The Impact of National Research and Development Expenditure on Research and Development Output

Noah Benjamin

University Honors in Political Science
Spring 2013

The American University
Washington, D.C.

Advisors: Professor Kimberly Cowell-Meyers (SPA), Professor Sonja Walti (SPA), and Dr. Matthew Hartings (CAS)

Abstract

Scientific and technological research and development, as a public good, is vital for a thriving society. However, due to market failure, the public sector must make up for the private sector's under-funding of such scientific R&D. Nevertheless relatively little is known about how effectively government is able to fund R&D. This study aims to establish a clear connection between government funding for scientific R&D and the products or outputs of such R&D. While many have examined the role private industry, universities, and government agencies have as both institutions of funding and institutions of scientific R&D, results have been mixed and inconclusive. Instead, a direct comparison of the institutions of policy with the outputs of R&D hopes to avoid the pitfalls of ambiguity found in prior research. This study examines the relationship between measures of funding for R&D and measures of R&D output such as patents and journal articles using a cross-sectional analysis of 31 OECD countries. The results of this study demonstrate that R&D expenditure and R&D outputs are positively correlated. Furthermore, this positive relationship is remains strong when controlled for possible intervening variables such as the strength of a country's education system, its levels of corporatism, its GDP, and its military expenditures.

Introduction

Science and technology have long been considered vital elements of a flourishing society. Even in the 18th century, philosopher David Hume argued that the study of the sciences not only lends itself well to making an individual well-rounded and prosperous, but that a society that values the development of the sciences will likewise be more well-rounded and prosperous (Stephan 1996). Advancements in science and technology lead to breakthroughs in health care, technologies that redefine worldviews, products that can fuel economies, and much more (Jaffe 2002). These, in turn, have complex national and global effects ranging from contributing to the GDP in the case of new popular products, to increasing the lifespan of the average human. It is, therefore, in the best interest of a state and the global community to promote the development and progression of science and technology. Unfortunately, although there are many examples of the positive effects funding of the sciences has on a nation, scientific research is faced with the classic collective action problem. Economists have found that the social rate of return on scientific research and development exceeds the private rate of return, meaning that in the absence of extra funding, it is not (on average) economically beneficial for private entities to spend much on scientific research and development (Jaffe 2002). Nevertheless, due to the tremendous societal benefits scientific research and development (R&D) can have, finding ways to promote investment in such R&D in an efficient and ultimately productive manner is a vital issue in governmental policy (Jaffe 2002).

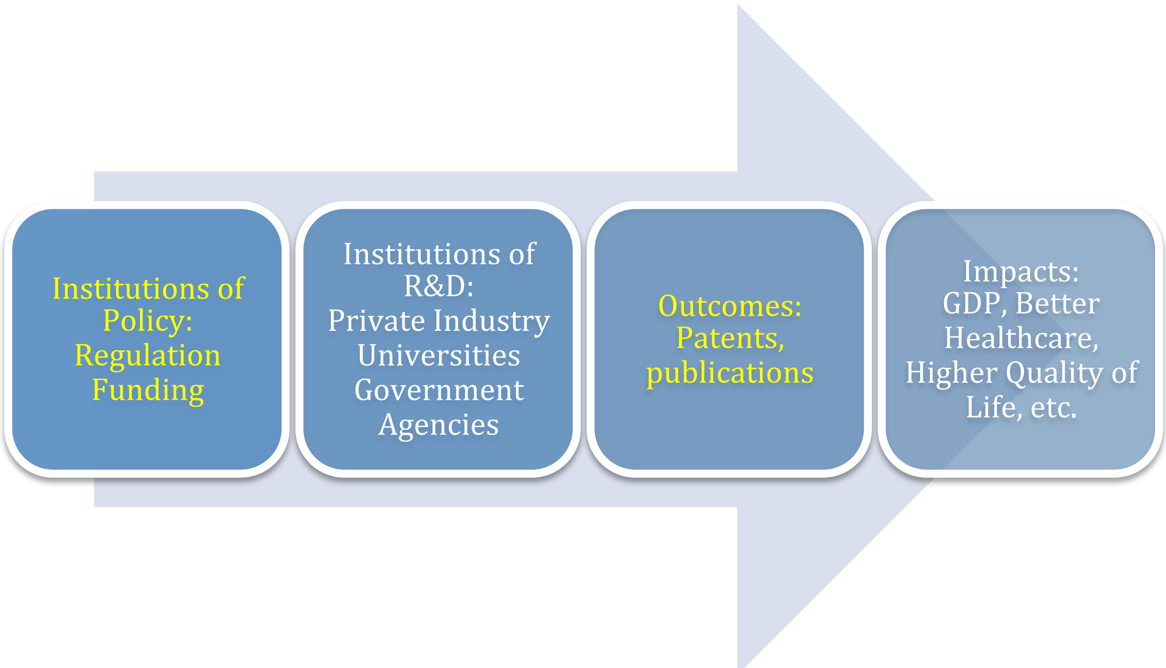
Despite the benefits of a robust scientific research community, the debate about the role of science in society in recent years has become increasingly about the money spent by the government on science in the face of rising deficits and other needy targets of funding. Many have noted the positive results, meaning both social and societal advancement, that funding of the sciences has had on the United States. Fareed Zakharia in the Washington Post argued that in spite of a floundering economy, scientific industries such as biotechnology have stayed impressively strong. He noted that one research initiative, the Human Genome Project, was calculated to have driven $796 billion in economic activity and to have raised $244 billion in personal income while supporting 310, 000 jobs—and it only cost the US government $3.8 billion over 15 years (Zakharia 2012). Unfortunately, powerful organizations such as the AARP have chastised Congress for cutting service to the elderly in favor of increased scientific expenditure (Epstein 2011). Many such arguments have gained traction in the public political discourse, placing funding for vital organizations such as the NIH and NASA under threat of severe budget cuts. Furthermore, economists have been unable to quantify the effects funding of the sciences have on scientific accomplishments, and especially less tangible outcomes like supporting the GDP—thereby increasing the vulnerability of funding for the sciences.

