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The Effect of Defense R&D on Military Capability and Technological Spillover

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THE EFFECT OF DEFENSE R&D EXPENDITURES ON MILITARY CAPABILITY AND TECHNOLOGICAL SPILLOVER

THESIS

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Abstract

Generally, the purpose of defense research and development (R&D) is to expand military capability for the armed forces of a country. Any spin-off of technologies from defense R&D programs is usually not a prime motivation but more often an unintended consequence. Nevertheless, many of the technologies used in civilian life were initially research and development projects for military purposes. These technologies eventually become adapted to civilian applications since they had beneficial economic and social "spillover" effects. However, there is a lack of research measuring the final outputs of defense R&D, including technology "spin-offs."

This study mainly tried to understand the effect of defense R&D expenditures on military capability and technological spillover. Statistical measures such as correlations were used to understand these effects. The study revealed that there is a highly positive correlation between defense R&D expenditure and military capability, as well as between defense R&D expenditure and technological spillover index.

The study contributed to the academic literature in three ways by providing: new measures of military capability, a new estimation method for defense R&D expenditures, and a new method to measure technological spillover effect from defense R&D expenditures.

...To the real owner of the stars, which I carry on my shoulders: to Turkish Nation,

...To my father and mother who always believe, trust and support me,

...To my lovely wife who is the meaning of my life.

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THE EFFECT OF DEFENSE R&D EXPENDITURES ON MILITARY CAPABILITY AND TECHNOLOGICAL SPILLOVER

''When we start outsourcing everything and we are in that kind of a trade deficit, then just remember, who feeds us, who fuels us and who helps us to fight, that's to whom we are enslaved. So if we cannot do those three things, our national security is very much at risk.''

Mike Huckabee (U.S. Presidential Candidate, 2008)
(Hoffman, 2008, para. 4)

I. Introduction

In developing countries such as Turkey, Research and Development (R&D) is widely discussed in a commercial or industrial context, but rarely in a military context. This is unfortunate because many of the technologies used in civilian life were initially military research and development projects that eventually become adapted to civilian applications. In fact, military R&D often has beneficial economic and social "spillover" or "spin-off" effects (Dunne & Braddon, 2008; Hartley, 2011). For example, Light Amplification by Stimulated Emission of Radiation (LASER), the Global Positioning System (GPS), and even the Internet are three well-known innovations that were originally derived from military R&D efforts. These and many other technological innovations would have not been possible without military R&D efforts.

Background

Defense R&D (also referred to as military R&D or defense-related R&D) expenditures are an important source of information about a nation's military technological capability and its commitment to a national defense industrial base (Hartley, 2006). To understand defense R&D, it is important to define the term and then examine defense R&D in the context of R&D in general. According to the Organization for Economic Co-operation and Development (OECD) Frascati Manual, *research and development (R&D)* is defined as "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" (OECD, 2002:30). In the same vein, Thee (1990) defines *defense R&D* as a "mission-oriented R&D activity comprising basic and applied research, with the development, testing and experimental production of new weapons and weapons systems, including the improvement and modernization of existing weapons and weapons systems."

The Frascati Manual describes the most popular methodology for collecting and reporting statistics related to research and development data used by academic researchers and military analysts (Motte, 1992). The Frascati Manual groups R&D activities into two primary approaches, which are institutional and functional. The institutional approach, often called sectoring, categorizes R&D activities by funding source, and the functional approach categorizes R&D activities by their objective. Funding sources for R&D activities include *government*, *higher education*, *business enterprise*, and *private non-profit enterprises*. The functional approach breaks down R&D activities into *types of R&D* (basic research, applied research, and experimental development), *product fields*, *fields of science and technology* (natural sciences, engineering and technology, medical sciences, agricultural sciences, social sciences, humanities), and *socio-economic objectives* (defense, and control and care of environment) (OECD, 2002). Figure 1 shows the decision tree for sectoring R&D units and Figure 2 shows the functional breakdown of R&D activities. Institutionally, defense

R&D comes from either government or business enterprise sectors. Functionally, it serves the socio-economic objective.

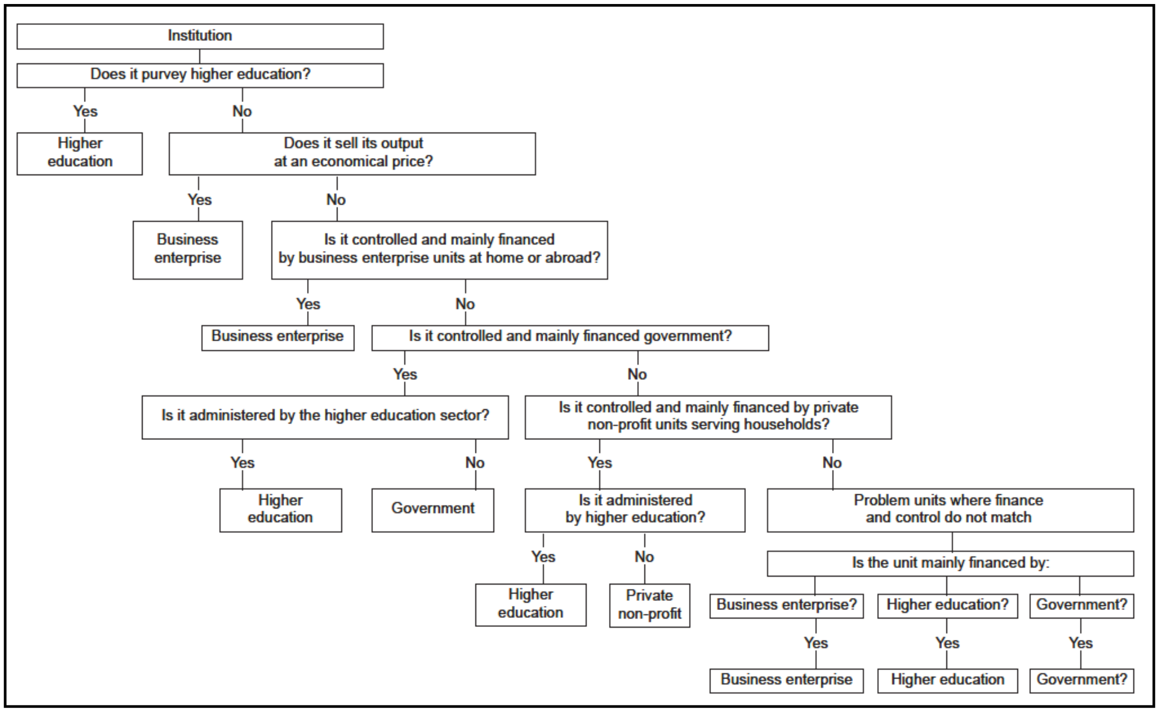

Figure 1. Decision Tree for Sectoring R&D Units (Note: Reproduced from OECD, 2002:55)

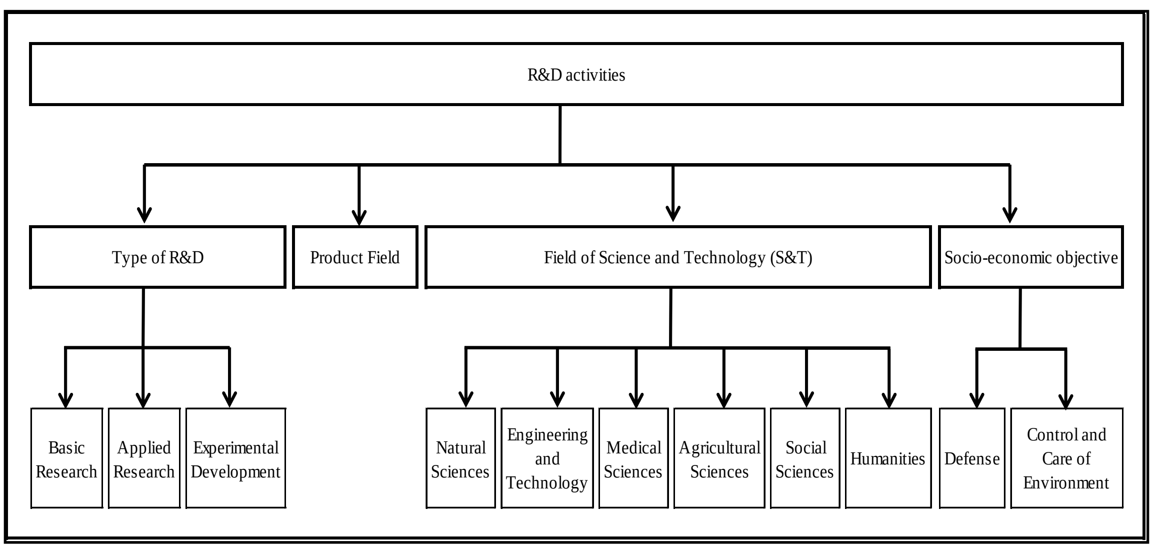

Figure 2. Functional Breakdown of R&D Activities (Note: Adapted from OECD, 2002:77-88)

Funding their own defense R&D as part of their military or defense budgets is one of the ways that countries develop science and technology to improve their warfighting capability. In this way, some nations are able to develop both their military capability and their industrial infrastructure simultaneously, thus becoming technology exporters. However, nations that do not fund their own defense R&D may be at a distinct military and industrial infrastructure disadvantage. Such countries tend to become technology importers. There is inherent risk to technology-importing countries when their relationships with technology-exporting countries change. The problem occurs when technology-exporting nations force their customers into long-term dependent relationships requiring the use of proprietary parts and maintenance procedures. When the relationship sours, the technology-exporting nation can simply withhold supplies, which slowly weakens the dependent nation's military capability. For instance, after Turkey's intervention in Cyprus in 1974, the United States (U.S.) imposed an arms embargo against Turkey (Turkey's armed forces were supported by American weapon systems, parts, and supplies) (Kurtoglu & Agdemir, 2001).

Of course, technology-exporting nations with large armed forces are in the best position to engage in advanced weapons manufacturing due to economies of scale and large budgets. Hence, they are in the best position to export weapons and exert implicit pressure by doing so. Although smaller nations may not be able to become technology or weapons exporters, they may still benefit from funding their own defense R&D. For example, they may gain a proprietary technological/military advantage. Additionally, internal defense R&D expenditures may result in positive socio-economic spillover effects such as patents.

Problem and Purpose Statement

All nations must determine what proportion of their defense budgets will be spent on defense R&D and what proportion will be spent on weapons procurement. The largest nations, like the United States and China, are able to expend large sums on both (see Table 1). The smallest nations, by necessity, focus on weapons procurement. Mid-sized nations face a funding dilemma: to invest in defense R&D or to outsource it. Many nations prefer to purchase military equipment and material from technology-producing countries without funding their own defense R&D. This allows the country to maximize its military capability and strength, at least in the short run. For instance, Saudi Arabia purchases most of its military equipment from its allies such as the U.S. (Quandt, 1981). However, without its own R&D program, Saudi Arabia and countries like it face the aforementioned risks associated with this strategy.

Table 1

Defense and Defense R&D Expenditures

Defense and Defense R&D Exp.		**The United States**	**China**	**Rest of the World**
Total Defense Budget (2011)*	$ B	$690 B	$130 B	$769 B
	% of the world	43%	8%	48%
Total Defense R&D Budget**	$ B	$ 83 B	$ 15 B	$ 22 B
	% of the world	69%	12.5%	18%
Defense R&D as a Proportion of Defense Budget	%	12%	11.5%	3%***

* Source: (Stockholm International Peace and Research Institute (SIPRI), 2012)
** Estimates in the study are used.
*** Calculation does not include countries that do not invest in defense R&D.

Since the expenditure on defense R&D also has potential "spillover" effects (e.g. economical, technological, social, etc.), countries should consider these effects when making funding choices. However, there is a lack of available measures of final outputs of defense R&D, including technology "spin-offs" (Hartley, 2011). The main purpose of this study was to understand the effect of defense R&D expenditures on military capability. This study also attempted to address spillover and spin-off effects of defense R&D. Note: The researcher uses Turkey as a representative mid-sized country facing the internal defense R&D expenditure dilemma in many of the tables.

Research Questions

To address these purposes, this study attempted to answer the following research questions.

1. How can defense R&D expenditure data be estimated when countries choose not to reveal it?

2. What are the currently available measures of military capability? Could other measures be developed? Are military capability measures consistent?

3. What is the effect of defense R&D expenditures on military capability?

4. What are the effects of defense R&D expenditures <u>beyond</u> military capability?

Methodology

The research methodology consists of quantitative research elements. The approach began with a literature review to investigate key concepts and existing data. The second step was to determine how to estimate defense R&D data when many countries choose not to reveal it. The next step was to calculate measures for military capability and spillover effects. The overall study ended with the presentation of the results, including new methods of estimating defense R&D. Additional details on the data collection and estimation approach and data analysis techniques are presented in Chapter III.

