzke (2007), 178-181
144 Karp (1996); Mistry (2003)
145 Karp (1996), 89
country seriously interested in acquiring them.” This applies even more so to SRBMs.\textsuperscript{146} Karp argues that a defense budget of greater than 2.5 billion dollars is enough, over several years, if allocated properly, to procure and develop ballistic missiles with ranges between 300 and 1000km.\textsuperscript{147} Barkley finds a similar result in a quantitative analysis of ballistic missile proliferation, arguing that military expenditures per percentage of GDP are no different between ballistic missile and non-ballistic missile states.\textsuperscript{148} Unsurprisingly, ballistic missile and rocketry proliferation is not as resource intensive as nuclear proliferation-although it is expected that creating a domestic production capacity will prove more resource intensive than simple acquisition. Early’s work has shown that the mechanism of rocket and missile proliferation differs from nuclear, in that it migrates from the military realm to the civilian one.\textsuperscript{149} This has important implications for understanding how states manage their resources and translate them into scientific breakthroughs when they choose to pursue reverse engineering and domestic production. So, to fully understand Egypt’s long failure, the proliferation literature needs to understand how raw resources and scientific know-how interact.

There is no doubt that a nation’s raw capability play a role in any major military project. How states manage these resources plays a bigger role. Early’s investigation on the proliferation of space launch technology provides an important caveat. A state’s ability to translate raw capabilities into scientific breakthroughs is highly dependent on the quality of a state’s research and development infrastructure.\textsuperscript{150} Money doesn’t grant an equal amount of power to all-other factors play an important role. For 10 billion dollars Iraq was only able to procure and modify

\textsuperscript{146} Ibid, 88.
\textsuperscript{147} Ibid, 88.
\textsuperscript{148} Barkley (2008). 469.
\textsuperscript{149} Early (2014). 32.
\textsuperscript{150} Ibid, 10.
SRBMs, while for roughly the same price, the US was able to develop and deploy numerous Atlas ICBMs. Scientific and human capital plays an incredibly large role in much of the proliferation and innovation literature. Its level of human capital development limits a state's ability to invest in advanced technology. How well educated is your workforce? Do you have the proper research institutions set up? Do you have access to skilled academics as well as workers? These are important aspects that limit the power of raw measures of national capability. The literature also considers the institutions and organizations available to you. Certain organizational and institutional characteristics are more likely to quickly and efficiently transform raw capabilities into technological advances and innovations. Work on scientific and human capital has shown that not only do institutions and organizations play an important role, but achievements in one field can often translate to success in other similar efforts. Early and Way (2017) found support for this idea when they found that there is a positive spillover effect on a state’s ability to acquire nuclear weapons from their ability to produce long-range missile systems. Egypt’s lack of human capital and organizational structure likely contributed to their failure to reverse engineering SRBMs.

SRBM’s, despite variation in their accuracy, have important military and strategic utility that helps drive their demand. When equipped with WMD capabilities, in regions such as the

---

151 Karp (1996), 89
152 Karp (1996); Early (2014); Mistry (2003)
154 Bozeman et al (2001)
Middle East, they are truly strategic weapons. They allow relatively weak states, such as Egypt, to threaten deep into enemy territory, even if that enemy has land and air superiority. US forces in the First Persian Gulf War were so concerned with Iraqi Scud weapons that they were hesitant about an invasion, and the absorption of Iraqi Scud attacks eventually took roughly 25-30 percent of the entire allied war effort. This is compounded by their ability to avoid air defenses with their speed and fight path. SRBMs present states with a cheap and effective way to cut through air defenses and deliver conventional and WMD munitions, at a significantly smaller cost.

SRBMs carry with them a significant normative power, especially given their tendency to be used to target civilians. Missiles make excellent media stories and are quite frightening to civilian populations, who match ballistic missiles with the cold war concept of a nuclear holocaust. Less advanced ballistic missiles “can have effects that are disproportionate to their destructiveness. In short, ballistic missiles have a symbolic significance that is potentially much more important than their military effectiveness”. The normative powers these weapons have attained grant states that possess them greater influence over regional, and possibly international affairs. North Korea, for example, has used their missile program as leverage over the West multiple times as well as a means of bolstering domestic support for an otherwise unimpressive regime. Iraq’s unsophisticated Scud variants even made the most powerful countries in the world hesitant about an invasion in early 1991. Although the mission was a complete success, and the Scuds proved fairly ineffective militarily, they still served a strategic purpose. Scud attacks

---

157 Nolan (1991), 71
159 Ibid, 63.
160 Karp (1996), 47.
161 Ibid, 49.
on Israel, aiming to provoke an Israeli response, could have dissolved the allied coalition—
including numerous important Arab allies.\textsuperscript{162}

To many states, ballistic missiles are a clear solution to a plethora of security issues,
many of which have been used to explore the broader phenomena of strategic proliferation.
Traditional measures of security, such as rivalries, past conflicts, military competition, and
conventional arms imbalances, play a major role in the proliferation literature. The literature has
a bevy of security concerns that push states to seek out ballistic missiles, the presence of
sophisticated air defense networks\textsuperscript{163} or a combination of past conflicts, enemy ballistic missiles
and WMD capabilities, or domestic interest in WMDs.\textsuperscript{164} The last motivation is of particular
salience to this study. States interested in WMDs will naturally seek a ballistic missile capability.
Domestically producing SRBMs is the first step toward a truly effective strategic WMD
deterrent, states understand this, and ballistic missile programs are very often coupled with, at
the very least, an interest in WMDs. Pinkston also raises an important point that is not as
prominent in the literature, isolation. States that feel isolated, particularly from those who they
perceive as military allies, and sources of important military equipment, such as ballistic
missiles, will be more likely to seek a domestic production capability.\textsuperscript{165}

\begin{flushright}
\textsuperscript{162} Ibid, 45.
\textsuperscript{163} Barkley (2008); Nolan (1991)
\textsuperscript{165} Pinkston (2008)
\end{flushright}
Returning to Egypt, their concerns fall well within this camp. Egypt had an intense rivalry with a regional nuclear power, a weak air force that prevented them from striking deep into Israel, and concerns over the conventional advantages Israel had over them and their Arab allies. Egypt also felt betrayed by the Soviet Union, which placed extremely strict controls on Egyptian Scud B exports, refused to engage in significant technology and production transfers, and began a rapprochement with the United States.\textsuperscript{166} This pushed Egypt to question its reliance on the USSR.

The broader field of strategic proliferation focuses on similar factors. Space proliferation often revolves around the space launch capabilities of one’s rivals. Once the US fell behind in the Space Race after Sputnik, it launched one of the most ambitious and expensive rocketry programs ever. The fear of a rival having a large advantage in such an important sector is a large and important motivation for the acquisition and development of domestic space launch capabilities.\textsuperscript{167} Singh and Way find that enduring rivalries and dispute involvement both have a positive effect on states exploring, pursuing and acquiring nuclear weapons (Singh and Way: 2004).\textsuperscript{168} While Dong-Joon and Gartzke also find that security concerns such as nuclear and conventional threats are major contributors to nuclear proliferation (Dong-Joon and Gartzke 2007: 186)\textsuperscript{169}

\textsuperscript{166} Nuclear Threat Initiative, Egypt (2015).
\textsuperscript{167} McDougall (1985); Deudney (1982).
\textsuperscript{168} Singh and Way (2004).
\textsuperscript{169} Jo and Gartzke (2007).
Theory

This paper approaches proliferation from the understanding that SRBMs, and the ability to build them domestically, represents the first and simplest building block toward a truly capable WMD deterrent. SRBMs and its associated technology are widely available in the open market. This makes reverse engineering a key path toward LRBMs and a strategic nuclear deterrent. Modern proliferation of ballistic missiles follows this trend. Out of roughly 30 states with ballistic missiles, 18 of them have imported SRBM systems.\textsuperscript{170} Out of that 18, 10 have both felt the need and have been successful (though in widely varying degrees) in reverse engineering and either modifying and improving or fully domestically producing SRBMs. Table 1.0 below shows these cases. This process was always done with, at the very least, an eye on complementing it with a WMD component or producing more advanced missiles.

The cases can be split into three categories; 1) those that successfully reverse engineered SRBMS within ten years; 2) those that took more than ten years; and, 3) those that have not engaged in any reverse engineering. The first category seeks to understand which states pose the highest proliferation risk. These are states that successfully reverse engineered imported SRBM systems within a ten-year window. These states present the biggest threats to security and stability by, often, furthering ballistic missile development domestically, or linking it to a WMD component. Additionally, these states represent new suppliers, which are often outside of any non-proliferation regimes. North Korea, within twenty years of acquiring SRBMs, became one of the biggest exporters of SRBM systems, technology, equipment, and support. Much of this support was sent to states (such as Pakistan, Iran, Egypt, and Syria) that, in turn, could reverse engineer and either further proliferate or link their new-found ballistic missile capabilities with

\textsuperscript{170} Early and Fahrenkopf (2017).
WMDs. While important, raw capabilities should play a secondary role to strategic motivations, and scientific and human capital.

Reverse engineering and developing a domestic SRBM production capability, while by no means easy, has become less and less technically, financially, and resource demanding over the years. This concept, known as technological diffusion is evident in much of the proliferation literature. As time goes on, it becomes easier and easier to gain access to a certain technology. The second and third wave of ballistic missile proliferators will have significantly more opportunities to exploit and gain foreign assistance and necessary technologies that now have legitimate civilian uses. Regarding opportunity conditions, those that are focused more on scientific and human capital should play larger roles in explaining the success Category One states, and the failures of Category Two states.

The broader proliferation literature’s findings on the effects of security concerns most likely have the greatest cross-over into this work. Reverse engineering SRBM systems is often the first step or done in tandem with attempts to acquire WMD-based deterrents. Therefore, we should see some of the same conditions driving WMD, LRB, and space proliferation within Category One and Two states. States with rivals that have ballistic missile capabilities are at a severe disadvantage strategically. When India started down the path toward ballistic missiles, Pakistan was compelled to follow suit. North Korea, facing the United States, South Korea, and Japan as rivals, needed ballistic missiles that could strategically threaten Japan, US troop deployments throughout the region, as well as the United States itself. North Korea’s acquisition and development of advanced ballistic missiles from SRBM technology further their policy of
Juche as well as enhancing their security from US attack.\textsuperscript{171} Juche is the North Korean policy of self-reliance. This was increased in the defense realm following the USSR acquiescence during the Cuban Missile Crisis.\textsuperscript{172} Although having a rival with ballistic missiles may be incentive enough to acquire your missiles, it does not necessarily mean you will attempt to indigenize or modify the acquired missile technology.

\textit{Hypothesis 1}

\textit{A rival with ballistic missile capabilities will be a necessary condition for indigenous production within 10 years.}

Although the literature points to numerous cases of states developing ballistic missiles to counter a rival’s programs and capabilities, this does not mean a rival with ballistic missile capabilities will be enough for a country to shift priorities and accept the large costs and barriers to indigenize an SRBM capability. Not all rivalries are the same, and less intense rivalries may not threaten a country’s security enough to seek out a domestic production capability. Besides, while willingness variables are important, capabilities are as well. A country may desire domestic SRBM and greater capabilities, but an inability to turn resources into scientific and technical advances may limit their ability to do so within this policy prescription’s ten-year window, if at all.

\textit{Hypothesis 2}

\textit{A rival with ballistic missile capabilities will not be sufficient for domestic production.}

\textsuperscript{171} Pinkston (2008)
\textsuperscript{172} Ibid
Two of the most important factors in judging whether a country is likely to indigenize SRBM technology are whether it will receive *Foreign Assistance* and if it already has a *Military Rocketry Program*. *Foreign Assistance* can help a state with minimal capabilities and scientific and technical capital to overcome these barriers and develop a substantial domestic SRBM capability. Israel, for example, received massive support from France in the design and application of their Jericho rocket (Mistry 2003: 111).\(^{173}\) Israel, in turn, helped South Africa, another country well below the basement for domestic SRBM capability, develop their space and military rocketry program (Mistry 2003: 85).\(^{174}\) Foreign assistance is a key part of missile proliferation and has allowed numerous states to jump-start their programs. North Korea, before it had even acquired SRBMs, was involved in a ballistic missile program with China. The DF-61 project lasted over seven years and provided North Korea with monumentally important technical expertise as well as training, experience, and equipment.\(^{175}\) While this never resulted in an actual missile of any sort, the experience and continued illicit foreign assistance helped North Korea overcome significant barriers in the early and mid-1980s to produce the Hwasong 5 and Hwasong 6, and continue onto the more advanced Nodong and Taipodong LRBMs.

North Korea, one of the most infamous missile proliferators also has helped numerous countries’ missile programs. Foreign assistance does not have to be simply equipment, training, and expertise with missiles. North Korea provides Iran with expertise, training, equipment, and missiles, and in return, Iran provides North Korea with massive amounts of financial aid as well.

---

\(^{173}\) Mistry (2003), 111  
\(^{174}\) *Ibid*, 85  
\(^{175}\) Bermudez (1999)
as oil. Without the monetary aid and oil shipments from Iran, the North Korean program would not be where it is today.\textsuperscript{176}

\textit{Hypothesis 3}

\textit{Foreign Assistance will be both necessary and highly sufficient for domestic production}

Ballistic missiles aren’t the only missiles out there. States also seek to become self-sufficient in the production, or modification and improvement of purchased tactical missiles, such as anti-tank missiles, anti-air missiles, air to air missiles and short-range artillery rockets. India and South Korea both managed to turn tactical missiles into effective SRBMs. A \textit{Military Rocketry Program} focusing on tactical missiles provides a country with a wealth of experience, connections, and a platform on which to launch their SRBM programs. North Korea, before acquiring SRBMs, had a potent missile program dating back to 1965. Years before attempting to reverse engineer and produce SRBMs, North Korea was producing and reverse engineering numerous Chinese and Soviet missile systems.\textsuperscript{177}

\textit{Hypothesis 4}

\textit{A Military Rocketry Program will be both necessary and highly sufficient for domestic production}

The vast wealth of knowledge, connections, equipment, infrastructure, and personnel that come from a \textit{Military Rocketry Program} provide a great boost to a country’s attempts to indigenize SRBM technology. A country that does not have a separate \textit{Military Rocketry Program} before they acquire SRBMs is unlikely to be able to set up an entire R&D division,

\textsuperscript{176} IISS (2006)

\textsuperscript{177} Early and Fahrenkopf (2017).
recruit experts, equipment materials, develop infrastructure and begin reverse engineering within a ten-year window. Simply put, the benefits that a Military Rocketry Program would bring are necessary for a country to have a domestic SRBM capability within a reasonable period. Additionally, a country that is not already working on a domestic tactical missile capability probably does not have a very large desire for an SRBM capability, which would only bring even more costs, attention, and scrutiny than a tactical missile program would ever garner.