In an effort to develop a broader way of measuring the impact funding for the sciences has on scientific accomplishments, and in the face of increasing pressure to cut scientific research funding due to the global economic crisis, this study uses measures of scientific output such as patent applications and scientific journal publications to compare against various measures of scientific funding and governmental structures in a comparative country analysis.

Theory and Hypothesis

Theoretical Framework

No longer does a lone Thomas Edison, an unschooled genius, conduct research by himself and make great discoveries. Instead, modern scientific research and development occurs within a highly complex and intertwined system of institutions that interact with each other. Richard R. Nelson, in his book National Innovation Systems, explains that "the principle vehicles through which technological advance proceeds," are research and development (R&D) facilities attached to business firms, universities, and government agencies (Nelson 1993, p5). These institutions of scientific research and development interact with one another to share discoveries, work on projects together, build off of each other's results, and sometimes even fund each other. These institutions, however, do not act alone. They operate within a larger institutional framework that eventually produces scientific output in the form of discovery.



This institutional framework, demonstrated above, represents the interactions between 4 key aspects of scientific research and development: the governmental institutions of policy that govern scientific R&D, the institutions that actually conduct the R&D, the outcomes the R&D produce, and the indirect impacts these outcomes have upon the nation (or even the global community). Governmental institutions of policy include the regulations placed upon scientific R&D, for example the bans on stem cell research that exist throughout the world, and especially funding for the sciences (which is a type of policy). The National Institute of Health (NIH) and the National Science Foundation (NSF) are examples of organizations that disseminate the funding allocated by the governmental policy—thus they act in this function within the governmental institutions of policy. Universities, private industry, and government agencies are institutions of R&D, meaning that they actually conduct the scientific R&D. Some organizations actually act as both institutions of funding (policy) and R&D. The NIH, NASA, and the NSF, for example, are both organizations that both distribute grants and conduct their own research. Organizations within this level often work together, as previously discussed, to conduct their projects. These institutions of R&D in turn produce outputs such as scientific journal publications and patents. Finally, the outputs of scientific R&D projects ultimately lead, through sometimes more direct but often indirect means, to less tangible impacts. Such impacts could range from an improved life expectancy because of a new artificial heart to a spike in GDP because of a new commercial technology. Impacts could even be introducing new perspectives on life as the discovery of evolution did over a hundred years ago. This framework is what could be called a New Institutional Framework, meaning that it sees economic processes as the interaction of various political, social, private, and other institutions that provide the rules within which the process operates (Klein 1999).

It is important to note, however, that each of the institutions within this theory does not act only within their category. For example, private industry not only receives funds from organizations such as the National Institute of Health (NIH), the National Science Foundation (NSF), and the National Aeronautics and Space Administration (NASA) but also funds its own research and development and often the R&D of other organizations. Universities and government agencies are also involved in the receipt and distribution of R&D funds. However, as Jaffe explains “the social rate of return to R&D expenditure exceeds the private rate, leading to a socially suboptimal rate of investment in R&D” (Jaffe 2002). Thus, if it can be shown that spending on scientific R&D increases R&D output, the impetus behind such funding can be validated beyond case example such as the Human Genome Project cited by Zakharia.