Summary

This chapter introduced the overall topic by presenting background information, the problem, research questions, and a summary of the methodology employed in this study. Chapter II presents a detailed literature review of defense R&D, defense R&D data analysis, military capability measurement, and the spillover effects of defense R&D. Chapter III provides a full description of the methodology, including the dataset collection, estimation, and analysis approaches. Chapter IV illustrates the results of the study and delineates the analysis of data and findings. Finally, Chapter V provides the resulting conclusions for the study and outlines recommendations for further research.

II. Literature Review

This chapter starts with the definition of defense research and development (R&D) and then describes difficulties associated with collecting and analyzing defense R&D data. Next, various measurements of national and military capability are introduced. The literature review ends with an analysis of the spillover effects of defense R&D and their interrelationship with civil R&D.

Defense R&D Definition

While it is clear that defense R&D contributes to the total defense capability of a nation (Hartley, 2011; Braddon, 1999; Anderson, 2006; Dunne & Braddon, 2008), no consensus has emerged as to its proper measure and the mechanism of its influence (Hartley, 2011; Dunne & Braddon, 2008). While the basic definition of defense R&D is relatively straightforward, in practice it becomes difficult to separate specific budgetary line items. Thee (1990) defines *defense R&D* as "a mission-oriented R&D activity comprising basic and applied research, with the development, testing and experimental production of new weapons and weapons systems, including the improvement and modernization of existing weapons and weapons systems." Similarly, Motte (1992) defines *defense R&D* as "the expenditure on research and development that is absorbed by the military as opposed to the civil sector of the economy."

While overall R&D expenditure is divided into civilian and defense sectors, some R&D expenditures can be described as "dual-use." The deciding factor for categorization is the primary purpose of the expenditure. For example, nuclear and space R&D (if primarily for defense purposes) are defense R&D; however, meteorology or telecommunications R&D (if primarily used for civil purposes) are civilian R&D (OECD, 2002). As another example, countries with large nuclear R&D programs, such as France, divide the expenditure between the civilian (power plants) and the defense (weapons) sectors (Brzoska, 2005). Finally, enterprise-financed R&D, whose main purpose is defense, should also be assessed under the defense R&D umbrella (OECD, 2002).

Defense R&D Data

Accurate and complete defense R&D data are difficult to obtain due to the scarcity of sources and inherent secrecy involved (Braddon, 1999). Additionally, no single source provides defense R&D data for all countries. Defense R&D data are available from the Bonn International Center for Conversion (BICC) Annual Conversion Surveys, OECD Main Science and Technology Indicators; Stockholm International Peace Research Institute (SIPRI) Yearbooks, European Defense Agency (EDA), and from national defense statistics of defense ministries of countries (Hartley, 2006, 2011). Worldwide comparisons can be made by only gathering data from all of these sources.

In addition to the scarcity of data-producing sources, there are also issues with the reliability of the published data. Table 2 (derived from Hartley (2006, 2011)) details many of these data reliability issues. The lack of consensus as to the mechanism by which defense R&D contributes to total military capability can be partially explained by the data reliability issues mentioned below. All of the problems below limit the availability of defense R&D data, and make it difficult to assess the efficiency of a nation's defense R&D spending. In addition, the problems make it difficult to compare nations and to follow the trends and variations.

Table 2

Problems in Defense R&D Data

NUMBER	PROBLEMS
1.	Activities such as production engineering and pre-production tooling are often included in development contracts and defense contractors might come across further difficulties in reporting their R&D activities where work is sub-contracted.
2.	The distinction between military and non-military R&D may not be obvious and whether and how such civil R&D should be included in measures of defense R&D is an issue.
3.	The data are subject to security/secrecy problems. Even an open society such as the United States has 'black' research programs.
4.	International comparisons require conversion to a common currency, usually the US dollars. The data also vary depending on whether they are in current or constant prices; whether they use market or PPP exchange rates. Further problems arise where time-series data are affected by discontinuities and changes in the price and exchange rate base year.
5.	The published data on government-funded defense R&D do not include any non-government funds (e.g. privately-funded defense R&D).
6.	Defense R&D is subject to annual fluctuations reflecting peaks and troughs in equipment procurement cycles, and defense R&D can vary substantially between years.
7.	There is lack of data or reliable data for countries such as China, Israel, Iran, North Korea, etc.
8.	Generally, the data is not in time-series.

Note: Adapted from Hartley (2006, 2011)

The lack of empirical studies on defense-related R&D topics may be explained by the data scarcity and reliability issues. Finally, defense R&D is an input into national defense, and there is a lack of published data and measures to assess the final outputs, both direct in the form of weapons performance and indirect in the form of spin-offs (Hartley, 2006). Therefore, removing data gaps and developing a reliable way to measure final defense output would enable a comparative assessment of the efficiency of national defense R&D programs. Such output is measured using the accounting convention wherein defense output is measured by defense inputs; however, it is possible to determine the efficiency of defense R&D through assessing military capabilities and cost trends (Hartley, 2010).

Military Capability Concept

The U.S. Department of Defense (DoD) defines *military capability* as "the ability to achieve a specified wartime objective, for example, win a battle or a war or destroy a target" (GAO, 1986). The DoD further divides military capability into four components: 1) *readiness*, 2) *sustainability*, 3) *modernization*, and 4) *force structure* (GAO, 1986). *Readiness* is defined as the ability of the military forces, units, weapon systems, or equipment to deliver the output for which they were designed in peacetime and at the outset of hostilities (GAO, 1986). *Sustainability* is the duration the forces can continue to fight. Sustainability involves the ability to resupply engaged forces during combat operations and is sometimes measured in terms of the estimated number of fighting days for which supplies are available (GAO, 1986). *Modernization* is the technical sophistication of forces, units, weapon systems, and equipment. Finally, *force structure* refers to the numbers, size, and composition of units constituting the military forces. Force structure is usually described as numbers of divisions, ships, or wings (GAO, 1986).

Although several attempts have been made to measure total national power (Singer, Bremer, and Stuckey, 1972; Cline, 1975; Organiski and Kugler, 1978), few attempts have been made to measure military power as distinct from economic and political power (Friedensburg, 1936; Wright, 1955). While military power/capability is usually the most important component in total national power calculations, typically it is not provided as a separate element. In fact, there is no consensus on how to measure the military capability of a nation (distinct from total national power) at a given time.

Early theorists often relied on population and raw material data to extrapolate estimated military power. For example, one of the formulas determined military power by multiplying the supply potential of raw materials and population (Friedensburg, 1936). Another attempt by Wright (1995) calculates military power by multiplying secondary energy production and population (Höhn, 2011). These early attempts to quantify military power were useful when raw materials such as coal directly influenced military power. In the modern era though, the influence of these raw materials on military power is diminished. Later, Marshall (1966) endeavored to calculate the military power of the former Soviet Union by relying primarily on force structure data. Importantly, he points out that the estimation of a nation's military power can only be possible *relative* to another country or set of countries. Marshall (1966) points out that, otherwise, the calculation says nothing about the actual capabilities of forces of one country to deal with another. Thus, the measures of total national power used in this thesis research provide relative data.

The Composite Index of National Capability (CINC) is among the best-known and most accepted methods for measuring total national capabilities (Power Index, 2006). CINC was developed within the Correlates of War project founded by J. David Singer in 1963 (Power Index, 2006). It is comprised of three dimensions: *military strength,* measured by adding military expenditure and military personnel; *industrial activity,* measured by adding iron/steel production and energy consumption; and *demographic factors,* measured by adding total population and urban population (Singer et al., 1972;

Singer, 1987). The most recent revision to the Correlates of War project was published in 2007. In the CINC formula, each component is a dimensionless ratio of the world's total and the formula is:

$$CINC = \frac{TPR + UPR + ISPR + ECR + MER + MPR}{6}$$

Where:

$$Ratio = \frac{Country}{World}$$

TPR = Total population of country ratio,

UPR = Urban population of country ratio,

ISPR = Iron and steel production of country ratio,

ECR = Primary energy consumption ratio,

MER = Military expenditure ratio,

MPR = Military personnel ratio.

More recently, Arena (2012) proposed a formula for military power calculation, which is derived from CINC. CINC does not take into account the quality and the technological sophistication of armed forces. Therefore, Arena (2012)'s goal was to account for the size of a military *and its sophistication*. He subsequently proposed the following formula (see Appendix A for $Arena_{milpow}$).

$$M_{i,t} = Arena_{milpow} = \Pi_{i,t}\, q_{i,t}$$

Where:

$Arena_{milpow}$: Arena's military power index,

$\Pi_{i,t}$: Discounted measures of the military personnel of country *i* in year *t*,

$q_{i,t}$: Discounted measures of the quality ratios (military expenditures per troop) of country *i* in year *t.*

Discounted measures of the military personnel of country *i* in year *t* is specifically:

$$\Pi_{i,t} = \frac{milper_{i,t}}{milper_{i,t} + \delta_t{}^{\Pi}}$$

Where $milper_{i,t}$ is t he military personnel for country *i* in year *t*, and $\delta_t{}^{\Pi}$ is a 5-year moving average that is specifically defined as,

$$\delta_t{}^{\Pi} = \frac{\overline{milper_{i,t-1}} + \overline{milper_{i,t-2}} + \cdots + milper_{i,t-5}}{5}$$

Where $\overline{milper_{i,t}}$ is the global average military personnel in year *t*. Similarly, the discounted measures of the quality ratios of country *i* in year *t* is,

$$q_{i,t} = \frac{qualrat_{i,t}}{qualrat_{i,t} + \delta_t{}^{q}}$$

Where $qualrat_{i,t}$is the quality ratio for country *i* in year *t* (taken by dividing the military expenditures for that country by its military personnel), and $\delta_t{}^{q}$ is 5-year moving average of the average quality ratio.

Another recent attempt to measure military power is produced by the Global Firepower (GFP) website (http://www.globalfirepower.com). This website uses over 40 publicly available factors to compute a power index score (referred to as GFP_{milpow} in this research), which is used to rank order 68 countries by military power (see Appendix B for GFP_{milpow} list). The explanation behind the rankings and the computation of GFP_{milpow} itself is not provided, which makes the data difficult to interpret; nevertheless, many published articles (Zedalis, 2007; Nazar, 2007; Hamdy, 2010; Prasetya, 2012; Silhan, 2012) cite the website. Prior to January 2013, the website was only providing the rankings and the raw data for each included nation; however, in January 2013, the website was updated and now it includes the aforementioned GFP_{milpow}. Included in the over 40 variables are military factors (the number of tanks, aircraft, ships etc.), demographic factors (total population, available work force, etc.), logistical factors (labor force, railway coverage, etc.), financial factors (annual defense budget, external debt, etc.), and geographic factors (coastline, land area, etc.).

The formulas described above all include measurements of tangible assets ("hard" powers). However, there are also formulas (Cline, 1975; Beckman, 1984) that measure national power by relying on intangible assets ("soft" powers) such as social development level, government integrity, etc. In the last three decades, the Chinese have developed various concepts of Comprehensive National Power (CNP) to measure national power including "soft" powers (Pillsbury, 2000). One of the CNP formulas created by Wang Songfen from Chinese Academy of Social Sciences (CASS) is outlined in Table 3.

Table 3

Weighted Coefficients in Comprehensive National Power (CNP) Formula

NATIONAL POWER FACTOR	**WEIGHTED COEFFICIENT**
Total CNP	1.00
Natural Resources	0.08
Economic Activities Capability	0.28
Foreign Economic Activities Capability	0.13
Scientific and Technological Capability	0.15
Social Development Level	0.10
Military Capability	0.10
Government Regulation and Control Capability	0.08
Foreign Affairs Capability	0.08

Note: Reproduced from Pillsburry (2000) (Original source Songfen (1996))

Since 2002, the Indian government has been developing their National Security Index (NSI), which is the result of a general paradigm shift from focusing solely on "hard" powers to also including "soft" powers (Hwang, 2008). According to Hwang (2010), the NSI sometimes produces unconvincing results, such as ranking Norway as the third most powerful country. Hwang (2010) points out that ranking Norway, with its population of five million people, as the third most powerful country in the world is implausible. Certainly, Norway is a very rich country due to its offshore oil and the high level of social infrastructure, which skews its per capita measurements. Hwang (2008) proposed another measure of national power, which was derived from CNP and NSI. In addition, Hwang (2008) adds energy production and nuclear weapons to his formula to calculate national power, which he called Integrated State Power (ISP). In his formula (see Appendix C), Hwang (2008) proposes that military expenditures and arms production should be calculated by multiplying their percentage share of Gross Domestic Product (GDP) with certain socio-economic factors. The NSI and ISP formulas are detailed in Table 4 and Figure 3, respectively.