MacKenzie and Spinardi leverage this idea further. They are concerned with how science itself, rather than other more traditionally grounded supply variables affect nuclear proliferation. MacKenzie and Spinardi (1995) note that if nuclear weapons development is based more on tacit knowledge rather than explicit knowledge a long enough hiatus from nuclear weapons development could see the "uninvention" of the bomb. The focus on the importance of tacit knowledge's role in nuclear weapons development has important crossover to ballistic missile proliferation. Much of the proliferation of ballistic missiles is based on reverse engineering a state’s experience developing such tacit knowledge may prove incredibly important, possibly more so than other more concrete supply-side variables. My variable "Military Rocketry Program" lines up well with Mackenzie and Spinardi's focus on the importance of tacit knowledge. States that have preexisting technical and administrative experience with missile systems may have the tacit knowledge required to develop ballistic missile technology. The ability of Foreign Assistance and Military Rocketry Programs to increase a state’s ability to leverage, at times, limited resources into effective technical and

179 Ibid pg 47
180 Mistry (2003); Karp, (1996); Nolan (1991)
scientific breakthroughs drives the logic of the final hypothesis.

Hypothesis 5

Traditional measures of capabilities (i.e., national capabilities) will not be necessary or sufficient for SRBM reverse engineering.

The Military Rocketry Program and Foreign Assistance variables are unique in that they affect what capabilities a state can bring to bear on their ballistic missile program, but they also represent numerous motivations that can influence a state to pursue a domestic ballistic missile capability. For a state to accept the costs and potential risks of developing a domestic tactical and cruise missile capability, they must have some security or domestic motivations for doing so. These motivations can be carried over into their desire for a domestic SRBM capability. Additionally, through seeking foreign assistance, which can be a costly, and dangerous process, states show that they are indeed incredibly motivated to possess a domestic SRBM capability.

Research Design

This analysis will rely on crisp set QCA (csQCA) developed by Charles Ragin. QCA creates valid generalizable results in complex causal relationships, even in situations with a small number of observations. QCA is particularly useful in developing theory. QCA clarifies complex causal relationships between variables and helps researchers better understand how combinations of variables can jointly create paths towards the phenomena of interest.\(^{181}\) QCA allows this study to probe the causal links between the variables associated with proliferation and apply them to

\(^{181}\) Ragin (2000); Ragin (2008); Bara (2014)
SRBM reverse engineering.\textsuperscript{182} This not only sheds light on SRBM reverse engineering but provides insights into the causal relationship between variables and proliferation. QCA’s ability to capture causal inferences across multiple pathways makes it an effective method for this study.

\textit{csQCA} is an effective method for studying proliferation given its tolerance for relatively small sample sizes. This study, with only 18 cases and several complex, interacting conditions, is a perfect example of an intermediate study: too small for standard quantitative approaches and too large for an in-depth case study. \textit{csQCA} approaches variables (also known as conditions) from a different perspective than binary logistic regression. Rather than if each variable has an independent effect on the outcome, \textit{csQCA} bears the assumption of maximum complexity.\textsuperscript{183} By listing every possible combination of conditions, and utilizing the Quine-McClusky algorithm, \textit{csQCA} reduces the pathways that display the outcome of creating what is known as the “complex solution” and the “parsimonious solution”.\textsuperscript{184}

The complex solution discards variables within the pathways that show the outcome, but do not enhance our understanding of it, based on the measure of consistency or coverage. Consistency is a measure of the proportion of cases that show the variable (or combination of variables) and the outcome. This fulfills a similar role as the parameter of significance in regression analysis.\textsuperscript{185} Another way to think about consistency is whether a specific variable or pathway is \textit{necessary} for the outcome to occur. Coverage is the second parameter within \textit{csQCA}. Coverage is similar to the parameter of strength in regression analysis, measuring the correlation

\textsuperscript{182} Jordan et al (2011)
\textsuperscript{183} Ragin, (2000), 95; Bara (2014), 699
\textsuperscript{184} Ragin and Sonnet (2004), 15.
\textsuperscript{185} Bara (2014), 699
between coefficients and variance.\footnote{Ragin (2008), 45; Bara (2014), 699} Coverage is better thought of as \textit{sufficiency}; how powerful a single variable or a combination of variables is in determining whether or not we see a particular outcome—in this case, whether a state reverse-engineers SRBM technology within a ten-year window.

The parsimonious solution is critical to reaching the most powerful pathways regarding consistency and coverage, known as the “intermediate solution.” The parsimonious solution is the simplest solution to the outcome. It uses all possible “remainders” or pathways that bear no cases to develop superset pathways. Within these pathways fit any other explanations of the outcome, thus simplifying the solution.\footnote{Ragin and Sonnet (2004), 14-16} However, it does this by allowing pathways that do not make theoretical sense. Thus it is up to the researcher to only drop variables from the “complex” solution that are not a part of the parsimonious solution \textit{and} also do not violate the theoretical and qualitative knowledge on the subject.\footnote{Ibid, 17; For a more detailed discussion on the csQCA process see Rihoux & De Meur (2009), Grofman & Schneider (2009), Bara (2014) or Ragin and Sonnet (2004)}

Studies with larger samples will seek to find individual variables that are quasi-necessary for the outcome and pathways that are quasi-sufficient. That is, an individual variable will, in most cases, need to be present for the outcome to occur, and the outcome occurs in most cases that make up a combination of variables (also known as a pathway). These quasi-findings are important, even at the pathway level. This study, given its smaller number of cases, seeks pathways that are wholly sufficient and conditions that are wholly necessary. Such conditions can help to further solidify the causal relationship between the variables and the outcome.
**Dependent Variable**

To stay true to the policy applications this paper is trying to provide; the dependent variable is the indigenization of SRBM technology within ten years of a country's acquisition of SRBMs. Ten years provides a window large enough for a determined country to indigenize the technology, while also being short enough for policymakers to judge a nation’s likelihood of indigenizing, based on current factors of opportunity and willingness. The ten-year window also helps avoid countries that pursue domestic capabilities for unforeseen reasons, such as a sudden conflict. The cases counted in this study are states that imported SRBMs\(^{189}\) and had complete command control and research access to these weapons. With these conditions, there are 18 total cases, 6 that display the outcome, 4 that fall into Category 2, and 8 that fall into category 3.\(^{190}\)

**Independent Variables**

The data for my independent variables draws from several sources throughout the literature. To account for the inability for sheer monetary statistics to account for the capability of a nation regarding ballistic missile development, I use the Composite Index of National Capability from the Correlates of War Project version 4.00.\(^{191}\)

The CINC score, which combines the annual values for the total population, urban population, iron and steel production, energy consumption, military personnel, and military expenditure is a better overall measure of a country's ability to produce such missiles and

\(^{189}\) Cases in which new states inherited SRBMs were not counted for the purposes of this study, as in the case of the new states formed upon the Soviet Union’s breakup.

\(^{190}\) Early and Fahrenkopf (2017).

\(^{191}\) Singer et al. (1972); Singer (1987).
replicate and improve upon their technology than GDP or military expenditure alone.\textsuperscript{192} A country is considered to possess the adequate national capability if their CINC score at the time of SRBM acquisition is greater than the previous state with the lowest CINC score upon gaining a domestic production capability. This is meant to create a bottom level of national capabilities that a country needs to possess for indigenizing SRBM technology. While the original variable was based on measures of central tendency such as mean and median, this proved to be an ineffective means of analysis. Countries such as the US, USSR, and France skewed the data out of the range of most countries. The high capabilities of the US, USSR, and France allow them to pursue projects much more advanced than simple SRBM production, thus having them in the measure of required capabilities for indigenization would set the required capabilities at an inaccurate standard.

The higher education variable for this paper uses the Barro and Lee database and focuses on the percentage of the population 25 and older that has completed tertiary levels of education\textsuperscript{193}. The year used is the closest previous year to when a country acquires SRBM. For example, Pakistan received their first SRBM in 1993, so the tertiary levels measured are 1990, not 1995. This stays true to the policy prescriptions of this paper. Governments will only be able to measure past education levels, not future ones, and this paper plays by that same rule. A state that is above the median score for states that already have attained domestic SRBM capabilities is considered to have sufficient higher education values for SRBM development. While these engineers and technicians are important, they represent a small number of the overall population with tertiary degrees. A country in pursuit of missile technology may focus its efforts on training

\textsuperscript{192} Ibid
\textsuperscript{193} Barro and Lee (2010).

North Korea was not measured in the Barro and Lee database, through outside research it was clear they did not meet the criteria set for this study.
more engineers both at home and abroad, possibly increasing the number of engineers and technicians, without actually increasing their education levels. North Korea pursued such a route. Overall though, a better-educated workforce shows that the state has the resources, infrastructure, institutions, and bureaucratic know how to engage in endeavors that require advanced scientific and technical know-how.

The Rival with a Ballistic Missile Capability variable relies on the data compiled by James Klein, Paul Diehl, and Gary Goertz, in their book “War and Peace in International Rivalry.” If according to their data a country has a rival with ballistic missiles after they first acquire SRBMs they fulfill the rival with a ballistic missile threshold.\footnote{Klein et al (2006).} This threshold stays in line with the policy prescriptions of this paper, which aim to understand why states reverse engineered SRBM technology, not why they first acquire it.

The foreign assistance variable requires sustained, significant foreign assistance from another state, not just a foreign company or organization, through at least half of their indigenization window. The sending of advisors to help set up missile battalions, training for use and repair such as was the case with the USSR and Egypt does not qualify as foreign assistance.\footnote{Nuclear Threat Initiative, Egypt (2015).} Israel, however, receiving assistance from French companies, such as Dassault, as well as the French government, is considered to have received \textit{Foreign Assistance}.\footnote{Mistry (2003) 111.} Data on foreign assistance is drawn from the existing literature. Where there is a question over the degree of assistance, length, and utility of said assistance, if all due diligence checks fail to answer the question, the variable is coded as a 0. Foreign assistance, as defined in this paper, is a very powerful tool for countries that may lack the raw capabilities or the scientific and engineering

\footnote{Klein et al (2006).}
\footnote{Nuclear Threat Initiative, Egypt (2015).}
\footnote{Mistry (2003) 111.}
know-how required for domestic SRBM production. While a state that is determined to gain a
domestic capability will eventually do so a state that is far below the raw capability threshold
and the technological threshold will take a far longer time than this study can measure, or anyone
can accurately predict. Foreign assistance can cut down the necessary time, and resources, for a
state lacking capabilities such as money or scientific know how.

To account for states experience with military missile and rocketry programs I include a
count variable of the years since initiation of a military rocketry R&D program. This approach
has been shown to be positively associated with states’ nuclear programs, SRBM programs, and
space launch programs. Data for this is drawn from the National Space and Ballistic Missile
Dataset.

The exploration of chemical or biological weapons variable and the exploration of
nuclear weapons variables seek to address a state’s willingness to reverse engineer SRBM
systems. Ballistic missile is a necessary component for a truly effective nuclear or “poor man’s
bomb” deterrent. If a state is known to possess or to be seeking CW or BW at the time they
acquire SRBMs, they are coded as a 1 for that variable. If they are exploring the development of
nuclear weapons at the time of SRBM acquisition, they are coded as 1 for that variable. The
nuclear exploration variable is based on the data compiled by Singh and Way (2004), for the CW
and BW variable I use the data from the article Poor Man’s Atomic Bomb? Exploring the
Relationship between ‘‘Weapons of Mass Destruction’’. Without such evidence, the variable is
coded as 0.

197 So long as their motivations to do so don’t change or diminish, as in South Africa, Argentina, and Brazil
198 Early (2014); Early and Way (2017); Early and Fahrenkopf (2017)
199 Early and Fahrenkopf (2017)
200 Singh and Way (2003); Horowitz and Narang (2014)
Lastly, the variables MTCR Presence and Sanctions measure whether the MTCR was in force when they acquired SRBMs and if the state was under sanctions at the time of acquisition. The MTCR is aimed at measuring a state’s opportunity by limiting its ability to acquire dual-use and foreign assistance. The Sanctions variable is meant to measure a state’s feeling of isolation or threats. The sanctions variable is coded using the data compiled within the 3rd edition of “Economic Sanctions Reconsidered.”