Accomplishing this, however, is very tricky because governments have many options in how and how much they fund R&D (Nelson 2003). It is almost impossible to track sources of funding from the government directly through the various institutions and into the scientific R&D outcome. It is even harder to track the connection between all of this and the impacts these have on the nation. Thus, most studies tend to focus on one specific institution or set of institutions—usually the private industry, universities, or the government agencies.

This study will attempt to bypass studying the institutions that conduct the research and development and instead look at how measures of funding relate to measures of outcome. The various options governments have in how and how much they fund scientific R&D translate into a variety of independent explanatory variables such as research and development expenditure as percent of GDP and levels of corporatism (controlling variables such as GDP, measures of education, and military spending also contribute). Some states, however, seem more successful than others in their ability to produce outputs of R&D. This study aims to determine what explanatory variables most affect the variance in the dependent variables, scientific and technical journal articles published and patents, and thus which systems of funding for R&D has which effects or successes.

Definitions

The institutions of funding states have determines how and how much funding is allocated to the sciences for research and development. The most basic part of a state's institution of funding is the amount it spends on scientific R&D. Thus, the easiest measure of a state's institution of funding is R&D expenditure. However, also involved in a state's institution of funding is the way in which the government functions to allocate the funding. While this is significantly more difficult to measure, levels of corporatism or pluralism can provide a gateway into such a measurement. Corporatism is defined by Alan Siaroff as "reflecting: within an advanced industrial society and democratic polity, the coordinated, co-operative, and systematic management of the national economy by the state, centralised unions, and employers (these latter two co-operating directly in industry), presumably to the relative benefit of all three actors" (Siaroff 1999). Corporatism thus measures the degree to which the central national government directs and manages the economy, which includes the allocation of funding for scientific R&D projects, with more managerial governments defined as corporatist and more "hands-off" governments defined as pluralist. Measures of national expenditure on R&D and measures of corporatism therefore provide a fairly well rounded measure of a state's institutions of funding as a whole.

Whereas the institutions of funding determine how and how much funding is allocated to the sciences for R&D projects, the outcomes of scientific R&D are instead defined as what these funded projects produce. For the private research community, the goal of their research is generally to produce new products that can then be marketed for profit. Thus, the output of research for the private community is best measured in terms of patent applications, representing new developments that warrant intellectual copyrighting. For the academic research community, however, the goal research is the mainly expanding the breadth and depth of human knowledge. While research developments in the academic community often lead to eventual products and patents, the academic community generally measures its own success in articles published in reputable scientific and technological journals. Therefore, the outputs of scientific R&D, both in the private and academic communities, can be measured using a combination of patent applications and journal articles published.

Hypothesis

I hypothesize that, while there will be a correlation between funding for scientific research and development and research and development output, the relationship will not be particularly strong. However, as other possible contributing factors such as education levels, levels of corporatism, military expenditure, and GDP are controlled for, I hypothesize that states with funding institutions that fund scientific R&D at a higher rate will have, on average, higher levels of scientific R&D output. Specifically, I expect to observe an increase in patent applications by residents and scientific and technical journal articles as research and development expenditure as percent of GDP increases. I also expect to observe an increase in the same measures of scientific R&D output as other independent variables such as GDP, measures of education, and corporatism increase, however I expect these relationship to be weaker. As controls such as GDP, corporatism, and measures of education are added to into the analysis, I expect the relationship between scientific R&D output and research and development expenditure as percent of GDP to strengthen. Finally, I expect military spending as a control variable to have no effect as a control to have little effect on the relationship between scientific R&D output and research and development expenditure as percent of GDP.

Literature Review

Economic Analyses of R&D Systems

Universities

There are several types of institutions that conduct scientific research. The most commonly thought of institutions of scientific research are academia, private enterprise, and government institutions. Universities, the institutions that conduct academic research, account for approximately 50% of the basic research conducted in the US, thus it is impossible to evaluate the success of a state's scientific R&D without evaluating academia's contributions (Adams and Griliches1998). Adams and Griliches (1998) evaluate the research output of various U.S. universities in the form of published and cited academic papers compared to R&D expenditures. They find that generally private universities out-perform public ones (by producing more and more highly cited articles), while those with stronger reputations similarly out-perform schools that are not as highly ranked. Furthermore, the aforementioned authors find that returns on R&D expenditures are diminished as the university reputability/ranking decreased (Adams and Griliches 1998).