Table 4

National Security Index-2007 Formula

WEIGHT	NATIONAL POWER FACTOR
25%	Economic Strength
18.75%	GDP at Official Exchange Rate, 2005
6.25%	Average Annual GDP Growth Rate in %, 2000-2005
25%	Defense Capability
10.00%	Armed Forces Personnel
7.50%	Defense Expenditure at Official Exchange Rate
2.50%	Main Battle Tanks
2.50%	Aircraft
2.50%	Principal Surface Combatants
20%	Energy Security
10.00%	Per Capita Energy Production in Metric Tons of Oil Equivalent, 2004
10.00%	Net Energy Imports in Millions $, 2004
15%	Technological Strength
2.25%	High Technology Exports as Percentage of Manufactured Exports, 2004
2.25%	Total Number of Patents, 2000-2004
6.00%	Research and Development Expenditure as % of GDP
2.25%	Researchers per Million
2.25%	Scientific and Technical Journal Articles, 2004
15%	Effective Population
9.00%	Population Aged 15-64, 2004
3.00%	Population Educated up to Post-Secondary Level, 2000
3.00%	Per Capita GDP at Official Exchange Rate, 2005

Note: Reproduced from Hwang (2010) (Original source Kumar (2008))

<table>
<tr><td rowspan="2">Integrity</td><td rowspan="2">Education</td><td rowspan="4">Military Expenditures</td><td rowspan="4">Arms Production</td><td>6.25%</td><td>Integrity</td></tr>
<tr><td>6.25%</td><td>Education</td></tr>
<tr><td rowspan="2">Life Expectancy</td><td rowspan="2">Economic Level</td><td>6.25%</td><td>Life Expectancy</td></tr>
<tr><td>6.25%</td><td>Economic Level</td></tr>
<tr><td colspan="2" rowspan="4">Energy Production</td><td colspan="2" rowspan="4">Nuclear Weapons</td><td>12.50%</td><td>Military Expenditures</td></tr>
<tr><td>12.50%</td><td>Arms Production</td></tr>
<tr><td>25.00%</td><td>Energy Production</td></tr>
<tr><td>25.00%</td><td>Nuclear Weapons</td></tr>
</table>

Figure 3. Integrated State Power Formula Weights (Note: Reproduced from Hwang, 2008:13)

Spillover Effects of Defense R&D and Interrelations with Civil R&D

Generally, the purpose of defense R&D is to expand military capability for the armed forces of a country. Any spin-off of technologies from defense R&D programs is usually not a prime motivation but more often an unintended consequence, unless a dual-use strategy has been developed (Dunne & Braddon, 2008). Nevertheless, concerns with the role of military R&D and its consequences in other secondary areas, such as industrial/social effects, have been the focus of research by economists over the years (Dunne & Braddon, 2008). However, measurement difficulties and unclear opportunity costs have generated a lack of consensus in this area (Dunne & Braddon, 2008; Hartley, 2011).

While some military R&D efforts eventually spill over into commercial applications, there is often a temporary advantage for the researching organization and its sponsors to keeping the technology secret. In fact, obtaining an impossible-to-mimic advantage is often the primary goal of military R&D spending. Military organizations that have R&D capability clearly benefit from early access to innovative technology, patents, data rights, and strategically marketing various levels of the technology to other countries (James, 2004). For instance, the U.S. exports many different versions of the F-16 fighter around the world but keeps its most capable versions for its own use.

Defense R&D investments may produce secondary benefits ("spin-offs") if successful; however, when these investments fail, the question of whether there would have been better alternative uses of the resources arises (Hartley, 2011). These alternative uses, or "opportunity costs" are, of course, speculative. There are diverse examples of technology spin-offs from defense R&D. They include the transfer of military aircraft and jet engine technology to civil aircraft, the innovation of Light Amplification by Stimulated Emission of Radiation (LASER) and the Global Positioning System (GPS), and the development of the Internet. However, the question of the market value of such spin-offs, and whether there are better alternative uses of defense R&D resources, still exists (Hartley, 2011).

Nations must decide whether to invest revenue in R&D spending or on alternative uses. Once they decide how much to invest in R&D spending, they must also determine what proportion of the R&D should be defense versus civilian in nature. Brzoska (2005) provides five "ideal type" approaches (often combined in practice), which are summarized in Figure 4 and discussed in the remainder of the chapter.

"Spin-off" approach: During the early Cold War days, military R&D was the fundamental activity in science and technology (S&T) in many countries. Military R&D dominated S&T because of the relative size of funding and advanced military knowledge and technology applications. The military knowledge gained was applied particularly in aerospace, space, and material sciences, but the overall record of producing civilian spin-off has been mixed using this approach (Brzoska, 2005).

"Warfare and welfare" approach: Beginning in the 1960s, some governments began to support military and civilian R&D simultaneously while the sectors continued to be institutionally split. In this approach, military R&D received priority, but it was implemented in a manner designed to simultaneously develop strategic civilian industries. For instance, in France, the high cost of developing an independent nuclear weapons force was matched with the development of a large nuclear power sector (Brzoska, 2005).

Level	Civilian Sector	Interaction/transfer	Military Sector
Knowledge and technology production	Civilian r&d	Spin-off Spin-in dual-use	Military r&d
Production of high-tech goods	Civilian high-tech sector	COTS	Military sector
Know-how of research and production of high technology	Civilian r&d sector	Spin-off Spin-in dual-use	Military r&d sector
Production factors	Researchers, infrastructur in civilian r&d	Conversion Reversion	Researchers, infrastructur in mlitary r&d
Financing of r&d	Civilian funding	risk technology development Intra-company investments Funding of strategic sectors	Military funding

Figure 4. Elements of Civilian/Military R&D Interaction (Note: Reproduced from Brzoska, 2005:21)

"Dual-use" approach: The purpose of *dual-use* approach is to improve generic knowledge and technology contributions from both military and civilian R&D. As a result, a technology "pool" is constructed (Brzoska, 2005). The difference between the *dual-use* and *warfare and welfare* approaches is that *dual-use* aims to collect the knowledge and technology under one roof while *warfare and welfare* aims for each sector to obtain its own results.

"Civil-military integration" approach: Unlike the first three approaches, the *civil-military integration approach* emphasizes the importance of civilian R&D to military R&D. In Germany, for instance, since the mid-1950s, most military R&D occurs in large

private companies such as Siemens and Daimler-Benz (Brzoska, 2005). Technological capabilities, knowledge, research assets, and researchers are used by both civilian and military purposes as far as secrecy requirements allow. Thus, there is a constant *conversion* and *reversion* of the factors of production (Brzoska, 2005). The U.S. has been operating using this strategy since the late 1990s (James, 2004). Much of new technology expertise comes from civilian R&D and industry while military R&D focuses on closing technology gaps on the one hand and on the integration of civilian and military technology for military purposes on the other (Brzoska, 2005).

"Spin-in" approach: This approach is the opposite of the *spin-off approach*. In the *spin-in approach,* civilian R&D and industry replace the dominance of military R&D. Japan after the 1950s is an example of the *spin-in* approach. In Japan, military R&D is subordinate to civilian R&D and the role of military R&D is to cover areas where no civilian knowledge or technology is available. Most of the military technology either comes from the civilian sector or is imported, and domestic weapons are built combining imported knowledge and expertise gained in civilian production (Brzoska, 2005).

Summary

In chapter II, first, the concept of defense R&D, and the problems of defense R&D were introduced. Then, the definition of military capability was provided, and the calculation of military capability was discussed. Finally, the chapter concluded by describing the interactions of military R&D and civil R&D.

III. Methodology

This chapter opens with a detailed description of the methodology used during the research. It outlines datasets reviewed, data estimation approaches, and data analysis techniques necessary to address the research questions. First, the datasets chosen for analysis and consolidation are introduced. Following the description of the dataset, the methodology used to develop the *military capability* and *defense R&D* measures is explained. Next, the chapter covers how some of the absent defense R&D data points are estimated. Finally, the chapter ends with the data analysis approach.

Datasets

In this study, it was necessary to develop three different consolidated datasets: one to calculate *military capability*, one to estimate *defense R&D*, and one to construct the *technological spillover index*. Four source datasets were aggregated by country and year providing the basis for the analysis of military capability. These datasets were the Stockholm International Peace Research Institute (SIPRI) Military Expenditure Database, the United Nations Human Development Report, the Transparency International's corruption perception index, and the World Bank Database (see Table 5). Together, these data facilitated a military capabilities analysis of 194 countries. However, 57 countries were excluded due to incomplete data. The researcher excluded a country's data points when five or more variables out of ten were not available. Ultimately, the final military power analysis dataset includes 137 countries.

Table 5

Datasets Used for Military Capability Calculations

SOURCE	COLLECTED VARIABLE DATA	YEAR
U.N. Human Development Report	Life expectancy, gross enrollment ratio, adult literacy	2011
Stockholm International Peace Research Institute (SIPRI)	Military expenditure	2012
Transparency International (www.transparency.org)	Corruption perception index (Integrity)	2012
World Bank Database	GDP, military personnel numbers	2011

Six datasets were aggregated by country and year providing the basis for the defense R&D data analysis. These datasets were the European Defense Agency (EDA) Report, the Center for Strategic & International Studies (CSIS) Asian Defense Spending Report, SIPRI Yearbook, the World Bank Database, the website of Turkish Statistical Institute, and Hartley (2011) (see Table 6). Together, these data facilitated a defense R&D analysis of 33 countries from all over the world. Although many different datasets were used, only 33 countries provided complete defense R&D data. A defense R&D data point was calculated for South Africa from raw input values (34 countries). Additionally, the researcher estimated defense R&D data for 48 countries. The methodology used to estimate this data is explained in section 3.3.

Table 6

Datasets Used for Defense R&D Calculations

SOURCE	**COLLECTED VARIABLE DATA**	**YEAR**	**ACCESSED ON**
European Defense Agency (EDA) Defense Data Report	Defense R&D expenditure of European countries	2010	Dec 15, 2012
Center For Strategic & International Studies (CSIS) Asian Defense Spending 2000-2011 Report	Defense R&D expenditure of Asian countries	October 2012	Jan 18, 2013
World Bank Database	GERD as percentage of GDP	2011	Jan 20, 2013
Stockholm International Peace Research Institute (SIPRI)	Military expenditures as percentage of GDP	2012	Jan 5, 2013
Turkish Statistical Institute (www.turkstat.gov.tr)	Defense R&D expenditure of Turkey	2012	Dec 10, 2012
Hartley (2011)	Defense R&D expenditure of different countries	2011	July 10, 2012

Two datasets were aggregated by country and year providing the basis for the analysis of the technological spillover index. These datasets were SCImago (2007) and World Bank Database (see Table 7). Together, these data facilitated the construction of a *technological spillover index* for 137 countries.

Table 7

Datasets Used for Technological Spillover Index Construction

SOURCE	**COLLECTED VARIABLE DATA**	**YEAR**	**ACCESSED ON**
SCImago (www. scimagojr.com)	Scientific Publications	1996-2007	Feb 13, 2013
World Bank Database	Patent Applications, Researchers in R&D per million people	2010 2009	Feb 13, 2013

Data for expenditure variables were adjusted to U.S. dollars to ensure commensurability in the final aggregated dataset. The available data are provided in three types of currencies: Dollars, Euros, and Turkish liras. Data that were originally measured in Euros were adjusted using euro-dollar exchange rates specified by the International Monetary Fund (IMF) (http://www.imf.org). Data that were originally measured in Turkish liras were adjusted using the Turkish lira-dollar exchange rates of The Central Bank of Turkey (http://www.tcmb.gov. tr). Since the majority of the datasets included data during a period of relatively low inflation (2009 to 2012), inflation effects were ignored for the purpose of the study.

Military Capability Formulas

The existing military power indexes (GFP_{milpow}), military power formulas ($Arena_{milpow}$), and the military power portions of total national power calculations (derived from CINC and Hwang's formula) were used during the research. The military power-related variables are separated from the total national power measures because the goal was to measure the effect of defense R&D on military capability, not on total national power.