<table>
<thead>
<tr>
<th>Variable</th>
<th>Expected Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basement-Level National Capabilities</td>
<td>Low Sufficiency and Low Necessity</td>
</tr>
<tr>
<td>Higher Education</td>
<td>Low Sufficiency and Low Necessity</td>
</tr>
<tr>
<td>Rival with Ballistic Missile</td>
<td>Low Sufficiency and High Necessity</td>
</tr>
<tr>
<td>Foreign Assistance</td>
<td>High Sufficiency and High Necessity</td>
</tr>
<tr>
<td>Rocketry Research Program</td>
<td>High Sufficiency and High Necessity</td>
</tr>
<tr>
<td>Chemical Weapon and Bio-Weapon Exploration</td>
<td>High Sufficiency and High Necessity</td>
</tr>
<tr>
<td>Nuclear Weapon Exploration</td>
<td>High Sufficiency and High Necessity</td>
</tr>
<tr>
<td>MTCR</td>
<td>Low Sufficiency and Low Necessity</td>
</tr>
<tr>
<td>Sanctions</td>
<td>Low Sufficiency and Low Necessity</td>
</tr>
</tbody>
</table>

---

201 Hufbauer et al (2009)
Results

The necessary conditions bear some interesting findings. With the consistency threshold set at 1.0 (at this threshold any condition found will be fully necessary for the outcome), I find three single conditions are wholly necessary for a state to reverse engineer SRBM technology within a ten-year window. These three conditions include foreign assistance, military rocketry R&D program, and rival with a ballistic missile capability. The last condition, rival with ballistic missiles, while necessary, is not particularly powerful given its low coverage score. However, foreign assistance and military rocketry R&D program have high coverage scores of 1.0 and .75 respectively. This makes foreign assistance, at least how it is coded here, fully necessary and sufficient for a state to reverse engineer foreign acquired SRBMs within a ten-year window, and military rocketry R&D program sufficient in 75% of cases. This shows strong support for Hypotheses 3 and 4 and falls in line with the broader proliferation literature’s work on the importance of tacit knowledge and scientific and human capital in large-scale military technology projects, such as LRBM production and nuclear weapons programs. Without the tacit knowledge and expertise that these two conditions supply, states cannot reverse engineer SRBM systems within a ten-year window. In addition to this, the knowledge, equipment, and experience these conditions can bring to a program make it highly likely that any program with these conditions will succeed in reverse engineering SRBMs within ten years.

Additionally, the high sufficiency of these two conditions has a bearing on a state’s willingness as well. States that seek significant foreign assistance, and have well developed military rocketry R&D programs, show that they are willing to see to completion a project that often bears significant political, diplomatic, and financial costs. These findings have both policy and theoretical relevance. Policymakers should be highly suspicious of any foreign assistance,
even if it falls within the framework of the MTCR. They should also be wary of exporting SRBM systems to any state that has a Military Rocketry Program. Even if this program is originally geared towards less sophisticated tactical or artillery rockets, the tacit knowledge and organizational capacity that is acquired from it, as well as the high costs, often signifies an interest in more advanced systems and the ability to pursue them. This finding reinforces much of the work from multiple ballistic missile, nuclear, and space proliferation literature.\textsuperscript{202}

These initial results also show strong support for the first two hypotheses. \textit{Rivals with ballistic missile capabilities} are a necessary, but very weak condition for states to reverse engineer SRBM systems. There are several possible explanations for this. Some rivalries are more powerful and threatening than others. Some may be satisfied by simply acquiring SRBMs, while others may push states to reach for the loftier security guarantees that domestic production capacity may provide. In short, a rival with ballistic missile capabilities appears to be a better measure of a state’s determination to acquire, not reverse engineer SRBMs.

Although important, the necessity tests look only at individual conditions. It is the sufficiency tests in csQCA that reveals which combination of conditions (or pathways) are the most powerful in explaining our dependent variable. As with many works using csQCA, the pathways need to be simplified by dropping redundant and less powerful variables.\textsuperscript{203} This process is done by creating an intermediate solution that falls between the most complex and the most parsimonious solution sets. Although the most complex solution explained all the occurrences of the dependent variable, it did so with 4 different pathways. These pathways are needlessly complex and contain conditions that are not relevant to the outcome. The conditions traditionally used to measure opportunity, \textit{National Capabilities as measured by the CINC Score},

\textsuperscript{202} Early (2014); Early and Way (2017); Horowitz (2010); Karp (1996); MacKenzie and Spinardi, (1995).
\textsuperscript{203} Bara (2014) 701.
and Higher Education as measured by the Barro and Lee dataset were dropped. Additionally, the exploration of chemical and biological weapons and the presence of sanctions and the MTCR were also dropped. As is the case in other works utilizing QCA, certain conditions such as these may play important roles, but they do not enhance our understanding of the outcome, nor do they create a better solution considering consistency and coverage, they needlessly create more complexity. ²⁰⁴

The intermediate solution leaves us with the following path toward reverse engineering: States that have a Rival with Ballistic Missiles, which receive Foreign Assistance, have a Military Rocketry Program and are exploring Nuclear Weapons are the highest proliferation threats due to their high likelihood of reverse engineering SRBM technology quickly. This pathway highlights the decreasing importance of traditional measures of national capacity in the process to reverse engineer SRBMs within a ten-year window. Instead, National Capabilities and Higher Education are easily replaced by Foreign Assistance and Military Rocketry Programs in each pathway of the outcome. This highlights the incredible importance of S&T human capital and organizational design that a Military Rocketry Program and Foreign Assistance can bring. This shows strong support for Hypothesis five, which highlights the broader proliferation literature findings on the importance of institutional design, human capital, and tacit knowledge when it comes to proliferation and technological innovation.

Measures of opportunity are still important in understanding this foundational step of proliferation, but it is knowledge and human capital that plays a bigger role in acquiring a domestic production capacity. And in a globalized world, these are becoming more available in multiple fields. The decision by the Australian Group in 2002 to limit even the electronic spread

²⁰⁴ Bara (2014) 701-702
of knowledge and technology related to chemical and biological weapons programs, such as “cookbooks” is evidence of the growing concern for the increasing role of knowledge in proliferation.205

The demand for a domestic SRBM production capacity is tied to some traditional measures of security as well. Rivalries, and the capabilities of those rivals, while weak on coverage score, is still wholly necessary to the outcome. If a state does not have a rival with ballistic missiles you are unlikely to see them reverse engineer SRBMs, but the variable provides little in the way of an explanation for why, or how, states make that leap. Instead, the Nuclear Weapons Exploration variable provides a better picture. States that feel the need to explore nuclear weapons recognize that having advanced ballistic missile capabilities are a natural part of an effective nuclear deterrent. Many current proliferation cases support this finding. Iran, North Korea, and Pakistan cooperate at great lengths on both nuclear and missile technology.

The only condition that could have been dropped here, due to redundancy amongst the complex solution paths, is nuclear weapons exploration. The rationale for keeping this condition is that only Turkey out of all six positive outcomes was not actively exploring nuclear weapons at the time of SRBM acquisition. This still makes NW a powerful condition in explaining states that reverse engineer SRBMs within a ten-year window. Turkey is an outlier and one that may not be so farfetched given Turkey’s regional status and serious concern over the Iranian nuclear program. Turkey may very well be setting itself up in a strong hedging position in case the Iranian nuclear program continues and is successful. 206

---

205 The Australia Group (2014).
206 Ulgen (2012)
Conclusion

Reverse engineering SRBMs is the gateway for the new wave of strategic space and weapon proliferation. This paper sought to adapt the broader proliferation literature toward better understanding a foundational and increasingly common step toward more advanced proliferation. Additionally, it sought to create a category that is easily replicated for policymakers to have a generalizable guide toward recognizing which states pose the greatest future proliferation risks. This study found that time and technological diffusion have made raw capabilities a minimal factor toward reverse engineering, and domestically producing, SRBM systems. Instead, states can leverage resources to create and utilize things such as, tacit knowledge, institutional design, and scientific and human capital that plays the most important role in a state’s ability, and even willingness to reverse engineer SRBMs. Foreign Assistance and Military Rocketry Programs are two important factors in determining a state’s willingness to bear, at times, the significant costs associated with such a program and its ability to be successful. It is not the raw capabilities that are important; it is the state’s ability to transform them into scientific and technical institutions that are effective and efficient. Foreign Assistance and Military Rocketry Programs are strong and important measures of this.

It has also shown that states that pursue a domestic SRBM capability often may prove to be future nuclear proliferation risks as well. While the capacity factors for nuclear and SRBM production may only share a similar reliance on scientific and human capital and institutional design, the demands for both have similar origins. This highlights what much of the qualitative ballistic missile literature discusses so often; that ballistic missiles are often an extension of a state’s broader strategic deterrent desires.
The outcome-oriented model of csQCA helps to solidify an important contribution of this paper. By directly explaining the outcomes of cases of successful SRBM reverse engineering and production, I provide a clear and generalizable pathway, as well as individual variables, that play a large role in explaining when a state is able to reverse engineer SRBM technology quickly. This serves two purposes; first, it will help guide policymakers in determining which states are the greatest future proliferation risks. Given the large amount of SRBMs sold by the United States and other major powers, as well as its intense focus and high costs incurred on counter and non-proliferation efforts, these states could benefit from a more clear understanding of the connections between SRBM proliferation and the more pertinent nuclear and LRBM proliferation. Secondly, it will help policymakers identify when states with SRBMs may feel pressured to reverse engineer their weapons. This will help states craft more focused counter-proliferation policies aimed at both a state’s willingness and opportunity to reverse engineer SRBMs.

This paper aimed to apply and adapt the broader rocketry and nuclear proliferation literature’s findings to a less advanced and less demanding, yet important, part of the proliferation story. The decrease in the raw capabilities required raises interesting questions for LRBM and nuclear proliferation. How long will the high resource barriers for more advanced proliferation last? Could the pathways to nuclear proliferation eventually look like those for the reverse engineering of SRBMs? Future research on missile, space, and nuclear proliferation should be aimed at addressing questions such as these. Understanding the differences between states that have no interest in such technology, states that hedge, states that fail, and states that succeed are important, yet understudied distinctions within the field. Through the lens of SRBM

---

207 Bara (2004), 707
reverse engineering, this paper sought to explore a step in proliferation that an increasing number of states are taking, and by doing so, help connect a growing and broad literature that is intimately connected and still has a lot to explore.
Chapter Four: Stealing from the Best: The Determinants of the Vertical Proliferation of Cruise Missile Production

Introduction

June 13, 1945, one week after the Allied landings in Normandy, a distinct loud buzz, soon to be known as the rapid combustion of the first cruise missiles' pulse jet engine, roared a few thousand feet above London. The loud pulsating "buzz" disappeared as the pulse jet engine, a crude form of guidance, was cut and the missile fell. The silence was followed by a massive explosion as the 1-ton warhead exploded near the docks used to deliver supplies to Normandy. London had just witnessed the V-1, also known as the "buzz bomb," the first land-attack cruise missile. The V-1 wreaked havoc on London until Allied forces realized planes could easily intercept and shoot down the V-1 missiles in flight. Current generation LACMs have far surpassed the capabilities of the V-1. LACMs are now capable of traveling thousands of miles, carrying large warheads, and enjoy pinpoint accuracy from redundant guidance systems. ASMs also boast large ranges, supersonic speeds, and deadly accuracy. However, producing these modern missiles is not cheap. They require advanced defense production capacities, financial and industrial resources, scientific and technical capital (S&T), and experience. The proliferation literature has broadly looked at proliferation as a binary variable. States' lack a capability until it is developed, after which they join the club. This has been the general approach to WMD and LRBM proliferation. This perspective lacks a key component to not only understanding the types of power states can bring to bear, but also the production capacities that states have.

Not all weapons are created equal. New members of the nuclear club develop simple gun-type fission atomic bombs. The major nuclear powers utilize fusion warheads on LRBMs, with

---

208 BBC (2003); Neufeld (2014).
multiple retargetable re-entry vehicles. While entry into the nuclear club is an important qualitative line to cross, the nuclear weapons employed by some states are more powerful and threatening than others. Specifically, the capability gaps between ASMs and LACMs is particularly pronounced. Modern ASMs and LACMs are effective, reliable, and difficult to counter weapons. These weapons grant states enormous strength in both projecting power and resisting more powerful forces, but not all states can purchase or produce ASMs and LACMs of this quality. To better understand proliferation and the strategic nature weapons have on the international system, it is essential to move away from a binary understanding of proliferation. Academics and policymakers need to be able to account for how weapons of different sophistication are not only built but how they influence the military power and capabilities of states' and non-state actors.

The wide gap in production capacity for ASMs and LACMs raises interesting questions regarding proliferation. Roughly 21 states produce ASMs and 14 LACMs. While this is an important milestone, as the previous chapter discussed, it only captures one part of the proliferation picture. The types of missiles these states produce vary widely. What drives states that have developed production capacities for LACMs and ASMs to continue to invest in producing increasingly advanced missiles? What resources do states need to increase the sophistication of their domestic missile production capabilities?

These questions are essential to both academics and policymakers concerned not only with proliferation but with power. Producing ASMs and LACMs is not always enough. Missiles that had significant power ten years ago can be made useless in short order against modern militaries as counter-measures and more advanced missiles are developed. Egypt and Syria

---

learned this the hard way during the Yom Kippur War, as their previously effective Styx ASMs became useless against Israeli counter-measures. While even the simplest LACMs and ASMs can pose problems, they face rising barriers to effectiveness every year. States that continue to invest in producing increasingly sophisticated missiles can change the balance of power against more dominant states. China has pursued this policy as part of their "assassins mace" strategy. This strategy has seen China invest heavily in producing more sophisticated ASMs and LACMs to bolster their anti-access and area-denial strategies. China's missile advances have caught the US off-guard and have significantly altered the balance of power in the South China Sea.

Finally, while the determinants for the horizontal proliferation of strategic weapons has received significant attention, this is only part of the proliferation puzzle. How states continue to invest in weapons programs to develop increasingly sophisticated forms of strategic and conventional weapons is the next stage of proliferation states embark. This second stage of proliferation is incredibly important because the utility and power of weapons change over time, and advances in the weapons themselves and countermeasures can alter the balance of power.

The vertical proliferation of ASM production presents a more complicated picture than the horizontal analysis. While security motivations play an essential role in a state's first steps toward production, they are not pertinent in a state continuing to produce more advanced missiles. Instead, the primary driver of a states' missile production sophistication is the organizational and scientific and human capital within the realm of ASMs and missile production more broadly. Time and the continued diffusion of more advanced ASMs throughout the international system positively contribute to states missile production capacities as well. This finding paints a grim portrait for nonproliferation policies. Once states cross a threshold, the

---

211 Schulte (1994)  
212 Gormley et al. (2014)
ability to prevent continued advances becomes increasingly difficult. The vertical proliferation of LACMs deviates partially from ASMs. While security concerns seemingly play little role in the vertical proliferation of ASM systems within states, security concerns play a regular role in states continuing to produce more advanced LACMs. Curiously, for LACM vertical proliferation specific scientific, technical, and organizational capital take a backseat to economic size, a more traditional measure of national capabilities. The one constant between ASM and LACM vertical proliferation remains time and the diffusion of more advanced LACMs into the international system.