Private Sector

Studies of private contributions to R&D are more common than those of university participation in R&D, however equally important. Such studies tend to focus on how government subsidization and regulation of private R&D influences private R&D expenditures. Hall and Van Reenen (2000) find that, contrary to economists' conventional wisdom, a one percent increase in tax credit generally increases private R&D spending on average by one dollar per tax dollar lost—meaning one dollar of revenue foregone. Klette, Møen, and Griliches (2000), on the other hand, evaluate four studies trying to solve the same problem and conclude that, as of yet, there is still no answer to whether or not public support for commercial R&D is effective. In an assessment of various international studies on public subsidization of private R&D spending, David, Hall, and Toole (2000) conclude that, while most studies find public subsidization to be complementary to private spending on R&D, there are enough that find it supplementary that any hard-and-fast conclusions cannot be drawn. Specifically, the authors found that, of the 19 studies examined at the firm level and lower, 9 reported a net substitution of public for private funds (supplementary). Of the 14 studies examined at the industry level and higher, only two reported net substitution. However, the total number of studies reporting net substitution was 11 out of 33 (33%), meaning that there was no conclusive evidence indicating that studies overwhelmingly favor a complementary analysis over a supplementary one. Each of these studies, most of which were syntheses of previous studies, or meta-analyses, comes to differing conclusions.

Government Organizations

The final system of innovation in scientific R&D is that of government organizations. In the United States, such institutions include the NIH, NASA, the NSF, and many others. These are fully government-funded institutions that both conduct their own research and development and also participate in the funding of other private and university R&D, largely in the form of grants. Thus, because these institutions both operate independently (which is all government funded anyway) and in conjunction with the other institutions, they are generally evaluated on the success of their funding for external R&D. In one such article, Jacob and Lefgren (2011) analyze projects that receive NIH grant funding to see if they show an increase in publications and citations. The authors find that there is a positive correlation between NIH grants and publications/citations, however that correlation decreases as external variables are controlled for. The problem Jacob and Lufgren encounter is the same one all of the authors of analyses of the different institutions that conduct R&D encounter; that there are so many external factors caused by the intricate interactions of universities, private companies, and government institutions, that all attempts to isolate and measure each part individually fail to fully explain any findings. Jaffe (2002) tries to solve this problem with regard to government grant funding by proposing a system in which projects that are on the borderline between receiving federal funding and not receiving funds are randomized.[1] Jaffe's proposal highlights the problems found throughout these types of analyses, that given the current measures of analysis available, there is no particularly effective way to analyze the success funding for R&D has on university and private R&D.

Evaluative Studies of Systems of Innovation

The previous studies do well to look at the specifics of how university, private, and government interact with each other and receive funding to produce R&D results, however they do not establish a cohesive method of looking at how policies in countries affect the various interdependent systems that together produce scientific R&D. In order to understand which funding policies of R&D are the most effective, it is necessary to understand how these policies affect all aspects of the system of innovation. Chang and Shih (2004) compare the systems of innovation in China and Taiwan in an attempt to propose the possibilities for future cooperation between the two countries. In their analysis, they provide a comprehensive assessment of all parts of the Chinese and Taiwanese systems of innovation including qualitative (and occasionally quantitative) descriptions of the countries' policy formulations, R&D performance, R&D financing, measures of collaboration and many more. Although this study provides a strong framework to evaluate how policies affect systems of innovation as a whole, this analysis is limited to two similar countries. In a more expansive but similar study, Nelson (1993) analyzes the

[1] Jaffe's paper is not a quantitative or even really a qualitative study. He surveys the common problems in analyses R&D funding, mainly problems of selection bias, and then offers a detailed solution by which future studies could conduct more effective research. His solution is to randomize the federal funding for borderline projects to eliminate the selection bias problem. However, he does not actually conduct such research himself.

systems of innovation of 15 countries. His goals, however, were almost exclusively to compare and contrast the various systems of innovation and refute those who claim one system works better than another. Both studies address the difficulties in connecting the policies of a state to the various processes that contribute to scientific R&D, however neither provides effective models for assessing what funding policies may best promote scientific R&D output.