Since one of the components of the CINC formula is military strength, it is assumed that the military power portion of the formula can be used as a military power index score. It is logical to separate military power from total national power because the CINC index is the average of the demographic, economic, and military components and each of these components have equal weight in the formula. From the CINC index formula, the following formula was created to measure military power and the military power index was modified to:

$$CINC_{milpow} = (\text{MER}+\text{MPR})/2$$

Where $CINC_{milpow}$ is the military power index derived from CINC total national power formula, MER is the military expenditure ratio, and MPR is the military personnel ratio.

The second formula, Hwang (2008)'s Integrated State Power formula, was also modified to meet the military power calculation requirement. Hwang (2008)'s formula takes into account 50% military power (by multiplying military expenditures and arms production with certain socio-economic factors) and 50% nuclear power and energy production. In Hwang (2008)'s military power calculations, nuclear weapons were excluded because the nuclear capability of many countries is unconfirmed or disputed. Energy production was also excluded from Hwang (2008)'s formula. Additionally, the variable "arms production as percentage of GDP" was changed to "employment in arms production" because of data availability. Finally, the new formula to calculate military power index was:

$$Hwang_{milpow} = (\text{ME\%} + \text{AP\%}) \times (\$\text{GDP} + \text{LE} + \text{INT} + \text{EDU})$$

Where:

$Hwang_{milpow}$: The military power index derived from Hwang's Integrated State Power formula

$GDP : Nominal GDP,

LE : Life Expectancy,

INT : Integrity,

EDU : Education,

ME % : Military Expenditures as Percentage of GDP,

AP % : Arms Production as Percentage of GDP.

$Arena_{milpow}$ was derived from the CINC total national power formula; since the formula was presented as the military power calculation, it will be used without any changes. Another military power index, mentioned before, is GFP_{milpow} and the scores are ready-to-use so there were no adjustments. However, GFP_{milpow} scores are indexed on a perfect value of zero such that countries with a smaller index have higher rankings. To prevent confusion during analysis of the data, GFP_{milpow} was inverted so that higher GFP_{milpow} index scores would indicate the higher ranking.

Defense R&D Expenditure Estimation

Recall that research question number one was, "How can defense R&D expenditure data be estimated when countries choose not to reveal it?" The researcher tried to answer this research question in this section. During the Cold War era, the U.S. intelligence community performed studies to estimate the Soviet Union's military R&D expenditures. The military R&D expenditure estimates from those studies had a direct and consistent relationship with the Soviet Union's national science expenditures (GAO, 1972). In a similar vein, this research relies on science expenditures (Gross expenditure on research and development (GERD)) to estimate military R&D expenditures when those numbers were not available. Specifically, military expenditures as a percentage of GDP and GERD as a percentage of GDP are used to aid in estimation of defense R&D expenditures for 48 countries.

Multiple correlations were conducted to gain insight into the relationships among expenditure variables. Military expenditure was highly positively related to defense R&D expenditure for countries whose defense R&D expenditure was known. The correlation coefficient was 0.99, which implies that the more a country spends on defense, the more it spends on defense R&D. Additionally, the relationship between overall R&D (GERD) and military expenditure was positive, with a correlation coefficient of 0.90. Finally, GERD is positively related to defense R&D with a correlation coefficient of 0.87.

Defense R&D data for 48 countries was estimated by multiplying the two variables: military expenditures as percentage of GDP and GERD as percentage of GDP. The result was then multiplied by GERD raw data. In this way, the defense R&D dataset is increased to 82 countries, with 34 provided data points, and 48 estimated data points. As a test of the estimation method, a correlation between the 34 known data points and the corresponding estimate for the same data point were performed. The estimated defense R&D data points and known defense R&D data points were positively correlated and the correlation coefficient for this relationship was 0.989. Therefore, the estimated defense R&D data and known defense R&D data move in the same direction and estimated data points appear reasonable for the purpose of this study.

Additional tests were performed to reveal if the estimation method was reasonable. Brzoska (2005) states that the United States (number one in defense R&D expenditure) spends approximately more than 60% of the world's total defense R&D expenditure. The estimation method predicts 69%. Sköns, Loose-Weintraub, Omitoogun, Stalenheim, & Weidacher (2001) reveals that total expenditure on military R&D for the five largest countries (USA, UK, France, China, and Germany) was 84%. The estimation method predicts 89%. Finally, Hartley (2011) reveals that the top six countries (France, Germany, UK, Spain, Sweden, and Italy) in Europe expend 99% of

Europe's defense R&D. The estimation method predicts 92%. Therefore, the results of the three tests support the assertion that the estimation method used in this study is reasonable and acceptable.

Technological Spillover Index Production

For the purpose of this study, spillover effects include such items as increased technological know-how, more engineering students and degrees, and commercial applications and patents. Since no existing measures for spillover were found, a *technological spillover index* was constructed. The *technological spillover index* was comprised of three variables obtained from the SCImago (2007) and World Data Bank datasets: 1) the total of resident and non-resident patent applications, 2) scientific publications for ten years, and 3) the number of researchers in R&D per million people. The index is calculated as the average of the three variables' data points (dimensionless ratios of each country to the world). In some cases, only two of the variables were available, in which case the index was the average of the two available data points.

The variables of the *technological spillover index* were chosen based on existing literature. According to Science and Engineering Indicators (2012), the outputs of academic research are scientific publications and patent applications. In addition, the technological strength factor in the National Security Index-2007 formula (shown in Table 4) includes similar variables to measure technological strength. The index includes business and higher education variables because the literature describes defense R&D spillover effects from both of these areas (Braddon, 1999; Peled, 2001; Dunne & Braddon, 2008). Additionally, the number of researchers per million people helps us to understand the work force in research and development so this variable is added to the index formula. Finally, the formula is:

$$TSI = Average\ (PAR + SPR + NRR)$$

Where:

$$Ratio = \frac{Country}{World}$$

TSI: Technological Spillover Index,

PAR: Patent Applications Ratio,

SPR: Scientific Publications Ratio,

NRR: Number of Researchers in R&D per million people Ratio.

Data Analysis Approach

As described above, three aggregated datasets were used for data analysis: the *military capability* aggregated dataset, the *defense R&D* aggregated dataset, and the *technological spillover index* aggregated dataset. Ultimately, these three datasets were combined into a format compatible with the SPSS software program to analyze the data. Statistical measures such as correlations were used to understand the effect of defense R&D on military capability and "spillover." Presumably, countries expect that their defense R&D expenditures will result in increased military capability in the future. Therefore, it is logical to view the relationship of defense R&D expenditures with military capability and spillover as chronological and causal. Nevertheless, this thesis research relies primarily on correlational relationships to test concepts and, therefore, no results from this study imply causation or direction. It is possible that the relationship is recursive or occurs in the opposite direction (military capability leads to defense R&D expenditure).

Summary

Chapter III introduced the data collection and aggregation methodology; it also described variable creation and testing. The chapter also explained data estimation procedures and presented data analysis formulas that were used to obtain the results. The next chapter will present the results and the analysis of the study.

IV. Results and Analysis

In this section, the results and analysis of the study are presented. First, the relationship between the total national power formulas and derived military power formulas are introduced. Then, the correlations of defense R&D with the four military capabilities formulas and with the technologic spillover index are presented. The chapter ends with the analysis of results.

Comparing National Power Formulas and the Derived Military Capability Formulas

In this study, two military power formulas were derived from two total national power formulas. The raw results from the two total national power formulas were normalized for easy comparison, and the first 15 countries and Turkey are shown in Table 8 (see Appendix D for full list). The correlation between two national power formulas was 0.842 (significant at the.01 level). It can be interpreted that although each formula takes into account different factors as input, the formulas reveal similar outputs.

In this study, the derived military power indexes are referred to as $CINC_{milpow}$ and $Hwang_{milpow}$. The normalized results of $CINC_{milpow}$ and $Hwang_{milpow}$ of the first 15 countries and of Turkey are shown in Table 9 (see Appendix E for full list). These *military power indexes* are highly correlated with the original *total national power indexes* (significant at the .01 level). Specifically, the correlation between CINC and $CINC_{milpow}$ was 0.798, and the correlation coefficient between Hwang and $Hwang_{milpow}$ was 0.969 (both significant at the .01 level).

Table 8

Normalized Raw Results of CINC and Hwang

RANK	COUNTRY	CINC RESULTS	COUNTRY	HWANG RESULTS
1	China	1.397	USA	1.000
2	USA	1.000	China	0.467
3	India	0.517	Russian Federation	0.238
4	Japan	0.300	United Kingdom	0.170
5	Russian Federation	0.276	France	0.146
6	Brazil	0.173	India	0.104
7	Germany	0.169	Japan	0.077
8	South Korea	0.168	Canada*	0.070
9	United Kingdom	0.149	Germany	0.057
10	France	0.133	Australia	0.044
11	Italy	0.123	Saudi Arabia	0.035
12	**Turkey***	0.101	Brazil*	0.031
13	Pakistan	0.097	South Korea	0.025
14	Indonesia*	0.096	Indonesia*	0.024
15	Iran	0.095	Mexico*	0.024
27	*Australia*	*0.036*	***Turkey***	*0.011*

* Countries, which appear on Table 8 but do not appear on Table 9.

Table 9

Normalized Results of CINCmilpow and Hwangmilpow

RANK	**COUNTRY**	$CINC_{milpow}$ **RESULTS**	**COUNTRY**	$Hwang_{milpow}$ **RESULTS**
1	USA	1.000	USA	1.000
2	China	0.321	China	0.494
3	Russian Federation	0.152	Russian Federation	0.070
4	India	0.146	France	0.038
5	France	0.100	Japan	0.026
6	United Kingdom	0.089	India	0.023
7	Japan	0.087	Saudi Arabia	0.022
8	North Korea**	0.080	Germany	0.021
9	South Korea	0.080	Israel**	0.017
10	Saudi Arabia**	0.076	United Kingdom	0.016
11	Germany	0.070	United Arab Emirates**	0.014
12	Brazil	0.063	South Korea	0.014
13	Italy	0.061	Italy**	0.011
14	Pakistan	0.048	Oman**	0.010
15	Iran	0.048	Australia	0.010
16	***Turkey***	*0.044*	*Brazil*	*0.010*
19	*Australia*	*0.034*	***Turkey***	*0.009*

** Countries, which appear on Table 9 but do not appear on Table 8.

Because the normalized values are heavily weighted towards the top few countries, it was determined that rank data (ordinal) might be more meaningful. In fact, rank data helps to smooth data distortions due to outliers (Agresti, 2010; Cateni, Colla, & Vannucci, 2008). Therefore, the rankings obtained from both the derived and original formulas were also compared. *CINC* and $CINC_{milpow}$ rankings have a correlation of 0.953, and *Hwang* and $Hwang_{milpow}$ rankings have a correlation of 0.969 (both significant at the .01 level). Clearly, military power plays an important role in these total national power calculations.

When the rankings from the Hwang total national power and $Hwang_{milpow}$ *indexes* are analyzed, the rankings of some countries are dramatically changed (see Table

8, Table 9, and Table 10). The three countries with the most dramatic decline in the ranking were Mexico, Venezuela, and North Korea. Mexico has the seventh largest oil production share in the world at 3.44%, while Venezuela has the twelfth largest oil production share in the world at 2.74% (CIA, 2010). It is likely that Mexico and Venezuela's rankings declined because the derived formula does not include the energy-related factor. Likely, North Korea's decline is because the derived formula does not include nuclear weapons capability. On the other hand, Namibia and Lebanon's rankings significantly increased. This is likely due to the two countries' unusually high spending on military expenditures as a percentage of GDP.

Table 10

Ranking Changes of Some Countries

NUMBER	COUNTRY	HWANG RANK	$Hwang_{milpow}$ RANK	CHANGE
1	North Korea	17	126	-109
2	Venezuela	31	109	-78
3	Mexico	15	92	-77
4	Nigeria	38	115	-77
5	Namibia	121	44	+77
6	Lebanon	106	31	+75
7	Argentina	30	97	-67

Comparing Military Power Formulas

Recall that research question number two was, "What are the currently available measures of military capability? Could other measures be developed? Are military capability measures consistent?" This research question was addressed by analyzing the relationship between four different *military capability indexes*. This paper has presented two existing measures of military power ($Arena_{milpow}$ and GFP_{milpow}) and two derived measures of military power ($CINC_{milpow}$ and $Hwang_{milpow}$). To determine whether these measures were consistent, statistical correlations were obtained. When the derived military power formulas' raw results are analyzed, each formula's raw results are found to be highly correlated (significant at the .01 level) except the correlation between $Hwang_{milpow}$ and GFP_{milpow}. The correlation coefficients are given in Table 11 and it can be seen that $Hwang_{milpow}$ and GFP_{milpow} are not significantly related.