This chapter proceeds as follows. I first highlight the existing approaches to understanding the determinants of proliferation with a focus on vertical proliferation. I then briefly discuss the development of ASMs and LACMs since their introduction into the system. This is followed by a discussion of my theory on the vertical proliferation of ASMs and LACMs. Next, I discuss my research methods and variables, with a focus on my new variable that captures the sophistication of states domestically produced missiles. Finally, I discuss the results of my quantitative analysis and offer some concluding remarks.

**Buzz Bombs to Tomahawks The development of ASMs and LACMs**

ASMs have become the most critical naval weapon in the inventories of many states. They can be both traditional air-breathing cruise missiles, which tend to have longer ranges, and the shorter-ranged rocket-powered missiles. Over 80 countries possess some variant of ASM, though the levels of sophistication, range, and payload vary widely. Modern ASMs and LACMs rely on near-perfect accuracy. This is incredibly difficult to do in the open ocean at long ranges.

---

213 Carus 1991, 14-15
Modern land attack cruise missiles rely on guidance systems that save radar images or actual high definition pictures of the landscape of their routes and targets for their mid-course and terminal guidance, which does not work in the open ocean.

Additionally, where land attack cruise missiles could still be effective with accuracies of over 50m CEP for large targets such as airfields, ASMs need pinpoint precision because near misses are unlikely to do any severe damage against surface vessels (unless the ASMs are armed with nuclear warheads, as many old Soviet missiles were). To account for this, modern ASMs have some form of mid-course inertial guidance and advanced terminal guidance, known as "fire and forget." Terminal guidance often employs one or more technologies such as; active and semi-active radar, radar homing, infrared, television man-in-the-loop\textsuperscript{214}, and home-on-jam.\textsuperscript{215} Survivability also plays a significant role: as ASMs increased in use and sophistication, the more advanced states developed layered countermeasures. Survivability includes the use of multiple missiles engaged in dogleg routes\textsuperscript{216} advanced countermeasures, sea-skimming and having large arsenals of advanced missiles.

ASMs, as we know them today, saw their start in the Soviet Union during the 1950s. The Soviet Union was greatly outmatched at sea by the massive US surface fleet which revolved around aircraft carriers. Knowing that they could not compete with the US in the nature that Japan had attempted to in the Second World War, the Soviets focused on developing stand-off weapons. ASMs could counter the power projection innovation of carrier task forces, for which

\textsuperscript{214} Man in the loop guidance is when the terminal phase of the flight has a human operator controlling the final strike.
\textsuperscript{215} Ibid, 14-15
\textsuperscript{216} Dogleg route capabilities allow multiple missiles fired from multiple platforms to arrive at the same target at the same time from different directions. This serves the purpose of overwhelming layered countermeasures and missile defenses.
the US was, and has remained, unmatched.\textsuperscript{217} Many of the first anti-ship missiles developed by the Soviets, such as the P-1 Scrubber, were equipped with nuclear warheads, given the lack of accurate and reliable mid-course and terminal guidance.\textsuperscript{218}

One of the first steps toward the modern anti-ship missiles was the P-15 Termit, better known as the Styx missile. This class of missiles has been widely exported and saw its first combat in the sinking of the INS Eilat. It was the sinking of the Eilat that showed the Soviet Union’s focus on anti-ship missiles could seriously challenge the dominant naval orthodoxy at the time.\textsuperscript{219} The success of these weapons when used against more powerful naval fleets, along with their extensive proliferation, helps to reinforce this point. Over 80 states now possess these weapons and view them as a necessary component of their naval forces.\textsuperscript{220} 22 states build their anti-ship missile systems. Out of these 22 states, 5 developed these weapons through indigenous means, while 17 had previously imported other versions of ASMs. The most common missiles on the market are the US Harpoon, Russian Styx and its multiple variants, Chinese Styx variants, and the French Exocet.

\textit{What Determines the Sophistication of States Missile Production Capabilities?}

There is limited work that investigates the vertical proliferation of weapons production capabilities within states. Despite this, the broader strategic proliferation literature's findings on the determinants of proliferation should still play essential roles in vertical proliferation. Acquisition and continued development are not the same. Gaining initial production capacity for weapons is a difficult first step that is driven by several factors influencing the proliferation

\textsuperscript{217} Horowitz 2010, 83-84  
\textsuperscript{218} Pike et al (2000).  
\textsuperscript{219} Fieldhouse and Toaka 1989, 22  
\textsuperscript{220} Early et al. 2015
decisions and capabilities of states. Initial production capacities rely on developing field-specific S&T human capital, designs, testing, production, and deployment capabilities. Developing the "hands-on experience" and going through rounds of failed tests and design changes is difficult and requires time and resources.\textsuperscript{221} Despite the higher initial cost of horizontal proliferation, continuing to invest in domestic production capacities to produce increasingly sophisticated missiles is also expensive.

States with well-developed nuclear programs, such as the United States, are continuously forced to confront these expenses. To modernize the U.S. nuclear arsenal, it would cost over 1.2 trillion dollars over thirty years. This is a massive investment and includes vertical proliferation as the U.S. develops more efficient weapons and delivery systems. Proliferation does not end with acquisition; it is an on-going process that eventually will demand the vertical proliferation of states' domestic production capacities. Continued investment is vital from an S&T capital perspective as well. U.S weapons designers are not considered "useful" until they have gained five to ten years of experience.\textsuperscript{222} Given the continued resource expenditure required to engage in vertical proliferation, we should expect to see states security environment influence their decisions to continue investing in their missile production capabilities.

Security threats have played an important role in states investing significant resources into developing more advanced missile production capabilities. The cornerstone of China's "Assassins Mace" strategy is based on producing and deploying increasingly sophisticated anti-access and area denial capabilities. One significant aspect of this has been the production of advanced ASMs and LACMs. China has invested heavily over the past twenty years to develop

\begin{footnotes}
\end{footnotes}
domestic production capacities for increasingly sophisticated ASMs and LACMs.\textsuperscript{223} This has been part of their effort to gain the upper hand in any conflict within the South China Sea.

Following the inability of U.S. missile defense systems to intercept even crude Iraqi LACMs during the 2003 war, there was an increasing focus for both new and old producers to increase the sophistication of their LACMs to even further leverage the penetration capabilities of LACMs. This, combined with the U.S. effectively utilizing LACMs as a primary mean for precise conventional stand-off strike capability, has turned LACMs into a critical piece of military hardware for states with pertinent security threats. Both India and Pakistan have invested heavily in advanced, domestically produced LACMs to ensure conventional strike penetration against one another.\textsuperscript{224} Increasing threats from North Korea and China have also triggered South Korea to begin investing in advanced LACMs. Russia as well as increasingly sought to produce more advanced LACMs. While the reasons behind Russia re-investing in producing modern LACMs is multifaceted, a primary concern has been the expansion of NATO and US investment in missile defenses in Europe.\textsuperscript{225}

Egypt and Syria learned the hard lesson of being caught with old weapons during the 1973 Yom Kippur war. The once dominant Styx missiles were useless in the face new Israeli counter-measures. Egypt and Syria attempted to acquire more advanced missiles but were rebuffed by the Soviet Union. With antiquated ASMs Syria and Egypt scored no hits on Israeli warships. It was the modern Gabriel missile that incorporated new technology to devastating effect.\textsuperscript{226} Israel security environment demanded the need for modern ASMs and was able to

\textsuperscript{223} Gormley et al. (2014).
\textsuperscript{224} Gormley (2008), 117, 119-121.
\textsuperscript{225} Gormley (2008), 122.
\textsuperscript{226} Chant (2013), 511; Schute (1994), 5-6
follow through with this demand. Egypt and Syria, though recognizing the need for more modern ASMs, lacked a domestic production capacity, which contributed to their losing the war.

**Hypothesis 1: Security threats will increase the sophistication of states domestic missile production capacities.**

Starting in the 1990s, the narrative regarding the utility of LACMs began to change. Nuclear powers and conventional powers alike raced to develop and acquire increasingly sophisticated LACMs. States began to become keenly aware of the effectiveness of LACMs as standoff weapons capable of devastating precision strikes, penetrating air defenses, and conducting area-denial operations. The use of LACMs by the U.S. throughout the 1990s and 2000s, particularly their effective use in both the Persian Gulf and 2003 Iraq Wars, and the inability of US missile defenses to intercept crude Iraqi LACMs during the 2003 Iraq war fueled this shift. Before this time LACMs were generally used to complement nuclear weapons.\(^{227}\) The increasing availability of dual-use technologies related to LACM development helped fuel this spread, but the opinion states had of LACMs changed dramatically throughout the 1990s and 200s, due to their frequent successful uses. It can be argued this is merely a matter of the level of sophistication of the weapons in the system at the time of the demonstration points, and this would be true. It does not change the fact though, that without narrative shifts from demonstration points states have little incentive to invest in modern LACMs.

**Hypothesis 2: Demonstration Point will play a decisive role in the sophistication of states LACM production capacity.**

\(^{227}\) Gormley (2008), Chapter 7.
Gaining an initial acquisition capacity for ASMs and LACMs does not eliminate the need for the S&T human capital required to design, test, develop, and manage complex missile programs. States' vertical proliferation efforts have seen constant investment in the S&T human capital that is so critical for initial acquisition efforts. As missile and rocket programs become more sophisticated, the margin for error in the designing, testing, and production of missiles decreases substantially. S&T human capital and the tacit knowledge that comes with it becomes increasingly important.\textsuperscript{228} These skills and experience are much harder to acquire from abroad and rely heavily on domestic sources.\textsuperscript{229} States' civil space capabilities have been shown to increasingly rely on S&T human capital as they continue to advance toward more sophisticated capabilities, such as the production of space launch vehicles.\textsuperscript{230}

The vertical proliferation of states' missile and nuclear capabilities have also been reliant on S&T human capital. States' experience with nuclear weapons and their nuclear capacity are essential factors in determining whether they will develop and implement additional nuclear delivery platforms.\textsuperscript{231} Chinese efforts to enhance their missile production capacities has consistently focused on developing extensive domestic S&T human capital.

Starting in the 1960s, China began investing heavily in developing domestic industrial and S&T human capital within the military domain, with a heavy emphasis on domestic missile production. These efforts saw the creation of numerous research institutes and government agencies that managed projects related to missile development and invested in training scientists, engineers, and technicians. These efforts were merged into one organization, which at one point, before again being separated into civilian and military sectors, managed over 5 million personnel.

\textsuperscript{228} Johnson-Freese (2007), 144.
\textsuperscript{229} Montgomery (2005); Johnson-Freese (2007), 144.
\textsuperscript{230} Early (2014).
\textsuperscript{231} Gartzke et al. (2014).
across factories, research institutes, and academies.\textsuperscript{232} China also sought to acquire support for developing S&T human capital and missile experience from foreign sources. This began with Soviet assistance on its first ASM, a Soviet Styx copy, developed in the late 1960s. Even today, China continues to invest significant resources in developing S&T human capital in the missile realms both abroad and domestically. China pursued this in a number of ways. Efforts were made to train Chinese students and workers abroad. There were significant investments in continuing to develop domestic research and technical academies. China produced licensed copies of advanced Russian weapons and related technology and employed foreign technicians and scientists to help develop weapons and train Chinese personnel.\textsuperscript{233} China has been so successful in these efforts that Russia has sought to limit China’s access to Russian technicians and intellectual property rights.\textsuperscript{234} China is not alone in pursuing this strategy, North Korea and Iran have also pursued such strategies to enhance their domestic missile production capacities rapidly.\textsuperscript{235}

The knowledge and experience from these efforts across the field of defense production and the experience in managing complex defense programs play an important role in states’ ability to pursue increasingly sophisticated missile production capabilities.

\textit{Hypothesis 3: States will continue to rely on S&T human capital to develop increasingly sophisticated missiles.}

A major concern of policymakers engaged in nonproliferation efforts is the increasing ease with which proliferators can acquire equipment, technology, and knowledge related to

\textsuperscript{232} Gormley et al. (2008), 11.
\textsuperscript{233} — Ibid, 12-13.
\textsuperscript{234} Ibid, 13.
\textsuperscript{235} Gormley, 2008.
proliferation. As time goes on and technology spreads it becomes increasingly easy for states to acquire the relevant knowledge and materials to proliferate. This concern dominated discussions of nuclear proliferation during the 1960s and 1970s and continues to dominate discussions regarding the effectiveness of the NPT.\textsuperscript{236}

Though the feared wave of nuclear proliferation failed to materialize, for a variety of reasons, this concern about the diffusion of relevant technology throughout the system is still incredibly pertinent to understanding how states proliferate. Part of this is the dual-use nature of much of the relevant technology. The dual-use nature of much of the technology and knowledge relevant for missile production makes it easy to be repurposed towards military applications.\textsuperscript{237} The boom in the proliferation of LACMs starting in the late 1970s and early 1980s came about not from focused LACM production efforts but from significant technological advances in numerous interrelated and dual-use fields.\textsuperscript{238} The threat of dual-use technology and equipment became readily apparent as the U.S. discovered numerous U.S., European, and South Korean parts and technology in the wreckage of a North Korean missile test. Much of this technology and equipment fell just below the threshold for controls.\textsuperscript{239} Equipment, technology, and knowledge that initially was closely guarded have slowly diffused throughout the system. Weapons that were once closely guarded become less valuable, and states are more likely to export them, furthering the diffusion of critical technology, components, and knowledge throughout the system. Nuclear proliferation has benefited from this as well. As nuclear technologies spread throughout the system for legitimate civilian and military applications, it has become easier for states pursuing nuclear weapons to develop nuclear programs.