Common Methodologies

The methodologies used by studies examining funding for science R&D fall into a few general categories. Some studies take a data set of many academic studies and assess them en masse to observe trends in the academic community in what could be called a "meta-analysis"—a study of studies (David, Hall, and Toole 2000; Hall and Reenen 2000; Klette, Møen, and Griliches 2000, Jaffe 2002). Many US based studies use patents, published scholarly articles, and citations and compare them to NIH or NSF funding data to assess the viability and success of such funding as a whole (Jacob and Lefgren 2011; Adams and Griliches 1998). Another common method of analysis is looking at case studies both of specific industries (Patel and Pavitt 1994) or case studies of countries (Chang and Shih 2004; Nelson 1993). Although all of these methods provide viable ways to investigate how funding for R&D affects the outputs of scientific R&D, none provide a complete enough picture to be able to make concrete statements about the relationship between R&D funding and R&D output.

Need for Further Research

The analyses of U.S. R&D efficiency of universities, private industries, and government institutions provide excellent methods for analyzing economically the direct effects one method of funding has on one type of R&D measure (Jacob and Lefgren 2011). However, these studies do not provide a way to assess the methods in which scientific R&D funding policy as a whole affects the eventual output of R&D systems as a whole. Furthermore, they are complicated by the interwoven relationships between all three institutions that dilute one's ability to analyze them all independently. The analyses of countries' entire systems of innovation allow the comparative analysis of the systems that involve scientific R&D across many countries. These studies, however, do not provide a strong quantitative analysis and instead are generally descriptive analyses (Laredo and Mustar 2001; Nelson 1993). Instead, a comparative study that uses measures of R&D output that represent the outputs of universities, private industries, and government institutions (such as patents and published articles) compared to a set of measures that represent government investment in R&D (such as the Financing R&D statistics used by Chang and Shih 2004) might be able to provide better insight into how government funding policies for scientific R&D affects R&D outputs. Furthermore, research that addresses the multiple possibilities for what explanatory or secondary variables contribute to or hinder government investment in R&D's affect on measures of R&D output would be able to provide a better picture of how the complex institutions of policy interact with the institutions that yield R&D outcomes.

Study Design

In this study, the effectiveness of government spending on research and development is explored using a cross-sectional comparative country analysis. Using data provided by the World Bank, a non-experimental, cross-sectional comparative analysis is conducted in which the dependent variables patent applications[2] and scientific and technical journal articles[3] are analyzed relative to the independent variable research and development expenditure as a % of GDP[4]. The variable patent applications, [by state] residents serves as a rough measure of the scientific research and development output by the private sector, while the variable scientific and technical journal articles serves as a rough measure of the scientific research and development output by academia. Although there is certainly some overlap, meaning that the private sector publishes scientific and technical papers and universities produce some patents, these two categories represent the end-goal most scientific

[2] http://data.worldbank.org/indicator/IP.PAT.RESD
[3] http://data.worldbank.org/indicator/IP.JRN.ARTC.SC/countries
[4] http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS/countries

research and development projects, whether they are conducted by the private sector, by universities, or by government organizations.

The World Bank data is broken down both by country and by year. The countries are further subdivided by the World Bank into categories defined by region, lending groups, or gross domestic income per capita. Given that this study is attempting to analyze the scientific outputs of the United States and other developed countries relative to each other, this study focuses on only what the World Bank defines as “High Income Countries.” The World Bank defines this as countries with gross national income per capita of greater than $12,476. The category of “High Income Countries” consists of 70 countries as diverse as Finland and Equatorial Guinea, therefore the study further limits its country pool to the 31 OECD High Income countries. Thus, countries are limited to those like enough to the US to provide accurate analysis of the data yet diverse enough to provide meaningful conclusions. Data for “research and development expenditure (% of GDP)” is only provided for starting in 1996 and the majority of countries only have data through 2009, therefore only data from 1996-2009 is analyzed.

Another independent variable to be controlled for is a corporatism scale that synthesizes eight common factors that contribute to a corporatist (meaning integrated and non-pluralist) system into a singular corporatist rating. The concept of national corporatism is defined by Alan Siaroff in “Corporatism in 24 Industrialized Democracies: Meaning and Measurement” as “within an advanced industrial society and democratic polity, the coordinated, cooperative, and systematic management of the national economy by the state, centralized unions, and employers (these latter two co-operating directly in industry), presumably to the relative benefit of all three actors.” The aforementioned scale, developed by Siaroff, analyzes 24 OECD countries based on corporatist factors including measures of social partnership, industry-level coordination, and overall policy-making patterns. This data set, which ranks OECD countries’ levels of corporatism on a scale of 1 to 5, provides a corporatism score per country for each decade (Siaroff 1999). However, given that only World Bank data between 1996 and 2009 is utilized in the current study, only the corporatism scores from the 1990s is used. A particularly difficult challenge in the use of this data is its limited country pool (only 24 cases). This forces any analyses using the corporatism scale to limit the cases from 31 further down to 24, which decreases the significance of the results. However, it has been previously shown that similar analyses can be effectively conducted using this data set (Walti 2004). Therefore this problem is not likely to undermine the ultimate significance of the results.