Table 11

Comparing Military Power Formulas

	$CINC_{milpow}$	$Hwang_{milpow}$	$Arena_{milpow}$	GFP_{milpow}
$CINC_{milpow}$	1	.962**	.705**	.245**
$Hwang_{milpow}$	.962**	1	.582**	.145
$Arena_{milpow}$	.705**	.582**	1	.582**
GFP_{milpow}	.245**	.145	.582**	1

** Correlation is significant at the 0.01 level (2-tailed)

However, when the rankings of the countries by their *military capabilities* are analyzed, all four measurements are highly correlated with each other (significant at the .01 level) (see Table 12). This demonstrates that these four measures are consistent. Without evidence of the superiority of one *military capability*, measure over the others, all four indexes were used in the analysis of research question number three.

Table 12

Comparing the Rankings of Military Power Formulas

	$CINC_{milpow}$ RANK	$Hwang_{milpow}$ RANK	$Arena_{milpow}$ RANK	GFP_{milpow} RANK
$CINC_{milpow}$ RANK	1	.689**	.908**	.803**
$Hwang_{milpow}$ RANK	.689**	1	.767**	.403**
$Arena_{milpow}$ RANK	.908**	.767**	1	.671**
GFP_{milpow} RANK	.803**	.403**	.671**	1

** Correlation is significant at the 0.01 level (2-tailed)

Relationship between Defense R&D and Military Capability

Recall that research question number three was, "What is the effect of defense R&D expenditures on military capability?" This research question was addressed by analyzing the relationship between *defense R&D expenditure* and *military capability* by four different military capability indexes. The defense R&D analysis includes 82 countries, which consists of both known and estimated defense R&D data. The defense R&D expenditure data for the first 15 countries and for Turkey are given in Table 13 (see Appendix F for full list) and the correlation coefficients are given in Table 14.

Table 13

Defense R&D Data for First 15 Countries and Turkey

COUNTRY	**RANK**	**DEFENSE R&D EXPENDITURE ($)**	**SHARE OF THE WORLD TOTAL**	**ESTIMATED-0 KNOWN-1**
United States	1	83,193,000,000.00	0.692	1
China	2	15,000,000,000.00	0.125	1
France	3	4,157,193,447.60	0.035	1
Russian Federation	4	3,600,000,000.00	0.030	1
United Kingdom	5	3,361,961,822.80	0.028	1
Israel	6	2,471,140,857.98	0.021	0
Germany	7	1,689,225,624.66	0.014	1
South Korea	8	1,600,000,000.00	0.013	1
India	9	1,300,000,000.00	0.010	1
Japan	10	1,000,000,000.00	0.008	1
Singapore	11	605,072,278.28	0.005	0
Brazil	12	438,200,150.12	0.004	0
Australia	13	242,700,000.00	0.002	1
Canada	14	201,600,000.00	0.002	1
Spain	15	188,188,483.27	0.002	1
Turkey	***16***	***146,275,609.27***	***0.001***	***1***

Table 14

The Relationship between Defense R&D and Military Capability

	$CINC_{milpow}$	$Hwang_{milpow}$	$Arena_{milpow}$	GFP_{milpow}
Defense R&D	.970**	.959**	.581**	.323*

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

The results imply that *defense R&D expenditure* of countries is positively related to *military capability* according to the four different military capability measures. However, the degree of relationship varies between measures. The strength of the relationship between *defense R&D expenditure* and the two derived measures ($CINC_{milpow}$ and $Hwang_{milpow}$) is stronger than the relationship between *defense R&D expenditure* and the two existing measures ($Arena_{milpow}$ and GFP_{milpow}). In other words, the two derived military capability indexes indicate a stronger relationship between *defense R&D expenditure* and *military capability* than the other two military capability indexes. Nevertheless, all four measures support the assertion that expenditures on *defense R&D expenditure* have a positive effect on *military capability* (recall that this relationship could be recursive or could occur in the opposite direction).

After conducting an outlier analysis, two outlier data points (the United States and China) were found in the *defense R&D expenditure* dataset. The distribution of the *defense R&D expenditure* data is shown in Figure 5.

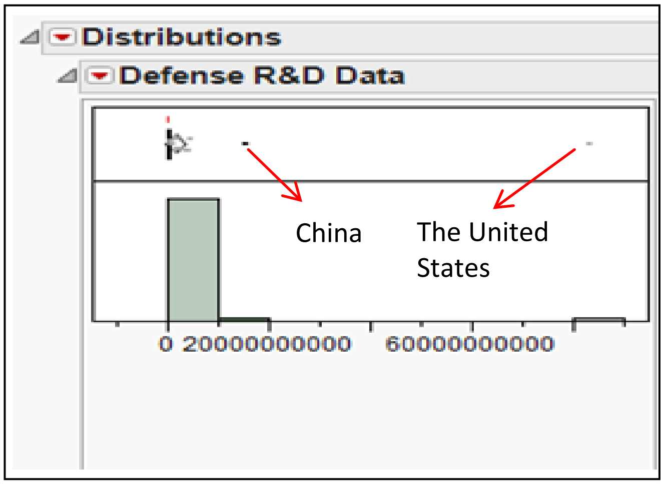

Figure 5. The Distribution of Defense R&D Expenditure Data

Therefore, the two-outlier data points were excluded to obtain more accurate results. After excluding the two outlier countries, the correlation results of the four military capability measures become closer to each other, specifically, the correlation coefficient for $CINC_{milpow}$ and $Hwang_{milpow}$ decreased and the correlation coefficient for $Arena_{milpow}$ and GFP_{milpow} increased (see Table 15).

Table 15

The Relationship between Defense R&D and Military Capability after Excluding Outliers

	$CINC_{milpow}$	$Hwang_{milpow}$	$Arena_{milpow}$	GFP_{milpow}
Defense R&D	.746**	.817**	.686**	.529**

** Correlation is significant at the 0.01 level (2-tailed)

Additionally, the relationship between the rankings of countries' *defense R&D expenditure* and four *military capability* measures was analyzed. The correlation coefficients are very close to each other and the rankings of countries' *defense R&D expenditure* and the rankings of countries' *military capability* are positively related (significant at the .01 level) (see Table 16).

Table 16

The Relationship between Defense R&D Ranking and Military Capability Ranking

	$CINC_{milpow}$ **RANK**	$Hwang_{milpow}$ **RANK**	$Arena_{milpow}$ **RANK**	GFP_{milpow} **RANK**
Defense R&D RANK	.796**	.755**	.827**	.662**

** Correlation is significant at the 0.01 level (2-tailed)

Spillover Effects of Defense R&D Results

Recall that research question number four was, "What are the effects of defense R&D expenditures beyond military capability?" This research question was answered by analyzing the relationship between *defense R&D expenditure* and *technological spillover index*. The results of the *technological spillover index* for the first 15 countries and Turkey are given in Table 17. The full list of *technological spillover index* is provided in Appendix G.

Defense R&D expenditure is positively related to *technological spillover index* with a correlation coefficient of 0.818 (significant at the .01 level). Countries that spend more on defense R&D are likely to produce greater numbers of researchers, patents, and scientific publications. When the United States and China are removed from this analysis, the correlation coefficient drops to 0.494 (significant at the .01 level), still a very strong relationship. Finally, the rankings of countries' *defense R&D expenditure* and *technological spillover indexes* are also positively correlated and the correlation coefficient for this relationship is 0.788 (significant at the .01 level). Note that the United States and China were not removed for the ranked analysis, since rank data is less influenced by outliers.

Table 17

Technological Spillover Indexes for First 15 Countries and Turkey

COUNTRY	TECHNOLOGICAL SPILLOVER INDEX	RANK
United States	0.18384388	1
China	0.10538958	2
Japan	0.09758488	3
South Korea	0.04988763	4
Germany	0.04094510	5
United Kingdom	0.03577937	6
Canada	0.02857774	7
France	0.02695104	8
Russian Federation	0.02219928	9
Australia	0.02254537	10
Finland	0.02064598	11
Denmark	0.01784690	12
Singapore	0.01726406	13
Italy	0.01711301	14
Sweden	0.01679087	15
Turkey	***0.00596503***	***35***

Analysis of Results

The main purpose of this study was to understand the effect of defense R&D expenditures on military capability and technological spillover. The study succeeds in providing insight into this research area. The results of the study provide several important findings and contribute new measurement tools for researchers.

One of the important findings from this research is that there are available measures of military capability and that these measures are highly consistent with each other when the raw results or rankings of the countries are analyzed. These findings imply that any of the military capability indexes can be used in further research to measure military capability. However, $CINC_{milpow}$ and $Hwang_{milpow}$ are less complex measures requiring fewer inputs. These measures appear to be consistent with $Arena_{milpow}$ and GFP_{milpow}, providing evidence of construct validity. Because they are simpler, require fewer inputs, and appear to have validity, researchers may prefer them.

Another important finding of this research is that defense R&D expenditure is highly correlated with military capability. Not surprisingly, the findings demonstrated that countries with higher defense R&D expenditures tend to have a stronger military capability (or alternatively, countries with stronger military capability tend to expend more on defense R&D). One possible interpretation of this finding is that medium sized countries that wish to increase their military capability should invest more in defense R&D (see section 5.1).

Finally, another finding of the study revealed that defense R&D expenditure is highly correlated with technological spillover effects. This finding demonstrated that countries that spend more on defense R&D are likely to produce greater numbers of researchers, patents, and scientific publications (or vice versa). One possible interpretation of this finding is that medium sized countries wishing to increase the numbers of researchers, patents, and scientific publications should invest more in defense R&D (see section 5.1).

In addition to the aforementioned findings, the study also contributed to the academic literature in three ways by providing: new measures of military capability, a new estimation method for defense R&D expenditures, and a new method to measure technological spillover effect from defense R&D expenditures. The contributions of this study include the following:

1) The study developed simpler measures of military capability than were previously available to researchers. Because $CINC_{milpow}$ and $Hwang_{milpow}$ rely on simpler inputs than $Arena_{milpow}$ and GFP_{milpow} and appear to have reasonable validity, researchers may choose to adopt them in future projects.

2) The study developed a new method to estimate defense R&D expenditure when countries choose not to reveal it. As mentioned before, some countries choose not to reveal their defense R&D expenditures; however, these data points are important to compare the strength of the countries' military capabilities. The new method is going to help future researchers fill the data gaps in this study area.

3) The study developed a new method for measuring the technological spillover effects from defense R&D expenditures. Based on an extensive search of the literature, no measure for technological spillover from defense R&D expenditures existed prior to this study. This contribution is going to help future researchers fill this gap in the literature.

Summary

Chapter IV presented the results and analysis of this study. The chapter started with the results of military power formulas and their relationship with each other. The chapter continued with the relationships of defense R&D expenditure with the military capability formulas and with the technological spillover index. Then, the obtained results were presented and finally, the analysis of the results was presented.

V. Conclusions and Recommendations

The purpose of this thesis research was to understand the effect of defense R&D expenditures on military capability and technological spillover. This chapter provides the research conclusions, limitations, and recommendations for further research. The first section provides the research conclusions. The next section summarizes the limitations of this study based on data availability, result interpretation, and research findings. The last section in the chapter provides some suggestions for future research designed to enhance knowledge in this area of research.

Research Conclusions

As mentioned above, generally, the largest nations are able to expend large sums on defense R&D investments and weapons procurement, whereas the smallest nations, by necessity, focus only on weapons procurement. However, mid-sized nations face a funding dilemma: to invest in defense R&D or to outsource it. The results of the study revealed that *defense R&D expenditures* are highly positively correlated with *military capability indexes* and with the *technological spillover index*. Despite the possibility of alternative explanations such as a recursive relationship, it is reasonable to conclude that investing in defense R&D leads to military capability and positive technological spillover. Presumably, the primary effects of defense R&D funding occur after expenditure.

Therefore, mid-size countries, such as Turkey, should seriously consider spending a greater proportion of their total defense budget on defense R&D. This may lead to increases in military capability and widespread technological spillover effects. As mentioned previously, when mid-sized countries such as Turkey choose to rely on outsourcing their defense R&D to more powerful nations, they are vulnerable to the loss of support from those more powerful nations. This study provides further incentive for mid-sized countries to invest in their own defense R&D.

Limitations of the Research

Although efforts were taken throughout this research to mitigate risks to reliability, there were still limitations and assumptions throughout the research. The limitations and assumptions are listed below:

1) The defense-related data of USA was a huge outlier. Although the United States has been the number one country in defense expenditures for decades, the expenditures were higher than the historical average during the period of the study because of the effect of Iraq and Afghanistan operations.

2) The decision to exclude nuclear weapons capability as one of the variables that contributes to military power is debatable. Certainly, if nuclear weapons capability were to be included in the analysis, it would influence the conclusions significantly.