\textsuperscript{236} Walsh (2005), 9-10.
\textsuperscript{237} Karp (1996).
\textsuperscript{238} Betts (1982); Gormley (2008)
\textsuperscript{239} Byrne (2014).
Diffusion, over time, makes it easier for states to not only source parts and equipment from multiple sources, but also knowledge.\textsuperscript{240} The international community has responded to the threat of diffusion and technological determinism by establishing stringent controls on the spread of military and dual-use technology. The multilateral export control regimes, such as the Missile Technology Control Regime (MTCR), the Nuclear Suppliers Group (NSG), Wassenaar Arrangement (WA), and the Australia Group (AG) have sought to limit the proliferation of dual-use and military goods related to WMDs and conventional weapons. These informal regimes are made up of states with significant production capacities for WMD and conventional weapons. UNSCR 1540 legally requires all member states to develop adequate trade controls to prevent the proliferation of dual-use and military goods related to WMD and delivery systems to non-state actors. The MECRs and UNSCR 1540 promote best practices, conduct capacity building, and share intelligence on proliferation threats and networks to attempt to undermine the ease with which states seeking WMDs and other conventional weapons can access them and related equipment, knowledge, and technology on the open market. This has been done with varying degrees of success, as the spread of these relevant goods continually proves to be difficult to control.

This does not necessarily make these weapons more dangerous, as weapons need to advance rapidly to overcome countermeasures and other weapons that can target missile launch platforms. Despite this, diffusion of missile-related technology likely increases the speed with which states can "catch up." Moreover, while major powers, such as the U.S. may be able to counter less advanced missiles effectively, these weapons can still significantly influence regional security dynamics. Also, the 2003 Iraq war is evidence that even crude LACMs can

\textsuperscript{240} Jo and Gartzke (2007).
impact major states military operations. The nature of LACMs and ASMs makes them dangerous weapons, even if they are not as advanced as the most sophisticated ones in the system.

_Hypothesis 4: The diffusion of missile-related technology will increase the sophistication of states missile production capabilities._

**Research Methods**

The data employed in this chapter is time-series and cross-sectional, with the country year as the unit of analysis. The quantitative analysis utilizes a random-effects regression model. Controlling for random effects best fits the vertical proliferation data because of its ability to control the variation of explanatory variables both within units and within the population. Random effects also have less dependence on sample size than fixed effects. Given the smaller number of country units that possess missile production capabilities and observations per unit in my data, this makes random effects the superior model.  

Despite this, I also run additional models that control for fixed effects and no effects as robustness checks. There is no significant difference between the primary models and the robustness checks.

**Dependent Variable**

The dependent variable for my analysis is a new set of missile sophistication scores that I developed for ASMs and LACMs from 1950-2007. My analysis relies on data compiled by the National Cruise Missile Dataset and the new methodology I developed for comparatively ranking ASMs and LACMs by their sophistication levels.  

I employ similar models to explain the

---

242 NCM (2018)
vertical proliferation of both ASMs and LACMs, except that I also control for states being land-locked states in the case of ASMs as that factor diminishes' states need for them.

The NCM

Much of the data for this dissertation is drawn from the National Cruise Missile Dataset. The NCM dataset codes the worldwide efforts to develop and possess cruise missile capabilities from the end of the Second World War until 2015. This dataset collects information on states' possession of strategic, anti-ship, and conventional ground attack cruise missile arsenals, how those capabilities were acquired, and whether states have the capability of producing them. The NCM has three separate datasets. The first breaks both land attack and anti-ship missiles up into categories based on their technological and strategic capabilities. The second dataset is a complete missile list. This list details, country by country, every missile that has ever been deployed in a state's arsenal and is available in the open source. The third dataset is a time series cross-section of the most technically advanced missile in a state's arsenal based on range and broken up by mission and launch platform.

The NCM uses a definition of cruise missile that is similar to Seth Carus’ in “Cruise Missile Proliferation in the 1990s”. We, like Carus, use the broad definition as laid out in the INF treaty to capture a more wide, and accurate array of the large variety of cruise missiles that exist in global arsenals. A cruise missile is: “an unmanned, self-propelled, vehicle that sustains flight through the use of aerodynamic lift over most of its flight.” This definition, as Carus

---

244 Carus (1992), 7-9.
points out, considers a broader array of tactical and strategic cruise missile weapons, such as rocket-powered anti-ship cruise missiles and cruise missiles within the loop terminal guidance.\textsuperscript{245}

**Coding Missile Sophistication**

The sophistication score ranks missiles based on their capabilities. This system is based on the open source data of the NCM and provides an essential portrait of the technological sophistication and military capabilities of the missile systems. The sophistication score breaks down several easily defined and identified capabilities that make missiles more sophisticated and deadlier. The sophistication score, while relying on a technical understanding of what makes missile advanced and deadly, is not technically detailed. It is not meant to explain the benefits of highly technical systems within missiles, such as particular engine designs, radar guidance techniques, and aerodynamics and radar cross-sections. Such data would be technically challenging to produce and nearly impossible to acquire. Instead, the sophistication score paints an essential portrait of how deadly missiles are based on their ability to marshal the capabilities in the score that have been found to play a role in making missiles more effective and technically challenging to produce.

Missiles with a higher score may not be inherently deadlier or more advanced when considering different tactical and strategic environments, or highly technical details. These types of capabilities can change quickly and without indication, as states perform upgrades to pre-existing missiles. This score is meant to capture significant changes in the technical sophistication of states' missiles as they add whole new capabilities reliant on considerable technological advances. Despite this, the sophistication score is the first systematic effort at

\textsuperscript{245} Ibid, 8.
trying to capture the vertical proliferation capabilities of states. Being able to understand the military utility and technological sophistication of weapons is an integral part of understanding how weapons affect the balance of power and a crucial second stage to proliferation that is often overlooked.

The ASM sophistication score goes from 1-24, the LACM score from 1-30. The following scale is split into three tiers. These tiers reflect the sophistication of the missile as well as the generalized threat it poses. This is an imperfect scale and is generalized to a large scale strategic, not tactical level. The minutiae of the technical details for each category can get incredibly complex in how differences within each category can affect missile sophistication and lethality. This index is meant as a general reflection of a missile's (and by that extension a nation's) ASM (or LACM) Capabilities and the threat they may pose to foreign navies. It is by no means a perfect capture, but a way to separate highly threatening missiles from others and to trace a nation's ASM sophistication over time.

The sophistication score is calculated as an additive score. It represents the sum of all the components, listed below, for which missile systems are equipped. This score is applied to each missile in a state's arsenal. It is not based on the total capabilities' states can produce, but is based at the missile level. In the coding of this variable, I code the single most advanced missile a state can produce, even if they produce a range of missiles.

**ASM Sophistication Score Scale**

*1st Tier: 1 Point Awarded*

1. Air Launched: Missiles that are air-launched require sophisticated technology to attach the weapons to aircraft, launch mechanisms, and advanced guidance and targeting
capabilities. Additionally, air-launched missiles provide states with even greater stand-off capabilities by increasing the practical range of the missiles.

2. Submarine Launched: Submarine launched missiles require very complicated launch mechanisms. Like an air-launched missile, they also provide states with increased stand-off capabilities. More importantly, through submarines, they can be placed strategically critical launch locations secretly and launch with little warning.

2nd Tier: 2 Points Awarded

1. Datalink: Datalinks allow states to communicate with missiles after they are launched. This provides states with numerous advantages. One advantage is states can provide man-in-the-loop guidance, where an operator either on the launch aircraft or elsewhere can make strike decisions in real time and help guide the missile to the target. Some datalinks also allow missiles to be reprogramed to additional targets if the mission changes.

2. Sea Skim: ASMs that can fly within 10 meters of the surface of the water have numerous advantages. First, missiles with sea-skim capabilities are significantly harder to detect. Sea-skimming ASMs are also significantly harder to intercept, especially as they close in on their target. Sea-skimming missiles require advanced altimeter technology that is difficult to implement effectively over water.

3. Dog Leg: Dog leg routes allow ASMs to follow a zig-zag path toward the target making them harder to detect and intercept. Dog-leg routes also allow multiple missiles to arrive at one target from multiple directions, increasing the likelihood some missiles will successfully strike the target. Dog-leg routes require advanced computing and
programming capabilities on board the missile and on the targeting platform that fires the missile.

4. Terminal Maneuvers: Terminal maneuvers allow an ASM to sporadically change direction and altitude as it closes in on a target. Terminal maneuvers are distinct from dog-leg routes as terminal maneuvers will take place right before the missile strikes the target. This requires advanced computing, programming capabilities, guidance, and flight control capabilities.

5. 200 kg payload: The small size of ASMs makes it difficult for them to carry large warheads. ASMs with large warheads require advanced material and engineering capabilities. However, missiles with large warheads are more likely to deal devastating damage with fewer hits against larger targets.

6. 200 km: Longer ranges allow ASMs to engage targets from further away. This allows land-based missiles to engage targets further out, and air and sea-launched missiles to be launched further out, keeping the launch platform out of danger. Producing missiles with extended ranges requires significant capabilities in the field of aeronautics, materials, and design.

3rd Tier: 3 Points Awarded

1. Terminal Supersonic: While this is not a "new" capability it is both technically difficult and incredibly dangerous. The Soviet Union was the first state to introduce and perfect supersonic ASMs. Supersonic missiles are incredibly hard to intercept given their speed. They also significantly increase the destructive power of the missiles themselves.
Supersonic ASMs require significant capabilities in multiple fields to produce the advanced supersonic jet and rocket engines that are required to deliver ASMs.

2. Computer targeting selection capability: Modern ASMs increasingly use pre-programmed computers to make targeting decisions on their own. ASMs with this ability can differentiate between high and low-value targets and work together with other missiles to determine the highest value targets and best attack decisions using pre-determined algorithms.

3. GPS: GPS has dramatically increased the guidance capabilities of ASMs. Before GPS, guidance relied heavily on gyroscopes. Though modern advanced gyroscopes are very accurate, GPS provides cheap and highly effective inertial guidance for ASMs.

4. 500km (Does not stack with 200km range): See 200km

**LACM Sophistication Score Scale**

1st tier 1 Point Awarded

1. Air Launched: See Above
2. Submarine Launched: See Above
3. 200km: See Above
4. 500 km: See Above
5. 1000km See Above
6. 200 kg: See Above

2nd tier 2 Points Awarded

1. TerCoM Terrain Contour Matching: Tercom guidance was one of the first efforts to increase missile guidance beyond using gyroscopes. Tercom uses a radar altimeter to
determine the missiles elevation; this is compared to pre-programmed contour maps which provide the missile with its location. This dramatically increases the accuracy of LACMs.\textsuperscript{246}

2. Electro-Optical: Electro-optical systems use cameras in the missile to either allow for man-in-the-loop guidance assistance, or for the missile to use pictures of the target pre-programmed in the missile compared to the target. This requires advanced computing and electro-optical technology.\textsuperscript{247}

3. Imaging Infrared Guidance: Imaging Infrared is a modern form of infrared imaging guidance. It is similar to Electro-Optical in that it relies on pre-programmed targeting information for LACM strikes but is significantly harder to counter.\textsuperscript{248}

3\textsuperscript{rd} tier 3 Points Awarded

1. GPS: See Above

2. Terrain Hugging: Same concept as sea-skimming ASMs.

4\textsuperscript{th} Tier 4 Points Awarded

1. Stealth: LACMs that utilize stealth technology are significantly harder to detect and intercept. Stealth technology and concepts require significant technical and industrial capabilities.

2. Supersonic: See Above

\textsuperscript{246} Kopp, (2014)
\textsuperscript{247} Kopp, (2005)
\textsuperscript{248} Kuehne et al., (2001).
3. **Digital Scene Matching Area Correlator (DSMAC):** DSMAC, introduced by the United States initially, is an incredibly advanced form of guidance. It requires not only significant computing power within the missile itself but also advanced and detailed maps of the target area. DSMAC compares pre-programmed high definition images of the target route and area and compares them to what the missile currently sees. The US DSMAC system can even tolerate substantial differences between the two that can be caused by weather, altitude, and light. DSMAC is a highly advanced and precise form of guidance.\textsuperscript{249}

\textit{Table 5.0}

<table>
<thead>
<tr>
<th>Years</th>
<th>Sophistication Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940</td>
<td></td>
</tr>
<tr>
<td>1960</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{249} Irani and Christ, (1994)
Table 5.0 above displays the sophistication scores over time of U.S. LACMs. As the U.S. innovated and added additional capabilities to their missiles, their associated sophistication scores increase. One example was capabilities introduced with the TLAM-C. One of the previous version of the Tomahawk, the TLAM-N, had a sophistication score, based on my index of 10. The TLAM-C has a score of 17. This increase was due to the addition of GPS and DSMAC to the guidance systems used by the missile. The level of sophistication required to develop and integrate these weapons, and the increased military utility they provide the missile explain the increase in score from the TLAM-N to the TLAM-C.  

Independent Variables

*The frequency of dispute involvement.* States security environment has been shown to play an essential role in their proliferation decisions. To account for this, I include a measure of conflict propensity that utilizes that number of interstate disputes using a five-year moving average number of militarized interstate disputes. This approach is commonly used in the proliferation literature. I employ data from Version 4.0 of the updated MIDs data set.

*Military rocketry R&D programs.* To account for states experience with military missile and rocketry programs I include a count variable of the years since initiation of a military rocketry R&D program. This approach has been shown to be positively associated with states’ nuclear

---

250 Early et al. (2017)
252 Ghosn et al. (2004)
programs, SRBM programs, and space launch programs.\textsuperscript{253} Data for this is drawn from the National Space and Ballistic Missile Dataset.\textsuperscript{254}

\textit{Demonstration point}. To account for states learning the effectiveness of ASMs and LACMs I include a variable for the demonstration point events for both ASMs and LACMs. After coding this variable in multiple ways, I determined that a 5-year lag in addition to the year the event occurred granted states adequate time to pursue domestic production capacity for ASMs and LACMs. This variable was coded specially for this analysis. Data for this variable was drawn from multiple sources; a demonstration point is deemed to have occurred when the weapon was used successfully in combat.