Research and development, particularly regarding technologies, are integral parts of military budgets; however, the relationship is not straightforward. Therefore, measures of military spending are examined as another possible contributing variable. Military spending as a share of GDP has been shown, particularly in country cross-sectional analyses, to have a negative effect on rates of economic growth (Knight, Loayza, and Villanueva 1996). Similarly, despite common sense that might indicate more military spending on R&D increases total spending on R&D, studies more strongly suggest that, like in previous examples, military spending more commonly supplements civilian R&D rather than complementing it (Cappelen, Gleditsch, and Bjerkholt 1984). Thus, this study uses measures of military spending—military spending as a percent of central government expenditure and military spending as a percent of GDP, both obtained from the World Bank database—as possible controlling variables in the analysis. Because this dataset is also a World Bank dataset, it has the same data breakdowns and limitations as all other World Bank data.

Finally, education is a possible intervening variable that could contribute to the scientific R&D output of a country. Those countries with more successful systems of science and technical education seem more likely to have a workforce that can produce scientific innovation in the form of R&D. However, education also has a well established complicated relationship with economic growth (McLelland 1966) making measures of education difficult to use as an explanatory variable for measures of economic output (including R&D output)—thus measures of education are used as controlling variables. There are two possible data sources that could be used as a control for education. The first is World Bank data that provides school enrollment in secondary and tertiary schools as a net percent of the appropriate school-aged population. Because the advanced nature of scientific R&D requires higher learning, such a statistic is well suited to differentiate between countries with educational systems conducive to scientific R&D and those without such educational systems.

Data Quality and Reliability

Data Sources

The majority of the statistical data provided by the World Bank comes from the statistical systems of the member countries. The quality and reliability of this data is therefore, largely dependent on the quality and reliability of the national statistical systems of the countries analyzed (World Bank, "Data Overview"), but the World Bank does help countries collect and assess data. This produces the possibility for unpredictable, biased statistics and statistics that may be measured differently from state to state. However, by limiting the analysis to only high-income OECD countries, countries that can generally be relied upon to keep records consistent with the international community, these risks can be limited. Furthermore the World Bank provides the International Monetary Fund's Data Quality Assessment Framework that assesses the reliability of each state's statistical systems, thus the countries analyzed in this study can be limited based on this assessment (Carson, Carol S. and Jack Boorman 2001). All OECD datasets are gathered in the same basic fashion as the World Bank data (often they are collected together. Therefore, all datasets used are credible, though not without imperfections, and as such data collection should not provide much source of error.

Variable Assessment for Use in Regression Analysis

While the main thrust of this study is the bivariate and multivariate analyses of the data utilizing Research and Development Expenditure as % of GDP as the main independent variable, Patents as the first main dependent variable, and Scientific and Technological Journal Publications and the second main dependent variable, it is also of value to examine the distributions and characteristics of each variable's data sets (all figures, tables, and the key can be found in the Appendices). An examination of the variables, both dependent and independent, helps understand the evolution of the variables over time and between countries. Furthermore, it helps the country comparison to observe whether some countries are at the forefront of a statistical category, whether said countries lag behind, or whether there is tremendous variation over time. It also serves to check the data or variable is reliable and whether it lends itself to a bivariate and multivariate regression analysis.

Each OECD country's Research and Developed Expenditure as % of GDP is graphed by year (figure 1). The data shows that the countries with the highest expenditure on R&D as % of GDP are Israel, Japan, South Korea, and the Scandinavian countries. At an average of 2.6% (figure 2), the United States is also among the countries with the highest average R&D Expenditure as % of GDP. The data from figure 1 also demonstrates the relatively even pattern of R&D Expenditure as % of GDP. There are few countries with large spikes or dips in the R&D Expenditure, and of those with somewhat peculiar graphical shape (Israel, for example) such variations are not unreasonable. The country with arguably the most interesting pattern of R&D Expenditure is South Korea, which has a consistent incline demonstrating a measured increase in R&D Expenditure as % GDP. Also of note in figure 1 is the missing data point from several of the countries. Australia, Luxembourg, Greece, New Zealand, and Switzerland all have a significant number of years without reported data (Australia and New Zealand report every other year, Switzerland reports every fourth year, and Luxembourg and Greece appear to have no pattern). These inconsistencies are taken account of during the bivariate and multivariate analyses, however they cause no problems when using the country averages for such analyses.