3) Clearly, "soft" powers (such as leadership, training, motivation) play an important role in military capability. As it was not possible to quantify these data, "soft" powers were assumed equal or ignored.

4) It was assumed that there is a transitive relationship between the capabilities of countries. In other words, it is assumed that if country A is more powerful than B, and B more powerful than C, that means A is more powerful than C. This ignores the possibility that country C may be more motivated to fight a war against country A than

country B. It also ignores the possibility of geographic advantages that could mitigate military power advantages. For example, if country C is land-locked, the fact that the country A has a powerful Navy may be unimportant, whereas if country B has a large coastline, that fact may be very important.

5) Doubtless, some countries give more importance to defending their territory while other countries give more importance to offensive capabilities. However, the data used in the study does not account for this distinction. Indeed, it was assumed that two countries would fight on a neutral battlefield.

6) Only 34 countries provided defense R&D data. To obtain a larger dataset, 48 defense R&D data points were estimated. The conclusions of the study depend largely upon the accuracy of the estimated data points.

Recommendations for Future Research

The success of future research in this area depends upon the availability of reliable data from increased numbers of countries. If extensive time series data become available, future longitudinal research may reveal causal relationships. In addition, future researchers may wish to focus on the effects of non-government defense R&D spending. It may be possible for researchers to control for economic fluctuations such as inflation or recession.

Furthermore, this research provides researchers with new tools for analysis such as defense R&D expenditure estimation, military capability measurement, and technological spillover measurement. Future researchers may be able to validate, test, or improve upon these tools. Ideally, future research will provide countries with actionable recommendations or their allocation of different portions of their defense budget.

Appendix A. Arenamilpow Index of Countries

COUNTRY	$Arena_{milpow}$	NORMALIZED $Arena_{milpow}$	RANK
United States	0.788693	1	1
France	0.470653	0.596750573	2
Japan	0.435105	0.551678537	3
China	0.428213	0.542940029	4
Germany	0.414851	0.525998075	5
Saudi Arabia	0.414097	0.525042063	6
Italy	0.412775	0.523365872	7
Russian Federation	0.397567	0.504083338	8
Brazil	0.38011	0.48194925	9
United Kingdom	0.379753	0.481496603	10
South Korea	0.346354	0.439149327	11
Israel	0.27667	0.350795557	12
Turkey	0.273657	0.346975312	13
India	0.246368	0.312375031	14
Colombia	0.217702	0.276028822	15
Singapore	0.212988	0.270051845	16
Poland	0.209643	0.265810651	17
Greece	0.198514	0.251699964	18
Canada	0.19777	0.250756632	19
Australia	0.178813	0.226720663	20
Chile	0.178715	0.226596407	21
United Arab Emirates	0.159412	0.202121738	22
Algeria	0.158223	0.200614181	23
Iran	0.154217	0.195534891	24
Mexico	0.15068	0.191050257	25
Portugal	0.150016	0.190208357	26
South Africa	0.141097	0.178899775	27
Malaysia	0.139289	0.176607374	28
Netherlands	0.135409	0.171687843	29
Angola	0.130708	0.165727349	30
Argentina	0.129123	0.163717695	31
Ukraine	0.128705	0.163187704	32
Venezuela	0.127402	0.161535604	33
Thailand	0.125872	0.159595686	34
Oman	0.117568	0.149066874	35

COUNTRY	$Arena_{milpow}$	NORMALIZED $Arena_{milpow}$	RANK
Morocco	0.10989	0.139331781	36
Indonesia	0.102897	0.130465213	37
North Korea	0.10274	0.130266149	38
Belgium	0.10258	0.130063282	39
Philippines	0.099069	0.125611613	40
Pakistan	0.089375	0.113320392	41
Romania	0.08903	0.11288296	42
Ecuador	0.08778	0.111298059	43
Nigeria	0.084903	0.107650252	44
Norway	0.082274	0.104316889	45
Peru	0.080329	0.101850784	46
Lebanon	0.077784	0.098623926	47
Switzerland	0.077515	0.098282855	48
Egypt	0.075955	0.096304899	49
Austria	0.075488	0.095712781	50
Kuwait	0.073721	0.093472365	51
Finland	0.073386	0.093047612	52
Kazakhstan	0.073339	0.092988019	53
Sweden	0.07284	0.092355327	54
Azerbaijan	0.072434	0.091840551	55
Czech Republic	0.072202	0.091546394	56
Syrian Arab Republic	0.069191	0.087728685	57
Viet Nam	0.067155	0.085147199	58
Jordan	0.067136	0.085123109	59
Iraq	0.066293	0.084054252	60
Denmark	0.063375	0.08035446	61
Spain	0.061034	0.077386258	62
Sri Lanka	0.060918	0.077239179	63
Hungary	0.059393	0.075305601	64
Bangladesh	0.053801	0.068215389	65
Bulgaria	0.049621	0.062915482	66
Croatia	0.043059	0.054595388	67
Serbia	0.04289	0.054381109	68
Qatar	0.039897	0.050586223	69
Uruguay	0.039573	0.050175417	70
Slovakia	0.038994	0.049441291	71
Belarus	0.035904	0.045523417	72

COUNTRY	$Arena_{milpow}$	NORMALIZED $Arena_{milpow}$	RANK
Bahrain	0.035876	0.045487915	73
Tunisia	0.034305	0.043496012	75
Kenya	0.034305	0.043496012	74
New Zealand	0.031755	0.040262815	76
Ireland	0.031646	0.040124611	77
Slovenia	0.028921	0.036669528	78
Georgia	0.028249	0.035817485	79
Armenia	0.025389	0.032191233	80
Lithuania	0.025329	0.032115158	81
Dominican Republic	0.023619	0.029947014	82
GAS Cyprus	0.023352	0.029608479	83
Cameroon	0.022392	0.028391275	84
Namibia	0.022143	0.028075563	85
Afghanistan	0.021637	0.027433995	86
Bolivia	0.020371	0.025828808	87
Uganda	0.018961	0.02404104	88
Brunei Darussalam	0.018359	0.023277752	89
Botswana	0.018204	0.023081224	90
Zambia	0.017532	0.022229182	91
Tanzania	0.01725	0.021871628	92
Ethiopia	0.016285	0.020648085	93
Chad	0.015856	0.020104147	94
El Salvador	0.015741	0.019958336	95
Kyrgyzstan	0.014117	0.017899233	96
Senegal	0.013877	0.017594932	97
Bosnia and Herzegovina	0.013476	0.017086496	98
Estonia	0.013473	0.017082693	99
Nepal	0.013363	0.016943221	100
Albania	0.012924	0.016386604	101
Guatemala	0.012298	0.015592886	102
Honduras	0.012195	0.01546229	103
Mali	0.011843	0.015015982	104
Paraguay	0.011298	0.014324965	105
Latvia	0.010756	0.013637753	106
Congo (Dem. Rep.)	0.009701	0.012300096	107
Congo	0.009487	0.012028762	108
Ghana	0.009204	0.01166994	109

COUNTRY	$Arena_{milpow}$	NORMALIZED $Arena_{milpow}$	RANK
Burkina Faso	0.00885	0.011221096	110
Macedonia	0.008621	0.010930742	111
Cambodia	0.008555	0.01084706	112
Gabon	0.008034	0.010186473	113
Zimbabwe	0.007092	0.008992092	114
Cuba	0.00617	0.007823069	115
Montenegro	0.005834	0.007397048	116
Rwanda	0.005678	0.007199252	117
Jamaica	0.005405	0.00685311	118
Madagascar	0.004525	0.00573734	119
Togo	0.004448	0.00563971	120
Mongolia	0.004396	0.005573778	121
Niger	0.003793	0.004809222	122
Lesotho	0.003709	0.004702717	123
Nicaragua	0.003597	0.00456071	124
Fiji	0.003519	0.004461812	125
Central African Republic	0.003487	0.004421239	126
Malta	0.003393	0.004302054	127
Papua New Guinea	0.002997	0.003799958	128
Guyana	0.002126	0.002695599	129
Sierra Leone	0.002068	0.00262206	130
Timor-Leste	0.001899	0.002407781	131
Moldova	0.00155	0.001965277	132
Belize	0.001074	0.001361747	133
Lao People's Dem. Rep.	0.000952	0.00120706	134
Liberia	0.000712	0.000902759	135
Cape Verde	0.000663	0.000840631	136
Seychelles	0.000635	0.000805129	137

Appendix B. GFPmilpow of Countries

COUNTRY	RANK	GFP_{milpow}	COUNTRY	RANK	GFP_{milpow}
United States	1	0.2461	Argentina	35	1.2971
Russia	2	0.2601	Nigeria	36	1.3412
China	3	0.3644	Austria	37	1.3722
India	4	0.4346	Algeria	38	1.4065
United Kingdom	5	0.5174	Syria	39	1.4643
France	6	0.6151	Venezuela	40	1.4842
Germany	7	0.6471	Colombia	41	1.4981
South Korea	8	0.6528	Norway	42	1.5147
Italy	9	0.6794	Yemen	43	1.5853
Brazil	10	0.6866	Denmark	44	1.6107
Turkey	11	0.7016	Finland	45	1.6131
Pakistan	12	0.7276	Kenya	46	1.6228
Israel	13	0.7539	Singapore	47	1.6333
Egypt	14	0.7543	Afghanistan	48	1.6403
Indonesia	15	0.7591	Greece	49	1.6493
Iran	16	0.7773	Romania	50	1.6544
Japan	17	0.7856	Serbia	51	1.6847
Taiwan	18	0.8588	Chile	52	1.7081
Canada	19	0.8638	Belgium	53	1.7249
Thailand	20	0.8919	Croatia	54	1.7413
Mexico	21	0.9092	Portugal	55	1.7618
Ukraine	22	0.9126	Jordan	56	1.7716
Australia	23	0.9361	Iraq	57	1.8043
Poland	24	0.9511	United Arab Emirates	58	1.8099
Sweden	25	1.0981	Libya	59	1.8361
Saudi Arabia	26	1.1003	Georgia	60	1.8521
Vietnam	27	1.1216	Mongolia	61	2.0348
North Korea	28	1.1723	Kuwait	62	2.1208
Ethiopia	29	1.1725	Paraguay	63	2.1238
Spain	30	1.1792	Nepal	64	2.1578
Philippines	31	1.1838	Qatar	65	2.4808
Switzerland	32	1.2266	Lebanon	66	2.5037
Malaysia	33	1.2465	Uruguay	67	2.5441
South Africa	34	1.2582	Panama	68	3.0468

Appendix C. Integrated State Power Formula

Hwang (2008) constructed the formula below to measure Integrated State Power:

(.625 \$GDP + .625 LE + .625 INT + .625 EDU + .25 EP + (.3125 ME% x \$GDP) + (.3125 ME% x LE) + (.3125 ME % x INT) + (.3125 ME% x EDU) + (.3125 AP% x \$GDP) + (.3125 AP% x LE) + (.3125 AP% x INT) + (.3125 AP% x EDU) + .125 NWC + .125 NW#) / (.625 $\$GDP_i{}^2$+ .625 $LE_i{}^2$ + .625 $INT_i{}^2$ + .625 $EDU_i{}^2$+ .25 $EP_i{}^2$ + .3125 $(ME\%\ x\ \$GDP)_i{}^2$ + .3125 $(ME\%\ x\ LE)_i{}^2$ + .3125 $(ME\%\ x\ INT)_i{}^2$ +.3125 $(ME\%\ x\ EDU)_i{}^2$ + .3125 $(AP\%\ x\ \$GDP)_i{}^2$+ .3125 $(AP\%\ x\ LE)_i{}^2$+ .3125 $(AP\%\ x\ INT)_i{}^2$+ .3125 $(AP\%\ x\ EDU)_i{}^2$+ .125 $NWC_i{}^2$ + .125 $NW\#_i{}^2$)

Where:

\$GDP : Nominal GDP,

LE : Life Expectancy,

INT : Integrity,

EDU : Education,

EP : Energy Production,

ME% : Military Expenditures as percentage of GDP,

AP% : Arms Production as percentage of GDP,

NWC : Nuclear Weapons Capability (dummy variable),

NW# : Number of Nuclear Warheads,

i : percentile.