\textit{Domestic defense industry}. To account for the size of states’ domestic defense industries, I include a variable which accounts for states’ total defense exports each year.\textsuperscript{255}

\textit{Economic Size}. To capture economic power, I control for countries’ level of economic development using the squared term for GDP per capita.\textsuperscript{256}

\textit{Defense pacts with US and USSR}. To control for the security guarantees provided by defense pacts with great powers, I include a binary variable for whether the state has a defense pact with either the U.S. or the USSR.\textsuperscript{257}

\textit{Non-great power and great power strategic rivalry}. To account for the security threat posed by great powers, I include a measure of great power rivalry. I also include non-great power rivalries as well.\textsuperscript{258}

\textsuperscript{253} Early (2014); Early and Way (2017); Early and Fahrenkopf (2017)
\textsuperscript{254} Early and Fahrenkopf (2017)
\textsuperscript{255} SIPRI (2017)
\textsuperscript{256} Gleditsch (2002).
\textsuperscript{257} Gibler (2009)
Domestic SRBM production. This variable captures an additional measure a states military rocketry S&T and R&D human capital. This is a binary variable that captures whether states’ produce SRBMs. Data for this variable is drawn from the NSBM.²⁵⁹

Composite Index of National Capabilities. To control for countries’ national industrial and military capabilities, I use the Composite Index of National Capability index. This variable is a composite measure of states’ military, industrial, and population capabilities as a proportion of the total global pool of those capabilities.²⁶⁰

The sophistication of possessed ASM/LACM. This variable utilizes a sophistication score created by the author for measuring the technological sophistication and capabilities of missiles. Sophistication scores range from 1-24 for ASM and 1-30 for LACMs and are determined based on a point system that ranks the sophistication that particularly missile capabilities require. For a more detailed explanation of this variable see the vertical proliferation chapter.

Years Since Missile Introduced. I include the log of the total number of years since the missile was introduced into the international system. Data for this variable is drawn from the NCM.²⁶¹

Most sophisticated ASM/LACM in the system. This variable utilizes the sophistication score to determine the most sophisticated missile currently developed. This variable seeks to capture the concept of technological diffusion. As technology advances, it becomes easier and easier to produce a less advanced version of weapons.

Domestic Education Levels. Despite how vital capturing the tacit knowledge and scientific and technical capabilities of a populace is to proliferation studies, it is incredibly hard to capture. The

²⁵⁸ Thompson et al. (2001)
²⁵⁹ Early and Fahrenkopf (2018)
²⁶⁰ Singer (1987)
²⁶¹ Early et al. (2018)
best relative measure for S&T human capital for which direct data exists is countries' education levels. To capture this, I use Barro and Lee's (2010) educational attainment data set. This dataset contains estimates of education levels at five-year intervals for 150 countries from 1950 to 2010.\textsuperscript{262} Using these data, my higher education variable codes the proportion of a country’s population 25 and over that have completed higher education programs. To account for the five-year interval of the data, I code the five-year estimates forward and backward two years. This was done by Early (2014) in his work on space launch capabilities.\textsuperscript{263}

\textit{Polity}. I also include the Polity2 variable from Marshall and Jaggers.\textsuperscript{264} Polity is included because there are findings in the nuclear and ballistic missile proliferation realm that indicate organizational capital can be influenced by government type.\textsuperscript{265}

\textit{Nuclear possession (LACM test only)}. This variable includes states that possess nuclear weapons. Nuclear possession is coded using a one-year lead.\textsuperscript{266} In chapter two nuclear possession had a positive and statistically significant influence on the acquisition of LACM production capabilities. States that are now reliant on LACMs as a portion of their nuclear deterrent can be expected to develop more sophisticated LACMs to maintain the strength of their nuclear deterrent.

\textit{Nuclear pursuit (LACM test only)}. This variable includes states that are (or were) actively pursuing nuclear weapons.\textsuperscript{267} States that are pursuing nuclear weapon may view LACMs as a potential delivery system. Given the importance of nuclear pursuit in the reverse engineering of

\textsuperscript{262} Barro and Lee (2010)
\textsuperscript{263} Early (2014).
\textsuperscript{264} Marshall and Jaggers (2004)
\textsuperscript{265} Mistry (2003); Hyman (2012).
\textsuperscript{266} Early and Way (2017)
\textsuperscript{267} Early and Way (2017).
SRBMs, it is important to include this variable as states may seek to develop more sophisticated delivery systems.

*Landlocked.* For ASMs I control for states that are landlocked. States with no ocean access have no strategic use for ASMs.\(^{268}\)

\(^{268}\) Early (2008).
## Results

### Table 6.0 Sophistication of ASM Production Capabilities.

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
<th>Model 7</th>
<th>Model 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disputes</td>
<td>0.0618</td>
<td>0.0328</td>
<td>0.0618</td>
<td>0.0310</td>
<td>-0.00281</td>
<td>0.0310</td>
<td>0.0485</td>
<td>0.0542</td>
</tr>
<tr>
<td></td>
<td>(1.22)</td>
<td>(0.64)</td>
<td>(1.22)</td>
<td>(0.62)</td>
<td>(-0.05)</td>
<td>(0.62)</td>
<td>(0.96)</td>
<td>(1.09)</td>
</tr>
<tr>
<td>Great Power</td>
<td>-0.137</td>
<td>-0.268</td>
<td>-0.137</td>
<td>-0.0107</td>
<td>-0.0807</td>
<td>-0.0107</td>
<td>0.0284</td>
<td>-0.472</td>
</tr>
<tr>
<td>Defense Pacts</td>
<td>(-0.34)</td>
<td>(-0.64)</td>
<td>(-0.34)</td>
<td>(-0.03)</td>
<td>(-0.19)</td>
<td>(-0.03)</td>
<td>(0.07)</td>
<td>(-1.18)</td>
</tr>
<tr>
<td>Demonstration Point</td>
<td>0.305</td>
<td>0.242</td>
<td>0.305</td>
<td>0.322</td>
<td>0.286</td>
<td>0.322</td>
<td>0.249</td>
<td>0.244</td>
</tr>
<tr>
<td></td>
<td>(1.82)</td>
<td>(1.43)</td>
<td>(1.82)</td>
<td>(1.91)</td>
<td>(1.69)</td>
<td>(1.91)</td>
<td>(1.48)</td>
<td>(1.47)</td>
</tr>
<tr>
<td>Rocketry R&amp;D</td>
<td>0.0319</td>
<td>0.0297</td>
<td>0.0319</td>
<td>0.0534*</td>
<td>0.0608*</td>
<td>0.0534*</td>
<td>0.0283</td>
<td>0.0449</td>
</tr>
<tr>
<td></td>
<td>(1.24)</td>
<td>(1.05)</td>
<td>(1.24)</td>
<td>(2.25)</td>
<td>(2.37)</td>
<td>(2.25)</td>
<td>(1.08)</td>
<td>(1.80)</td>
</tr>
<tr>
<td>Sophistication of Possessed ASMs</td>
<td>0.685***</td>
<td>0.685***</td>
<td>0.685***</td>
<td>0.696***</td>
<td>0.695***</td>
<td>0.696***</td>
<td>0.679***</td>
<td>0.694***</td>
</tr>
<tr>
<td></td>
<td>(17.22)</td>
<td>(17.22)</td>
<td>(17.22)</td>
<td>(17.68)</td>
<td>(17.53)</td>
<td>(17.68)</td>
<td>(17.15)</td>
<td>(17.60)</td>
</tr>
<tr>
<td>SRBM Production</td>
<td>-1.326*</td>
<td>-1.669**</td>
<td>-1.326*</td>
<td>-1.425*</td>
<td>-1.843**</td>
<td>-1.425*</td>
<td>-1.416*</td>
<td>-1.039</td>
</tr>
<tr>
<td></td>
<td>(-2.28)</td>
<td>(-2.72)</td>
<td>(-2.28)</td>
<td>(-2.45)</td>
<td>(-3.00)</td>
<td>(-2.45)</td>
<td>(-2.42)</td>
<td>(-1.84)</td>
</tr>
<tr>
<td>Higher Education</td>
<td>-0.0196</td>
<td>-0.0311</td>
<td>-0.0196</td>
<td>-0.0114</td>
<td>-0.0232</td>
<td>-0.0114</td>
<td>-0.0306</td>
<td>0.00984</td>
</tr>
<tr>
<td></td>
<td>(-0.41)</td>
<td>(-0.60)</td>
<td>(-0.41)</td>
<td>(-0.24)</td>
<td>(-0.45)</td>
<td>(-0.24)</td>
<td>(-0.63)</td>
<td>(0.21)</td>
</tr>
<tr>
<td>Defense Exports</td>
<td>-0.0668</td>
<td>-0.101</td>
<td>-0.0668</td>
<td>-0.0809</td>
<td>-0.110</td>
<td>-0.0809</td>
<td>-0.0843</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-0.94)</td>
<td>(-1.40)</td>
<td>(-0.94)</td>
<td>(-1.14)</td>
<td>(-1.51)</td>
<td>(-1.14)</td>
<td>(-1.19)</td>
<td></td>
</tr>
<tr>
<td>Log of Real GDP</td>
<td>-0.893**</td>
<td>-1.21***</td>
<td>-0.893**</td>
<td>-0.862**</td>
<td>-1.166**</td>
<td>-0.862**</td>
<td>-0.922**</td>
<td>-1.10***</td>
</tr>
<tr>
<td></td>
<td>(-2.78)</td>
<td>(-3.40)</td>
<td>(-2.78)</td>
<td>(-2.69)</td>
<td>(-3.25)</td>
<td>(-2.69)</td>
<td>(-2.83)</td>
<td>(-3.53)</td>
</tr>
<tr>
<td>Years since ASM</td>
<td>1.542***</td>
<td>1.849***</td>
<td>1.542***</td>
<td>1.542***</td>
<td></td>
<td></td>
<td>1.197**</td>
<td>1.338**</td>
</tr>
<tr>
<td>Introduction</td>
<td>(3.63)</td>
<td>(4.15)</td>
<td>(3.63)</td>
<td>(2.52)</td>
<td></td>
<td></td>
<td>(2.32)</td>
<td></td>
</tr>
<tr>
<td>Most Sophisticated</td>
<td>0.119**</td>
<td>0.134***</td>
<td>0.119**</td>
<td>0.0784</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missile in System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3.28)</td>
<td>(3.65)</td>
<td>(3.28)</td>
<td>(1.95)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>polity2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.11***</td>
<td>(3.70)</td>
</tr>
<tr>
<td></td>
<td>(1.83)</td>
<td>(2.69)</td>
<td>(1.83)</td>
<td>(2.31)</td>
<td>(3.12)</td>
<td>(2.31)</td>
<td>(1.94)</td>
<td>(2.60)</td>
</tr>
<tr>
<td>N</td>
<td>447</td>
<td>447</td>
<td>447</td>
<td>447</td>
<td>447</td>
<td>447</td>
<td>447</td>
<td>447</td>
</tr>
</tbody>
</table>

T statistics in parentheses

*=** p<0.05  **p<0.01  ***p<0.001*
Table 1.0 shows the results for the sophistication of ASM production capacity. Models 1, 4, 7, and 8 show the results for the primary analysis, which controls for random effects. Models 3 and 6 are the regular linear models, and models 2 and five control for fixed effects. The findings across the different models controlling for random effects, fixed effects, and regular linear regression are consistent. Across all models, in the ASM tests, we see no support for hypothesis 1. A state's security environment plays no role in the sophistication of their ASM production capacities. The broader strategic literature has found that weapons possessed by rivals and neighbors have played a role in driving proliferation\(^{269}\). It is possible the primary security driver for states to invest in increasing the sophistication of their ASM production capacity is based on the capabilities of rivals.

The ASM analysis also shows limited support for Hypothesis 3. Rocketry R&D, one of the primary measures for S&T human and organizational capital, is significant in only 3 of the eight models. These models include only one of the diffusion variables, the sophistication score for the most advanced missile in the system. Though the sophistication of states possessed missiles is statistically significant and positive. States can gain S&T human capital from reverse engineering, maintaining, and deploying ASMs. Part of most missile deals includes technical assistance in maintaining and deploying the missile systems. Overall, though, the results are too weak to draw any solid conclusion on the role of S&T human capital's role in the level of sophistication for states ASM production capabilities. The only other significant S&T variable, the production of SRBMs, is negative and significant across all the variables, but one.

This counterintuitive finding can be explained as resource limitations. Major powers have no problem investing in numerous weapons programs. Less developed states though, with either niche defense industries or new proliferators have significantly fewer resources. Competition for resources between different weapons programs has been shown to influence the diversification of states' nuclear delivery platforms negatively.\textsuperscript{270} States may view investments into advanced ASMs as less valuable as ballistic missile programs, which have much greater strategic potential. Deciding between complimentary weapons has also been seen in the WMD literature. Chemical and biological weapons have been considered the "poor man's atomic bomb," where states that can't acquire nuclear weapons will rely on chemical and biological weapons.\textsuperscript{271} This competition has also been applied to state’s proliferation decisions on diversifying their nuclear platforms.\textsuperscript{272} It is possible that states view ballistic missile as a substitute for LACMs. When resources are scarce, states will pursue ballistic missile programs over LACM programs.

Resource limitations may also signal interaction between S&T human capital and more traditional measures of national capability. S&T human capital in one realm can, and has been shown, to be compatible with other programs, the ability and desire to invest in multiple programs to leverage the S&T human capital into advances requires additional investment. There may very well be an interaction between national capabilities and S&T human capital that best explains how resource limitations and competing weapons system influence the sophistication of states ASM production capacities.