The distribution of Scientific and Technological Journal Publications and Patents among OECD countries is very different from the distribution of R&D Expenditure as % of GDP. Because R&D Expenditure is already normalized by % GDP, the largest countries do not dominate the data. This is not the case with Scientific and Technological Journal Publications or Patents. It can be seen that the US has far and away the most Scientific and Technological

Journals published followed by other high GDP countries such as Japan, Great Britain, France, and Germany (figures 3 and 4). The most important information gathered from figure 3 is that the data is consistent and there are no major spikes or dips in the data. Much like R&D Expenditure as % of GDP, it is also of note that South Korea once again has a consistent and steady incline in the number of journal articles published.

To mitigate the problems caused by the impact country size (both in GDP and population) has on scientific and technological journal publications, journal publications were normalized by population (figure 6). Relative to the raw scientific and technological journal publications data, scientific and technological journal publications per capita provides the best dataset for several reasons. Notably, the curves in figure 6 are much more consistent with few dramatic fluctuations relative to the GDP normalization (figure 5). Furthermore, this data successfully eliminates the effect country size has on the data while keeping GDP as a possible controlling variable for the multivariate analysis. Whereas the United States had been several rungs above all other countries in number of journal publications per year, when normalized per capita, the United States' journal publications drop back towards the upper middle of the data set (figures 6 and 7). Similarly, other high GDP and high populations such as the United Kingdom, France, Japan, and Germany that were at the top have also dropped towards the middle of the data set. Switzerland, Sweden, Israel, Finland, and Denmark, on the other hand, make dramatic gains and are at the top of journal publications per capita. This data seems much more meaningful and thus is used for the bivariate and multivariate analysis in the place of raw scientific and technological journal publications.

Much like scientific and technological journal publications, the data for Patents, too, is skewed in favor of the largest countries (figure 8). The United States, United Kingdom, France, and Germany are all at the forefront of patents produced per year, however Japan is the leading country in patents produced and South Korea the third ranked country. Because of the tremendous imbalance in patents produced between the large economic countries and the small ones, patents too is normalized for GDP and population (figures 9-12). The graphs of patents normalized by population (Figures 11 and 12), like their journal publications counterparts, avoid the pitfalls of the GDP normalizations (figures 9 and 10). Surprisingly, Japan and South Korea remain dramatically ahead of all other countries in terms of patents per capita, followed by the United States and Germany (figure 11). This indicates that there is some quality to patents that, unlike scientific and technological journal publication, is not effectively normalized by GDP nor population. While there are still several curves that remain somewhat erratic, none are erratic enough to cause concern. The one that is, Israel, has 2 data points in 2006 and 2007 that can be thrown out as outliers. Another country with a surprising curve is South Korea, which has a dramatic growth curve leading it to be the most patents per capita of any country by 2009. However, this is consistent with South Korea's other dramatic growth curves that have appeared in much of the data. Thus, the normalization of patents by population appears to be the best variable to use in the bivariate and multivariate analyses due to its relative consistent data that can be safely averaged by year (figure 13).

There are also several control variables that are tested in the multivariate analysis. First among these is GDP, which, because it is not being used as a normalizing variable, is instead used as a possible control variable (figures 14 and 15). The USA and Japan have by far the highest GDPs, followed by the United Kingdom, France, and Germany. Furthermore, most countries show a distinct rise in GDP over time. There are no countries that show any peculiarly shaped curves, however, Mexico, which is toward the bottom of all the previously discussed statistics, is in the upper middle section of countries by GDP.