Appendix D. Complete List of Raw Results of National Power Formulas

COUNTRY	CINC*	CINC RANK	HWANG **	HWANG RANK
China	0.1985779	1	7274136000000	2
United States	0.1421487	2	15560390000000	1
India	0.0734437	3	1624570000000	6
Japan	0.0426745	4	1191698000000	7
Russian Federation	0.0392739	5	3705139000000	3
Brazil	0.0245967	6	477393399548	12
Germany	0.0240815	7	894295443562	9
South Korea	0.0238778	8	382058307230	13
United Kingdom	0.0211575	9	2644074000000	4
France	0.0189237	10	2267324000000	5
Italy	0.0174203	11	313236028852	19
Turkey	0.014317	12	167121963006	27
Pakistan	0.0137718	13	276728333157	20
Indonesia	0.0137077	14	380207527433	14
Iran	0.0134501	15	270309795500	21
North Korea	0.0129246	16	331277804664	17
Mexico	0.0122686	17	371458319734	15
Ukraine	0.011835	18	140681110337	33
Spain	0.0113889	19	259818200597	24
Saudi Arabia	0.0108829	20	544039081355	11
Canada	0.0106829	21	1090645000000	8
Egypt	0.0097128	22	181788176473	26
Bangladesh	0.0080595	23	41121940247	60
Thailand	0.0079734	24	131491507748	35
Nigeria	0.0077921	25	114243228683	38
Viet Nam	0.0076122	26	121266728793	37
Australia	0.0071125	27	678992572822	10
Poland	0.0069389	28	264299819568	23
South Africa	0.0063162	29	160881213237	28
Colombia	0.0061742	30	125972751719	36
Philippines	0.0057217	31	45634892986	57
Netherlands	0.0056463	32	270210944799	22
Algeria	0.0052899	33	160736324604	29
Iraq	0.0052218	34	94970885398	44
Argentina	0.0047209	35	155188833449	30
Venezuela	0.0045591	36	151543883408	31
Morocco	0.0044709	37	16710894414	71

COUNTRY	CINC*	CINC RANK	HWANG **	HWANG RANK
Syrian Arab Republic	0.0044535	38	52945275034	53
Malaysia	0.0044027	39	148619298424	32
Congo (Dem. Rep.)	0.0041745	40	6323345045	88
Belgium	0.0038946	41	88490134947	46
Ethiopia	0.0038581	42	3023833761	107
Greece	0.0038126	43	72882986647	50
Israel	0.0036381	44	340992265172	16
Kazakhstan	0.0032326	45	88128051843	47
Singapore	0.0032264	46	106180267527	40
Romania	0.003213	47	79312841252	48
Chile	0.0031071	48	64010340699	51
Peru	0.002986	49	35867007397	63
United Arab Emirates	0.0029798	50	132227392997	34
Sweden	0.0029788	51	207454377541	25
Austria	0.0025715	52	74827489203	49
Belarus	0.0025568	53	12588455149	76
Angola	0.0024825	54	43222416863	58
Czech Republic	0.0023531	55	98877201589	43
Finland	0.0021444	56	89402233837	45
Sri Lanka	0.0020778	57	8990448704	82
Tanzania	0.0019317	58	1585107673	116
Portugal	0.0018413	59	46188059853	56
Kenya	0.001777	60	4452361829	94
Norway	0.0016396	61	329806347252	18
Hungary	0.0016075	62	42887528419	59
Cambodia	0.0015558	63	2108954025	112
Ecuador	0.0015182	64	46819437055	55
Denmark	0.0014931	65	102527302393	42
Jordan	0.0014484	66	8187017749	83
Nepal	0.0014372	67	3322070025	103
Slovakia	0.0014329	68	33265801905	64
Bulgaria	0.0014218	69	39105162551	61
Afghanistan	0.0014201	70	2109572050	111
Cuba	0.0013522	71	17573885140	69
Kuwait	0.0013343	72	102693225456	41
Uganda	0.0013199	73	2121241171	110
Azerbaijan	0.0012793	74	20416626644	66
Oman	0.0012173	75	52101950572	54
Ghana	0.0011087	76	3014848576	108

COUNTRY	CINC*	CINC RANK	HWANG **	HWANG RANK
Switzerland	0.001083	77	107678273282	39
Bolivia	0.0010495	78	14484395218	73
Zimbabwe	0.0009938	79	4506413306	93
Serbia	0.0009741	80	31485837563	65
Dominican Republic	0.0009689	81	3287574828	105
Cameroon	0.0009505	82	6851042594	87
Qatar	0.0008841	83	63747140049	52
Lebanon	0.0008443	84	3180909572	106
Tunisia	0.0008221	85	17093297415	70
Guatemala	0.0007892	86	5647759632	89
New Zealand	0.0007705	87	38392724427	62
Zambia	0.0007486	88	3552770458	100
Madagascar	0.000711	89	2058957574	113
Senegal	0.0006968	90	978342734	122
Burkina Faso	0.0006447	91	585501563	127
Ireland	0.0006346	92	18316497517	68
Armenia	0.0006142	93	4530116181	92
Rwanda	0.0005813	94	3921944221	97
Croatia	0.0005799	95	18709293936	67
El Salvador	0.0005754	96	5437535833	90
Chad	0.0005676	97	7181065097	86
Mali	0.0005161	98	645153590	126
Niger	0.000505	99	496975869	128
Georgia	0.0005039	100	3338413180	102
Uruguay	0.0004743	101	8148112726	84
Lao People's Dem. Rep.	0.0004708	102	1126851885	118
Honduras	0.0004543	103	1988518664	114
Paraguay	0.00045	104	15083388342	72
Lithuania	0.0004423	105	10891937888	80
Bosnia and Herzegovina	0.0004001	106	12207589706	77
Sierra Leone	0.000393	107	164763079	132
Bahrain	0.00039	108	10907022284	79
Nicaragua	0.0003883	109	1072833656	120
Congo	0.0003614	110	7794341422	85
Kyrgyzstan	0.000357	111	4934313000	91
Slovenia	0.0003461	112	14435804915	74
Moldova	0.000346	113	1096879691	119
Latvia	0.0003449	114	4351943184	95
Togo	0.0002974	115	283738547	129

COUNTRY	CINC*	CINC RANK	HWANG **	HWANG RANK
Macedonia	0.0002899	116	4024288752	96
Albania	0.0002759	117	3654277291	99
Estonia	0.0002528	118	11556915170	78
Mongolia	0.0002492	119	3524162851	101
Papua New Guinea	0.0002366	120	3833365616	98
Liberia	0.0002231	121	81601837	136
Central African Republic	0.0002061	122	145088409	134
GAS Cyprus	0.0002019	123	3300184068	104
Jamaica	0.0001915	124	881013204	123
Botswana	0.0001868	125	1781228750	115
Namibia	0.0001794	126	1043716034	121
Gabon	0.0001527	127	9138902194	81
Brunei Darussalam	0.0001447	128	14141361533	75
Montenegro	0.0001332	129	1292862098	117
Timor-Leste	0.0001131	130	2805685492	109
Lesotho	0.0000976	131	261722077	130
Fiji	0.0000812	132	770719840	125
Guyana	0.0000492	133	174246426	131
Malta	0.0000345	134	807815921	124
Cape Verde	0.0000221	135	155422141	133
Belize	0.0000207	136	120671725	135
Seychelles	0.00000377	137	67433204	137

* Source (Correlates of War)

** Source (Hwang, New Thinking in Measuring National Power, 2008)

Appendix E. Complete List of Raw Results of CINCmilpow and Hwangmilpow Indexes

COUNTRY	$CINC_{milpow}$	$CINC_{milpow}$ RANK	$Hwang_{milpow}$	$Hwang_{milpow}$ RANK
United States	0.48337	1	10.613	1
China	0.15524	2	5.241	2
Russian Federation	0.07358	3	0.742	3
India	0.07060	4	0.246	6
France	0.04820	5	0.406	4
United Kingdom	0.04313	6	0.174	10
Japan	0.04192	7	0.278	5
North Korea	0.03869	8	0.010	126
South Korea	0.03843	9	0.144	12
Saudi Arabia	0.03676	10	0.237	7
Germany	0.03368	11	0.226	8
Brazil	0.03052	12	0.102	16
Italy	0.02964	13	0.117	13
Pakistan	0.02342	14	0.056	43
Iran	0.02308	15	0.059	38
Turkey	0.02141	16	0.092	19
Egypt	0.01765	17	0.047	53
Canada	0.01680	18	0.097	17
Australia	0.01643	19	0.108	15
Viet Nam	0.01619	20	0.036	65
Thailand	0.01609	21	0.038	62
Colombia	0.01568	22	0.075	27
Israel	0.01530	23	0.182	9
Indonesia	0.01301	24	0.029	75
Spain	0.01296	25	0.066	32
Iraq	0.01241	26	0.075	25
Mexico	0.01222	27	0.021	92
Syrian Arab Republic	0.01202	28	0.072	28
United Arab Emirates	0.01181	29	0.144	11
Greece	0.01045	30	0.068	30
Algeria	0.00989	31	0.089	20
Poland	0.00900	32	0.078	24
Netherlands	0.00890	33	0.061	36

COUNTRY	$CINC_{milpow}$	$CINC_{milpow}$ RANK	$Hwang_{milpow}$	$Hwang_{milpow}$ RANK
Morocco	0.00831	34	0.054	46
Singapore	0.00758	35	0.086	22
Chile	0.00662	36	0.086	21
Ukraine	0.00655	37	0.095	18
Argentina	0.00619	38	0.019	97
Malaysia	0.00617	39	0.037	63
Sri Lanka	0.00606	40	0.049	51
Bangladesh	0.00591	41	0.020	95
Afghanistan	0.00576	42	0.038	59
Venezuela	0.00567	43	0.016	109
Angola	0.00551	44	0.045	54
Philippines	0.00526	45	0.022	88
Norway	0.00526	46	0.057	42
South Africa	0.00505	47	0.045	55
Congo (Dem. Rep.)	0.00499	48	0.015	117
Peru	0.00491	49	0.025	83
Ethiopia	0.00461	50	0.014	119
Belgium	0.00449	51	0.038	60
Sweden	0.00419	52	0.058	40
Cambodia	0.00411	53	0.018	105
Portugal	0.00410	54	0.053	47
Jordan	0.00406	55	0.085	23
Nigeria	0.00397	56	0.015	115
Oman	0.00395	57	0.108	14
Azerbaijan	0.00392	58	0.075	26
Kuwait	0.00378	59	0.062	35
Denmark	0.00371	60	0.049	50
Switzerland	0.00363	61	0.036	64
Romania	0.00359	62	0.030	74
Ecuador	0.00326	63	0.058	41
Nepal	0.00323	64	0.018	103
Finland	0.00304	65	0.049	49
Cuba	0.00301	66	0.070	29
Austria	0.00297	67	0.028	79
Lebanon	0.00295	68	0.067	31
Qatar	0.00279	69	0.051	48
Belarus	0.00279	70	0.036	67

COUNTRY	$CINC_{milpow}$	$CINC_{milpow}$ RANK	$Hwang_{milpow}$	$Hwang_{milpow}$ RANK
Kazakhstan	0.00262	71	0.023	86
Czech Republic	0.00200	72	0.035	69
Dominican Republic	0.00181	73	0.010	130
Serbia	0.00179	74	0.040	58
Hungary	0.00176	75	0.027	80
Armenia	0.00174	76	0.065	34
Bolivia	0.00168	77	0.022	91
Uganda	0.00160	78	0.019	98
Bulgaria	0.00158	79	0.028	77
Tunisia	0.00152	80	0.023	87
Georgia	0.00144	81	0.055	45
New Zealand	0.00130	82	0.032	72
Uruguay	0.00130	83	0.043	56
Croatia	0.00125	84	0.035	70
Slovakia	0.00114	85	0.028	76
Rwanda	0.00111	86	0.019	100
Ireland	0.00110	87	0.016	113
Kenya	0.00110	88	0.019	99
Tanzania	0.00103	89	0.014	120
Zimbabwe	0.00102	90	0.010	128
Chad	0.00096	91	0.023	85
Lao People's Dem. Rep.	0.00095	92	0.002	137
Bahrain	0.00082	93	0.065	33
Zambia	0.00067	94	0.028	78
Cameroon	0.00066	95	0.017	107
Slovenia	0.00065	96	0.031	73
GAS Cyprus	0.00064	97	0.047	52
El Salvador	0.00063	98	0.016	110
Guatemala	0.00060	99	0.006	134
Albania	0.00058	100	0.023	84
Senegal	0.00056	101	0.020	94
Ghana	0.00056	102	0.005	135
Namibia	0.00055	103	0.056	44
Lithuania	0.00054	104	0.020	93
Botswana	0.00051	105	0.038	61
Bosnia and Herzegovina	0.00050	106	0.026	81
Honduras	0.00049	107	0.016	111