The ASM analysis finds significant support for hypothesis 4. Across all the models, variables capturing the diffusion of ASM technology throughout the system is positive and

\textsuperscript{270} Gartzke et al. (2014).
\textsuperscript{271} Horowitz and Narang (2014)
\textsuperscript{272} Gartzke et al. (2014).
statistically significant. In all the models in which it is present the log of years since ASMs were introduced into the system is positive and statistically significant. The sophistication of the most advanced missile in the system is also significant in positive in all the models in which it appears except one.
### Vertical Results

<table>
<thead>
<tr>
<th>Table 7.0 Sophistication of LACM Production Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong></td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td><strong>Disputes</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>Great Power Defense Pacts</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>Demonstration Point</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>Rocketry R&amp;D</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>SRBM Production</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>Higher Education</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>Defense Exports</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>Log of Real GDP</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>Most Sophisticated Missile in System</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>Nuclear Weapons</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>Years since LACM Introduction</strong></td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td>t statistics</td>
</tr>
<tr>
<td><strong>N</strong></td>
</tr>
</tbody>
</table>

_t statistics in parentheses

* = p<0.05  ** = p<0.01  *** = p<0.001
Models 1, 4, and 7 show the results for the primary analysis which controls for random effects. Models 3 and 6 are the regular linear models, and models 2 and five control for fixed effects. Model 2 and five do not contain the nuclear acquisition variable. This is because for one unit (the U.S.) the nuclear acquisition variable is time invariant. The US is a nuclear power throughout the entire dataset. Fixed effects cannot run with time-invariant variables.

The findings from the LACM model bear some similarities to the ASM models but differ in several key areas. This is not entirely unexpected, as LACMs require more resources and more advanced equipment and technology than ASMs. They also fill different strategic and tactical niches. LACMs can serve as nuclear delivery vehicles, significantly increasing the strategic role they can fill in states security planning. For this reason, I include the nuclear possession variable for the LACM analysis. The findings on the security environment for the LACM model are counter-intuitive. The significance of disputes is mixed, they are only significant across three models, and are negative. It is not entirely clear why disputes would decrease the sophistication of states LACM capabilities. A potential explanation is a competition between different weapon systems arguments. States with fewer capabilities that expect to engage in conventional wars may be more focused on investing in more traditional military equipment rather than investing in the resource-intensive and time-consuming efforts to produce sophisticated LACMs. Still, the significance of disputes is mixed, hurting the ability to accurately judge the influence disputes may play in states LACM production capacities.

Great power defense pacts are statistically significant, and unexpectedly, favorable across all models, but one. While defense pacts with great powers may make states more secure, states have historically benefited from technical assistance on LACM programs from great power allies. The U.S. exports advanced missile systems to its allies, and the USSR and Russia have
provided significant foreign assistance to China and North Korea. For the LACM analysis, it is possible that great power defense pacts are capturing the scientific and technical human capital that states often acquire from great power allies.

As with the ASM analysis, I find no support for Hypothesis 3. I find the exact opposite of the expected effect. Rocketry R&D and SRBM production are both statistically significant and negatively associated with the sophistication of states' domestic LACM production capacities. This is a counterintuitive finding. My theory expected to see S&T human capital play an essential role as states proliferate vertically. One explanation is that, while S&T human capital is important, once states acquire initial production capabilities, they no longer require the same level of S&T human capital. Other programs may begin to hurt states ability to vertically proliferate as states with fewer resources then need to make choices about where to invest. The statistical significance of SRBM in an unexpected direction may reinforce this logic.

Historically, the utility of SRBMs was apparent well before LACMs. SRBM technology is also older and more established than LACM technology. Many states invested in SRBMs first. The rocketry R&D programs and SRBM production capacities may be used to continue investing in ballistic missile capabilities rather than switching to LACMs. This is the position taken by North Korea. North Korea initially invested significant resources in producing ballistic missiles and has continued to focus on ballistic missiles eschewing LACM production capacities.

We also see conventional measures of state capacity, economic size, is statistically significant and positively associated with the sophistication of states LACM production capacities. LACMs require more resources and more advanced technology and equipment than ASMs, so it is not unexpected to find that states with larger economies being able to continue to invest in LACM sophistication.
Possession of nuclear weapons is both statistically significant and positively correlated with the sophistication of LACM production capacities. Given that LACMs are a major nuclear delivery platform this is not unexpected. Possession of nuclear weapons can be affecting the LACM production capacities in several ways. First, states with nuclear programs have extensive conventional resources and S&T human capital. Nuclear weapons programs are expensive and require states to bring together multiple different scientific, engineering, and technical fields. Developing and managing nuclear weapons would be expected to have significant spillover benefits for other weapons programs, such as LACMs.

Additionally, states with nuclear weapons need to be able to deliver them. LRBMs are incredibly challenging to develop, and air delivered nuclear weapons from traditional manned fighters and bombers have the arduous task of penetrating enemy air defenses. LACMs provide stand-off precision strike capabilities for nuclear weapons that are incredibly difficult to detect and intercept. Given the pertinent demand and supply side factors connecting nuclear weapons to LACMs, it is not unexpected that states with nuclear weapons would invest heavily in producing advanced LACMs. The strength of nuclear weapons possession on both supply and demand side variables may be washing out some of the other results. As we can see in models 2 and 5, not including the nuclear acquisition variables makes rocketry R&D both statistically significant and positive and SRBM production insignificant. Future research should break this up further, to determine the motivations and supply-side dynamics that nuclear, non-nuclear, and nuclear aspirational states may have regarding the sophistication of missile production.

While there are substantial differences between what determines the sophistication of states ASM and LACM domestic production capacities, my analysis highlights at least one key factor that unites both analyses. While S&T human and organizational capital plays a vital role in
states initial acquisition of ASM and LACM production capacities, this analysis would appear to show that once states gain these production capacities, they are no longer the primary driving factor in the vertical proliferation of LACM and ASM production. Instead, the diffusion of ASMs and LACMs and their related technologies throughout the system play an incredibly important role in the sophistication of states ASM and LACM production capabilities.

Despite the weak showing for S&T human capital in the vertical chapter, S&T human capital may still play an important role. The variables used in this dissertation to capture SMIC and S&T capacity are broad. Even the domain-specific ones are of a broad nature. These proved suitable for understanding horizontal proliferation, but vertical proliferation relies on highly specialized S&T human capital. The more advanced weapons become the more specialized technicians, engineers, and scientists need to be. The Chinese ASM and LACM programs have invested in developing highly specific forms of S&T human capital and SMICs. These included weapon specific research and training academies, training Chinese engineers, technicians, and scientist abroad, and bringing foreign experts to work in Chinese weapons development projects. Chinese efforts to develop domain-specific S&T human capital was instrumental in increasing the sophistication of their ASMs and LACMs. \footnote{Gormley (2008); Gormley et al. (2014)}

Hypothesis 4 has strong support across both models. The variables capturing diffusion, \textit{years since the missiles entered the system}, and \textit{most sophisticated missile in the system}, have both statistically significant and positive effects across both models. These findings are in line
with some of the academic work on proliferation, but also one of the most significant issues the nonproliferation policy community is encountering\textsuperscript{274}

As the level of sophistication of ASMs and LACMs increase, it becomes easier to purchase increasingly sophisticated missiles. More producers increase the availability of missile system, granting states a variety of markets for missiles systems, technical support, and associated technology. The dual-use nature of much of these technologies also poses significant opportunities for states to purchase dual-use components, technology, and even know-how and translate that into missile production capabilities. Policymakers have attempted to confront the issues caused by technological diffusion through stringent controls on dual-use goods, including intangible ones such as technology and knowledge. However, the growing number of new producers entering the market, increasing demand for related dual-use goods and technology, have continued to make technological diffusion one of the most challenging aspects of proliferation to control.

These findings reinforce the concerns among policymakers on the threat posed by the diffusion of dual-use good and technology. These findings indicate that once states acquire the ability to produce ASMs and LACMs, it is unlikely that the sophistication of their production capabilities will remain static. The spread of more sophisticated ASMs and LACMs and their related technology throughout the system is one of the primary determinants for the sophistication of states ASM and LACM production capabilities. Magnifying this, are the weak findings regarding traditional demand variables and S&T human capital. States seeking an initial production capacity will rely on strong security demands to warrant the high investment and significant S&T human capital to meet the scientific, technical, and organizational challenges

\textsuperscript{274} — Jo and Gartzke (2007); Betts (1982); Karp (1996); Gormley (2008).
that production pose. Once a state develops production capacities, one of the most critical factors driving increasing sophistication is the spread of related technology throughout the system. Once you have it, it appears to be easier to maintain relatively modern missiles production capacities.

The results of the LACM analysis represents one positive finding for policymakers in this realm. The sophistication of states LACM production capacities seems to also rely on strong demand and supply-side variables in economic size and nuclear weapons possession. Whereas the diffusion of ASMs and related technology is one of the primary determinants for the sophistication of states ASM production capacities, LACMs seem to also rely on other factors. This is not unexpected given their higher resource demands.

The LACM analysis shows strong support for Hypothesis 2. Demonstration point is positive and statistically significant across 5 of the seven models. This supports much of the qualitative literature on the proliferation of LACMs. Initially, LACMs were viewed as an additional nuclear delivery platform. A means to efficiently penetrate enemy air defense while protecting the launch platforms. The U.S. effective use of LACMs as a form of stand-off precision strike capabilities throughout the 1990s and 2000s changed this narrative. States began to recognize the policy that LACMs had both significant convention and nuclear utility. Without the U.S. relying on Tomahawk LACMs as their primary stand-off strike delivery option, and the inability of advanced U.S. air defense to intercept crude Iraqi LACMs, this narrative would not have taken hold. These demonstration points, and the narrative they shifted accounts for states investing in producing advanced LACMs.
Conclusion

The findings from this analysis have shown that while the sophistication of states’ ASM and LACM missile production capacities have some diverse sources, one critical element is the diffusion of these weapons and their related technology throughout the system. States that have managed to absorb the high costs of gaining initial production capacities can utilize the broad diffusion of these weapons and their related technology to help keep their production capacities modern. Security concerns and S&T human capital do not appear to have the same role in the sophistication of states' missile production capacities as they do in their first steps towards production. LACMs, though, given their more resource demanding nature, do appear to rely on economic power as an element of their sophistication. LACM sophistication has also relied on the narrative surrounding their conventional utility, bolstered by their widespread use by the U.S. and their air penetration capabilities at even the most basic level of sophistication.

For ASMs, these results paint a stark picture for the sophistication of states' production capacities. While there is some support for S&T human capital across some of the models, the primary finding remains that once states gain ASM production capacities, it will be relatively easy to produce relatively modern missiles by relying on the diffusion of ever more sophisticated missiles and related technology. The few states that are genuinely the dominant producers in the system make substantial investments into producing ever-improved ASMs and LACMs. These improvements, through arms sales, and dual-use equipment and knowledge diffusion allow other producers to piggyback off the advances of a few key producers. The development of GPS is an excellent example of this. The U.S. invested significant resources in developing GPS technology. When they opened this up for use by civilians and foreign powers they allowed other producers to enhance their missile production capacities greatly. The large number of foreign components,
many of which do not even appear on strategic trade control lists found in North Korean missiles is also an example of this diffusion. The ease with which states can acquire relevant technology dramatically lowers the demand threshold for continued investment.

The LACMs results paint a more complicated picture. The more advanced nature of LACMs makes them like the traditional strategic proliferation literature, allowing for broader implications of these findings. The sophistication of states LACM production capacities also benefit significantly from the diffusion of LACMs and related technology throughout the system. However, LACM sophistication is also greatly impacted by several other factors. Great power defense pacts and economic size have statistically significant and positive effects on LACM sophistication. Here we may be seeing resources playing a secondary role. Great powers have often provided technical support, assistance, and advanced weapons to their allies, which have fueled the missile programs of numerous states, most notably China.

LACMs are inherently costlier than ASMs. States' abilities to purchase the relevant missiles, parts and related technology to help fuel their domestic production require larger financial capabilities than ASMs. Competition with other weapons programs may also account for the role played by economic power. States' first forays into missile production were often SRBMs and other conventional missile systems. These systems serve separate roles and are likely to be more developed from both a technical and organizational standpoint. Given the high cost of LACMs and competition from pre-existing missile production and deployment, these financial capabilities may be required to overcome competition from pre-existing SRBM production and other rocketry R&D programs.

---

275 Byrne (2014).
Finally, the possession of nuclear weapons significantly affects states' production capacity for LACMs. Nuclear weapons are such a major investment both from a source and strategic perspective. LACMs, as a nuclear delivery platform, are undoubtedly greatly influenced by states' possession of nuclear weapons. However, states with nuclear weapons also have substantial financial, industrial and S&T human and organizational capital. The influence nuclear weapons have on LACM production can be a measure of both supply and demand. Future research should focus on the role nuclear weapons play in states' broader proliferation decisions and capabilities.

These findings reinforce the increased focus policymakers are placing on dual-use technology and equipment in proliferation. As the sophistication of these systems develops, and the missiles and related technology and knowledge spread throughout the system, it becomes significantly easier to maintain modern LACM and ASM production capabilities. The initial cost of developing these production capacities is significantly higher than maintaining them. These findings show the window for nonproliferation is before the initial acquisition of production capabilities. Once states gain production capacities for these weapons, it becomes increasingly difficult to prevent vertical proliferation, as the related costs are significantly lower.

Policymakers should also be cautious about the proliferation of individual missile systems. Individual missile systems can provide states with both reverse engineering capabilities as well as S&T human capital through the technical assistance and knowledge and experience that maintaining and deploying the missile can provide.

There is also limited support for S&T human capital as playing an essential role in vertical proliferation, though S&T human capital seems to be limited by competition with other weapon systems. These results contribute to our understanding of proliferation by looking at
vertical proliferation as the second stage of states' proliferation efforts. States' vertical proliferation decisions and capabilities appear to compete with other types of missile systems. These findings underscore research that highlights the complicated nature of states defense programs. Defense programs may increase resources with which to pursue weapons, but it also creates competition within governments on which systems are most salient to states security concerns. LACMs and ASMs once acquired, may be competing with more advanced missile programs.

Overall, these results highlight the critical role that technological diffusion plays in the vertical proliferation of states missile production capacities. This aligns with the qualitative literature on these weapons and some of the findings on the proliferation of other strategic weapons. These results support the growing consensus among academics and policymakers that dual-use goods, technology, and knowledge and the ability to leverage these with S&T human capital and economic power are important supply-side factors in proliferation. The vertical proliferation of states missile production capabilities benefits significantly from technological diffusion.

The findings on vertical proliferation can be interpreted as a darkly deterministic problem facing nonproliferation efforts. However, other factors have also been shown to influence vertical proliferation. Competition between weapons systems, economic power, and S&T human capital have been shown to play a role in states' vertical proliferation of ASMs and LACMs. Additionally, technological diffusion is not a foregone conclusion. Norms regarding the proliferation and use of ASMs and LACMs can help limit their proliferation, as has been seen in the nuclear realm. Policymakers seeking to limit the vertical proliferation of ASMs and LACMs should look to build capacity domestically and abroad to control the spread of dual-use
technology and knowledge and exercise caution when exporting advanced ASMs and LACMs. If vertical proliferation is heavily reliant on outside sources of knowledge, equipment, and expertise, it is possible to slow vertical proliferation by decreasing diffusion which should significantly increase the costs. This result, though challenging, is a positive result for policymakers, because it signifies the difficulty and cost of relying solely on domestic sources to modernize missile systems.
Chapter Five: Conclusion

This dissertation has developed an understanding of not only the horizontal but the vertical proliferation of states ability to produce these systems. It has found that security threats and scientific and military industrial complexes (SMICs) and S&T human capital greatly influence the horizontal proliferation of these weapons and that the continued diffusion of these weapons and related technology throughout the system plays a significant role in their vertical proliferation. These findings supplement the limited, but growing work in the proliferation literature focusing on the importance of S&T human capital in supply-side explanations for proliferation.\(^{276}\) Policymakers focus on dual-use technologies and intangible goods such as knowledge and designs is well founded for both horizontal and vertical proliferation. Given the large role played by S&T human capital and diffusion, controls on goods and technology that fall within these realms are incredibly important.

Policymakers and academics should leverage these findings to develop future research and work on how these proliferate and how states seek to increase their SMICs and S&T through the open market. Finally, the vertical proliferation chapter is one of the first empirical analyses to focus on what happens once states acquire a weapon. Horizontal proliferation is important, but only part of the proliferation process. New research should seek to develop methods for capturing the sophistication of states weapons production capacities and to better understand the vertical proliferation process because vertical proliferation is truly how states increase their power.

\(^{276}\) Early (2014); Early and Way (2017); Karp (1996)
The importance of these weapons moves beyond their link to other forms of strategic proliferation because they alone can greatly alter the balance of power. Any future conflict in the South China Sea between the United States and China has been seriously altered by Chinese investment in “assassins mace” technologies. ASMs, LACMs, and ballistic missiles have formed a new trio of conventional weapons with serious strategic implications.\textsuperscript{277} China has invested significant industrial, financial, organizational, and S&T resources into developing weapons that challenge the power projection capabilities of the United States. The anti-access and area denial potential of these weapons has been repeatedly demonstrated in combat. Their ability to be linked with WMDs and their potency on their own make them an important part of proliferation and military power.

Childhood educational institutions are focusing extensively on investments in STEM. States seeking to build ASMs, LACMs, and SRBMs should follow suit. The SMIC and S&T human capital capacities that states have developed were important parts of the horizontal proliferation of all three weapons. Traditional capacities, such as economic and industrial size play little to no role. These results help to solidify the renewed focus on SMICs and S&T human capital and the organizational experience that comes from these capabilities in the proliferation of these weapons.\textsuperscript{278} SMICs represent investments in the broad field of weapons development. SMICs have positive spill over into other fields of defense production, because of the role S&T human capital plays as a resource that states can tap. S&T human capital is not only the technical, tacit, and scientific knowledge and experience of technicians, scientists, and engineers, but also their social connections, and the organizational capacity they develop managing large research projects. S&T human capital has been shown to play a large role in the efficacy of states

\textsuperscript{278} Early (2014); Early and Way (2017); Karp (1996) Horowitz (2010).
scientific and research endeavors. S&T human capital and SMIC investments in missile production have been shown to positively influence the development of nuclear weapons because of this phenomenon of S&T human capital. The knowledge, connections, and experience in one realm can be tapped for use in other projects. This is what we see with the horizontal proliferation of ASMs, LACMs, and SRBMs.

For LACM and SRBM production we see nuclear weapons playing an interesting role. Pursuing nuclear weapons is an important part in states decisions to reverse engineer SRBMs. This makes sense given the strategic utility of ballistic missiles. Ballistic missiles have been the primary delivery system for nuclear deterrents for decades. States with WMD ambitions have invested heavily in domestic missile production capacities; this begins with producing SRBMs. For LACMs we see the possession of nuclear weapons playing a significant role in states acquisition of LACM production capabilities. Nuclear weapons here can be playing two roles. First, states may view LACMs as an additional nuclear delivery system. Here, the proliferation of LACM production shares similar security determinants as nuclear weapons because states may be viewing them as an integral addition of their nuclear capabilities. Given the greater availability of ballistic missiles and their long history as a dominant nuclear delivery system, it makes sense to see the pursuit of nuclear weapons driving SRBM production and the possession of them driving LACM. States such as North Korea viewed ballistic missiles as the primary delivery component for their nuclear deterrent. Just as diversifying nuclear platforms often faces competition, LACMs as a delivery system is a luxury for states that can diversify their nuclear platforms. States that possess nuclear weapons also have demonstrated a commitment to and

---

281 Gartzke et al (2014)
significant capabilities in SMICs and S&T human capital. Nuclear weapons are the ultimate
defense project, and the scientific, technical, and organizational experiences from producing
nuclear weapons can be expected to have serious cross over into the production of LACMs. This
corresponds with the growing literature on the importance of S&T human capital in states
research efforts.282

Their S&T human capital and SMICs strongly determine the opportunity for states to
produce these weapons, but how states make production decisions is strongly driven by their
security environment. The horizontal proliferation chapters have shown a clear connection
between states security environment and their demand for domestic production capacities for
ASMs, LACMs, and SRBMs. For ASMs, we see dispute involvement driving ASM production.
For SRBM production we see rivals with ballistic missiles playing an important role. These
findings are in line with the security determinants of the proliferation of nuclear weapons,
LRBMs, and even space launch capabilities.283

The security environment that states face is an important determinant for production for
two primary reasons. First states with significant security threats may have serious concerns on
the availability and number of missiles in a conflict. There is no guarantee that states will have
enough missiles during a conflict or be able to purchase new ones. Argentina found itself in this
unenviable position after a European arms embargo canceled additional shipments of French air-
launched Exocet ASMs during the Falkland War. This insecurity even drives states with strong
allies to seek domestic production. North Korea doubled down on its policy of Juche, which
states North Korea should be fully self-sufficient after the USSR backed down during the Cuban

283 Early and Way (2017); Singh and Way (2004); Barkley (2008); Nolan (1991); Gormley (2008); Mistry (2003);
Bermudez (1999); Karp (1996); Bell (2016); Dong-Joon and Gartzke (2009); Early (2014); McDougal (1985).
missile crisis. Just as the French nuclear program was driven in part by a fear the U.S. would not trade New York for Paris, North Korea had concerns the USSR would back down in a confrontation with the US. Second states that are reliant on foreign missiles will generally possess less advanced missiles, frequently less advanced, as producers seek to retain a competitive advantage. With less advanced missiles states that may confront major powers or adversaries with more advanced missiles are at a significant disadvantage. The Yom Kippur War demonstrated this when Egyptian and Syrian Styx missiles, by then outdated, failed to score any hits on Israeli warships. While these weapons are available for purchase, states that cannot rely on foreign powers because of their security environment will be more likely to pursue domestic production.

The importance of SMICs and S&T human capital was strong throughout most models. In one model, however, there was an interesting result. For LACM horizontal proliferation when a variable capturing the sophistication of possessed LACM was added, S&T human capital variables lost significance as did nuclear possession. Instead, we see disputes and LACM possession playing significant roles in LACM production acquisition. This is only one model out of many, so does not truly undercut the primary results. It does, however, raise an important point. Possession LACMs may provide enough domain specific knowledge and specific, that when states security environments become particularly threatening, they may be able to leverage this alone to gain a domestic production capacity. Looking particularly at how states that have acquired missiles may decide to proliferate in the future is an important avenue for future research and is an important concern for exporting powers.

---

284 Bermudez (1999).
285 Chant (2014), 511; Schulte (1994), 5-6
Both the United States and North Korea are nuclear powers. Despite this, their nuclear arsenals are not the same. Not all states that deploy weapons can leverage their power to the same degree. North Korean nuclear weapons are not nearly as powerful as the multiplatform, long range, pinpoint accurate, multiple independent reentry vehicle warheads nuclear weapons employed by the United States. Not all nuclear threats are created equal, and not all weapons are either, this is the crux of vertical proliferation.²⁸⁶

Vertical proliferation is an important, yet understudied part of proliferation. Much of the proliferation literature is focused on the first stage of proliferation, horizontal. Proliferation is generally treated as being in a binary state. States either possess the weapons, or they do not. This is an important part of the proliferation process but is only one. It misses out on an entire stage of proliferation where states seek to produce increasingly sophisticated weapons systems. Vertical proliferation is important for not only having a more well-rounded understanding of proliferation, but also to have a better understanding of how these weapons and states’ abilities to produce them influences power. Just because states can build LACMs does not mean the power of those LACMs, nor their production capacities are equal to other states.

By creating a unique metric that broadly captures the sophistication of individual missile systems, this dissertation attempts to capture vertical proliferation. By focusing on the horizontal proliferation of individual missile capabilities, I can construct a broad measure of the sophistication of states missile production capacities and the power they can bring to bear in conflict. The vertical proliferation results paint a stark portrait of vertical proliferation. The dominant finding across both ASMs and LACMs is a grim one for policymakers. Time and the diffusion of missile-related technology and knowledge throughout the system is an important

²⁸⁶ Early and Asal (2014).
determinant of states’ missile production capacities. Once states acquire an ability to produce these weapons, they can piggyback off the advances made by dominant producers such as the U.S., Russia, and China. This can be occurring in several ways. Most likely states can purchase more advanced missiles and use these to bolster their programs. Additionally, they are likely able to take advantage of dual-use technology and knowledge which can boost their programs with little additional cost.

Despite the weak showing for S&T human capital in the vertical chapter, S&T human capital may still play an important role. The variables used in this dissertation to capture SMIC and S&T capacity are broad. Even the domain-specific ones are of a broad nature. These proved suitable for understanding horizontal proliferation, but vertical proliferation relies on highly specialized S&T human capital. The more advanced weapons become the more specialized technicians, engineers, and scientists need to be. The Chinese ASM and LACM programs have invested in developing highly specific forms of S&T human capital and SMICs. These included weapon specific research and training academies, training Chinese engineers, technicians, and scientist abroad, and bringing foreign experts to work in Chinese weapons development projects. Chinese efforts to develop domain-specific S&T human capital was instrumental in increasing the sophistication of their ASMs and LACMs. 287

These findings have several important contributions for researchers and policymakers. First, these weapons have received little attention in the proliferation and military power literature. ASMs, SRBMs, and LACMs have significant military utility. Their anti-access and area-denial capabilities make them uniquely suited for resisting states with conventional

287 Gormley (2008); Gormley et al (2014)
superiority and power projection. Understanding how and why states produce these weapons has important implications for proliferation, and military power.

Weapons production has increasingly become more like a web than a ladder. These results further strengthen the growing focus on S&T human capital and SMICs as having important roles in the ability of states to produce a wide variety of weapons. Producing these weapons also can be the first stage toward the production of more advanced weapons, such as LRBMs and nuclear weapons. This is fueled by the importance of SMICs and S&T human capital and the spillover effects that these can produce between different defense programs. Future research should seek to develop a better understanding of how SMICs and S&T human capital can fuel the development of a broad range of weapon system. This is important for policymakers and even arms producers as well. Developing a better understanding of how this drives proliferation should guide not only how states and arms companies sell their weapons, but how states seek to control related technology and knowledge. Additionally, future research should seek to develop better measures for capturing domain specific S&T human capital.

One of the grimmest findings of this study for policy makers is the role that diffusion plays in the vertical proliferation of states production capacities. Vertical proliferation is an understudied and incredibly important part of understanding proliferation and military power. The results of this section show that once states develop domestic production capacities for ASMs and LACMs, it is incredibly difficult to slow their vertical proliferation. States can piggyback off the advances of more sophisticated producers and take advantage of increasingly available dual-use technology and knowledge. Though specialized S&T human capital most likely plays some role, the broad diffusion of these weapons and technology are an important and difficult to control part of the process. States and arms companies exporting these weapons and
related technology should be wary of who they export these systems too and what is involved in
the deal. States should also continue to develop, enforce, and expand the control of related dual-
use technology and less advanced weapon systems to at least slow the effect diffusion can have
on vertical proliferation. The findings of this dissertation support the increasing focus among
researchers and policymakers on the role played by knowledge and experience in proliferation.
The vertical proliferation chapter is one of the only studies to attempt to capture the
sophistication of missile systems and states missile production capabilities. This second stage of
the proliferation process has significant implications for proliferation and power. Proliferation is
a web; it is inherently complicated. This dissertation has shown that two major components of
both horizontal and vertical proliferation of missile production defy common supply-side
explanations for proliferation. It isn’t about traditional notions of power. Instead, time and
knowledge play major roles, and can even have spillover effects between programs. This
significantly complicates nonproliferation and counterproliferation objectives, because diffusion
and knowledge are very difficult to stop. When it comes to states military production
capabilities, knowledge truly is power.
References


Bermudez, Joseph. 1999. A History Of Ballistic Missile Development In The DPRK. Monterey Institute of International Studies, Center for Nonproliferation Studies


Pike, John, Charles Vick, Mirko Jacobowski, and Patrick Garrett. "P-1 Strela Shchuka-A SS-N-1
Resolution 46, 712-724.
https://doi.org/10.1177/0022002704269655.
Sirrs, Owen L. Nasser and the Missile Age in the Middle East (New York: Routledge, 2006), p. 10
The Iran Primer, "Iran's Ballistic Missile Program," United States Institute of Peace, August 2015, http://iranprimer.usip.org
Studies Quarterly 45(4), 557-586.
Williams, Richard “Analyzing Rare Events with Logistic Regression”, University of Notre Dame, https://www3.nd.edu/~rwilliam/ April 8, 2018