COUNTRY	$CINC_{milpow}$	$CINC_{milpow}$ RANK	$Hwang_{milpow}$	$Hwang_{milpow}$ RANK
Kyrgyzstan	0.00048	108	0.059	39
Madagascar	0.00047	109	0.010	129
Paraguay	0.00047	110	0.016	114
Brunei Darussalam	0.00046	111	0.061	37
Burkina Faso	0.00044	112	0.017	106
Nicaragua	0.00042	113	0.010	127
Congo	0.00041	114	0.013	122
Estonia	0.00037	115	0.041	57
Mongolia	0.00037	116	0.016	108
Latvia	0.00035	117	0.019	101
Sierra Leone	0.00035	118	0.013	124
Mali	0.00035	119	0.022	89
Macedonia	0.00033	120	0.022	90
Togo	0.00031	121	0.020	96
Gabon	0.00023	122	0.015	116
Moldova	0.00020	123	0.005	136
Niger	0.00020	124	0.010	131
Jamaica	0.00016	125	0.013	123
Montenegro	0.00015	126	0.036	66
Fiji	0.00014	127	0.016	112
Papua New Guinea	0.00013	128	0.006	133
Central African Republic	0.00011	129	0.025	82
Malta	0.00010	130	0.014	121
Lesotho	0.00010	131	0.032	71
Liberia	0.00008	132	0.015	118
Timor-Leste	0.00006	133	0.035	68
Guyana	0.00005	134	0.019	102
Cape Verde	0.00004	135	0.009	132
Belize	0.00004	136	0.012	125
Seychelles	0.00001	137	0.018	104

Appendix F. Complete List of Defense R&D Data

COUNTRY	RANK	DEFENSE R&D DATA ($)	SHARE OF THE WORLD TOTAL	ESTIMATED-0 KNOWN-1
United States	1	83,193,000,000.00	0.691869519	1
China	2	15,000,000,000.00	0.124746587	1
France	3	4,157,193,447.60	0.034573046	1
Russian Federation	4	3,600,000,000.00	0.029939181	1
United Kingdom	5	3,361,961,822.80	0.027959551	1
Israel	6	2,471,140,857.98	0.020551092	0
Germany	7	1,689,225,624.66	0.014048342	1
South Korea	8	1,600,000,000.00	0.013306303	1
India	9	1,300,000,000.00	0.010811371	1
Japan	10	1,000,000,000.00	0.008316439	1
Singapore	11	605,072,278.28	0.005032047	0
Brazil	12	438,200,150.12	0.003644265	0
Australia	13	242,700,000.00	0.002018400	1
Canada	14	201,600,000.00	0.001676594	1
Spain	15	188,188,483.27	0.001565058	1
Turkey	16	146,275,609.27	0.001216492	1
Poland	17	140,763,963.61	0.001170655	1
Sweden	18	123,961,005.74	0.001030914	1
Norway	19	121,928,858.10	0.001014014	1
Iran	20	91,258,765.90	0.000758948	0
Netherlands	21	86,790,122.42	0.000721785	1
Italy	22	74,597,236.61	0.000620383	1
Ukraine	23	57,670,051.48	0.000479609	0
Finland	24	44,440,165.71	0.000369584	1
Ireland	25	34,407,406.19	0.000286147	0
Pakistan	26	26,641,290.91	0.000221561	0
Czech Republic	27	23,410,340.76	0.000194691	1
South Africa	28	17,560,000.00	0.000146037	1
Argentina	29	16,367,418.23	0.000136119	0
Tunisia	30	16,325,272.25	0.000135768	0
Switzerland	31	15,095,953.86	0.000125545	1
Serbia	32	14,547,644.80	0.000120985	0
Denmark	33	13,934,726.64	0.000115887	1
Chile	34	12,163,857.33	0.000101160	0
Greece	35	12,111,599.90	0.000100725	1

COUNTRY	RANK	DEFENSE R&D DATA ($)	SHARE OF THE WORLD TOTAL	ESTIMATED-0 KNOWN-1
Mexico	36	11,302,969.37	0.000094000	0
Belgium	37	10,683,290.42	0.000088847	1
Slovenia	38	9,011,123.23	0.000074940	1
Croatia	39	8,841,044.28	0.000073526	0
Portugal	40	8,105,366.00	0.000067408	1
Belarus	41	6,984,039.21	0.000058082	0
Bulgaria	42	6,285,128.69	0.000052270	0
Lithuania	43	4,381,662.06	0.000036440	0
Saudi Arabia	44	4,215,559.90	0.000035058	0
Thailand	45	4,185,017.73	0.000034804	0
Egypt	46	4,182,081.41	0.000034780	0
Colombia	47	3,885,384.02	0.000032313	0
Jordan	48	2,920,936.84	0.000024292	0
Ecuador	49	2,637,820.45	0.000021937	0
Romania	50	2,461,801.71	0.000020473	1
Uruguay	51	2,454,066.12	0.000020409	0
Azerbaijan	52	1,570,613.95	0.000013062	0
GAS Cyprus	53	1,219,046.26	0.000010138	0
Austria	54	1,161,227.22	0.000009657	1
Uganda	55	1,078,657.30	0.000008971	0
Kazakhstan	56	1,053,255.28	0.000008759	0
Estonia	57	859,308.14	0.000007146	1
Gabon	58	773,374.18	0.000006432	0
Kuwait	59	580,927.04	0.000004831	0
Armenia	60	503,758.29	0.000004189	0
Philippines	61	491,046.48	0.000004084	0
Senegal	62	482,583.47	0.000004013	0
Indonesia	63	468,160.46	0.000003893	0
Sri Lanka	64	362,437.59	0.000003014	0
Zambia	65	338,153.08	0.000002812	0
Ethiopia	66	319,373.14	0.000002656	0
Hungary	67	290,306.81	0.000002414	1
Malta	68	265,384.89	0.000002207	0
Macedonia	69	156,412.10	0.000001301	0
Kyrgyzstan	70	135,761.75	0.000001129	0
Slovakia	71	116,122.72	0.000000966	1
Burkina Faso	72	102,029.64	0.000000849	0

COUNTRY	RANK	DEFENSE R&D DATA ($)	SHARE OF THE WORLD TOTAL	ESTIMATED-0 KNOWN-1
Albania	73	97,560.03	0.000000811	0
Moldova	74	84,476.72	0.000000703	0
Mongolia	75	66,617.61	0.000000554	0
El Salvador	76	37,212.07	0.000000309	0
Latvia	77	34,836.82	0.000000290	1
Madagascar	78	29,774.94	0.000000248	0
Paraguay	79	9,535.26	0.000000079	0
Guatemala	80	9,022.82	0.000000075	0
Bosnia and Herzegovina	81	1,838.29	0.000000015	0
Lesotho	82	878.51	0.000000007	0

Appendix G. Complete List of Results of Technological Spillover Indexes

COUNTRY	TECHNOLOGICAL SPILLOVER INDEX	RANK
United States	0.18384388	1
China	0.10538958	2
Japan	0.09758488	3
South Korea	0.04988763	4
Germany	0.04094510	5
United Kingdom	0.03577937	6
Canada	0.02857774	7
France	0.02695104	8
Australia	0.02254537	9
Russian Federation	0.02219928	10
Finland	0.02064598	11
Denmark	0.01784690	12
Singapore	0.01726406	13
Italy	0.01711301	14
Sweden	0.01679087	15
Spain	0.01647052	16
Norway	0.01519572	17
India	0.01480387	18
Netherlands	0.01366050	19
New Zealand	0.01295407	20
Switzerland	0.01288726	21
Austria	0.01272514	22
Belgium	0.01191012	23
Portugal	0.01182449	24
Brazil	0.01106121	25
Slovenia	0.00934880	26
Ireland	0.00931389	27
Czech Republic	0.00856946	28
Poland	0.00844668	29
Estonia	0.00781105	30
Greece	0.00663789	31
Slovakia	0.00646538	32
Lithuania	0.00629579	33
Hungary	0.00619222	34
Turkey	0.00596503	35

COUNTRY	TECHNOLOGICAL SPILLOVER INDEX	RANK
Ukraine	0.00548257	36
Mexico	0.00545463	37
Argentina	0.00490199	38
Tunisia	0.00482222	39
Croatia	0.00441578	40
Bulgaria	0.00433416	41
Israel	0.00407253	42
Latvia	0.00392313	43
Iran	0.00388496	44
South Africa	0.00355426	45
Romania	0.00338917	46
Serbia	0.00284119	47
Malta	0.00278583	48
Egypt	0.00241113	49
Malaysia	0.00220474	50
Morocco	0.00206296	51
Thailand	0.00202983	52
Moldova	0.00195261	53
GAS Cyprus	0.00188732	54
Chile	0.00181801	55
North Korea	0.00151018	56
Pakistan	0.00129957	57
Macedonia	0.00125274	58
Colombia	0.00110178	59
Uruguay	0.00107337	60
Philippines	0.00096530	61
Senegal	0.00096435	62
Viet Nam	0.00084058	63
Saudi Arabia	0.00078665	64
Venezuela	0.00075340	65
Belarus	0.00065600	66
Nigeria	0.00055932	67
Bosnia and Herzegovina	0.00052406	68
Kuwait	0.00052123	69
Ecuador	0.00043089	70
Algeria	0.00042967	71
Albania	0.00042967	72

COUNTRY	TECHNOLOGICAL SPILLOVER INDEX	RANK
Indonesia	0.00042591	73
Sri Lanka	0.00040597	74
Kenya	0.00036535	75
Cuba	0.00033374	76
Jordan	0.00031571	77
Bangladesh	0.00027720	78
Paraguay	0.00025457	79
United Arab Emirates	0.00020867	80
Guatemala	0.00018105	81
Iraq	0.00017545	82
Peru	0.00015564	83
Lebanon	0.00015515	84
Georgia	0.00015152	85
Burkina Faso	0.00014436	86
Madagascar	0.00014283	87
Ethiopia	0.00013784	88
Armenia	0.00013344	89
Zambia	0.00013223	90
Azerbaijan	0.00012372	91
Ghana	0.00011629	92
Togo	0.00010154	93
Kazakhstan	0.00009455	94
Tanzania	0.00009252	95
Oman	0.00009139	96
Cameroon	0.00008673	97
Uganda	0.00008342	98
Nepal	0.00006769	99
Zimbabwe	0.00006362	100
Qatar	0.00005846	101
Mongolia	0.00005616	102
Lesotho	0.00005386	103
Syrian Arab Republic	0.00004492	104
Jamaica	0.00004077	105
Botswana	0.00004064	106
Montenegro	0.00003912	107
Bahrain	0.00003745	108
Rwanda	0.00003744	109

COUNTRY	TECHNOLOGICAL SPILLOVER INDEX	RANK
Kyrgyzstan	0.00003722	110
Bolivia	0.00003055	111
Papua New Guinea	0.00002911	112
Congo	0.00002262	113
Brunei Darussalam	0.00002195	114
Mali	0.00002001	115
Gabon	0.00001779	116
Fiji	0.00001755	117
Cambodia	0.00001723	118
Namibia	0.00001679	119
Niger	0.00001402	120
Belize	0.00001268	121
Lao People's Dem. Rep.	0.00001134	122
Nicaragua	0.00001087	123
El Salvador	0.00001021	124
Dominican Republic	0.00000806	125
Honduras	0.00000791	126
Afghanistan	0.00000501	127
Angola	0.00000463	128
Central African Republic	0.00000455	129
Guyana	0.00000447	130
Seychelles	0.00000372	131
Sierra Leone	0.00000372	132
Congo (Dem. Rep.)	0.00000371	133
Chad	0.00000322	134
Liberia	0.00000125	135
Cape Verde	0.00000093	136
Timor-Leste	0.00000044	137

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14. ABSTRACT

Generally, the purpose of defense research and development (R&D) is to expand military capability for the armed forces of a country. Any spin-off of technologies from defense R&D programs is usually not a prime motivation but more often an unintended consequence. Nevertheless, many of the technologies used in civilian life were initially research and development projects for military purposes. These technologies eventually become adapted to civilian applications since they had beneficial economic and social "spillover" effects. However, there is a lack of research measuring the final outputs of defense R&D, including technology "spin-offs."

This study mainly tried to understand the effect of defense R&D expenditures on military capability and technological spillover. Statistical measures such as correlations were used to understand these effects. The study revealed that there is a highly positive correlation between defense R&D expenditure and military capability, as well as between defense R&D expenditure and technological spillover index.

The study contributed to the academic literature in three ways by providing: new measures of military capability, a new estimation method for defense R&D expenditures, and a new method to measure technological spillover effect from defense R&D expenditures.

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Defense R&D, military capability, technological spillover

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