Second among possible control variables are those involving the educational excellence of a country. Given that the purpose of this study is examining the output of countries in areas of scientific research and development, the World Bank offers 3 variables that could be effective in controlling for education: secondary school enrollment % net, secondary school enrollment % gross, and tertiary school enrollment % gross. Secondary school enrollment as % net measures the number of students of secondary school (high school) age enrolled in secondary school as a percent of the total number of people that age. Secondary school enrollment % gross, meanwhile, measures the number of citizens enrolled in secondary school (regardless of age) as a percent of citizens of secondary school age. Thus, secondary school enrollment % gross can exceed 100 percent. While secondary school enrollment % net might provide interesting results as a control variable, many of the OECD countries have inconsistent reporting such that fewer than half of the years have reported data for 8 of the OECD countries. Given that both secondary school enrollment % net (figure 16) and secondary school enrollment % gross (figure 17), have fairly regular curves and the data for secondary school enrollment % gross has a more complete data set the latter is used as the controlling variable for secondary school. Of concern in the secondary school enrollment % gross data, however, is that the Austria, Belgium, Finland, and Sweden curves show a severe drop from 2003 to 2005 demonstrating a possible change in policy or, more likely, the way in which these countries measure the statistic. Nevertheless, the data is regular enough to warrant use as a control variable. Of the data for tertiary school enrollment % gross (figure 18), only Germany and Canada have less than 50% of data points reported. Furthermore, the data shows a consistent pattern of growth across all countries with few fluctuations. This indicates tertiary school enrollment % gross is a viable control variable for use in the multivariate analysis. Thus, secondary and tertiary school enrollment % gross is used for the multivariate analysis to control for the quality of education of a country.

The third possible control variable is a country's degree of corporatism. Using the Siaroff corporatism scale for the mid-1990s (figure 19) and the overall mean corporatism scale (figure 20) the degree to which a country is corporatist or pluralist is used in the multivariate analysis. The Siaroff scale only includes 24 of the OECD countries, excluding Chile, the Czech Republic, Estonia, Hungary, South Korea, Mexico, Poland, Slovakia, Slovenia, and Turkey, and therefore is somewhat more limited than other control variables. However, the Siaroff corporatism scale provides interesting insight on the structure of countries political systems. Of countries, Sweden, Austria, Norway, Denmark, Switzerland, Germany, and the Netherlands are the most corporatist (score in the high 3's or above) while Australia, Canada, Greece, Ireland, Italy, New Zealand, Portugal, Spain, France, the United Kingdom, and the United States are either weakly corporatist or generally pluralist (scores from 1 to the low 2's). All other countries measured are best described as moderately corporatist.

The fourth and final possible control variable is military expenditure, measured as both a % of total expenditure (figure 21) and a % of total GDP (figure 22). The USA, Israel, and Chile spend the most on military expenditures as a percent of total expenditure, followed closely by South Korea, Turkey, and finally the majority of countries (figure

21). While all countries show fairly regular data sets for military expenditure as % of total expenditure, Iceland, Japan, Mexico, and Turkey, have data reported for less than 50% of years between 1996 and 2009. Although by averaging the data points by country the data can still by utilized, such small data sets could cause problems in the multivariate analysis. Otherwise, the only country with a data curve of note is South Korea, whose military expenditure as % of total expenditure dropped from the top ranked in 1996 to the fourth country during the 2000's. Israel militarily far outspends all other countries by % of GDP, followed by the USA, Chile, South Korea, Turkey, and the rest of the OECD countries (figure 22). All of the military expenditure as % of GDP curves are also rather regular and only Iceland has less than 50% of data reported. The most interesting aspect of this data is the degree to which Israel far outspends all other countries as a % of GDP while all other countries are generally in a large pack. Because both military expenditure as a percent of total expenditure and military expenditure as a percent of GDP are fairly regular, the data can be averaged (figures 23 and 24) and used in the multivariate analysis.

Small Sample Size

The biggest statistical challenge for this study is the relatively small sample size. Using only 31 countries, and at times as few as 24 as necessary, there is increased risk that results are not be statistically significant due to the small N value (and hence fewer degrees of freedom). However, as has been established in previous studies (Walti 2004), such data sets can maintain significance in cross-sectional analyses—particularly when using advanced statistical methodologies that expand the data set. Moreover, the fact that results of the analysis are robust across the models, despite the small sample size, points to the significance and meaningfulness of the data.

The Relationship Between R&D Expenditure and R&D Outputs: Regression Analyses

Bivariate Data Analysis

In bivariate analysis a regression analysis of the Patents per Capita against R&D Expenditure as % of GDP and

Scientific and Technological Journal Publications against R&D Expenditure as % of GDP demonstrates just how strongly related these variables are (figures 25 and 26). The regression of Patents per Capita versus R&D Expenditure as % of GDP (excluding the outlier data points of Japan and South Korea) yielded an R-Squared value of 0.43 with a p-value of 0.000 indicating that Patents per Capita and R&D Expenditure as % of GDP are highly correlated and the data is significant (figure 25). Therefore, as R&D expenditures rise as a % of GDP, on average, so do Patents per Capita. However, the data also shows a heteroscedastic pattern—marked by an increase in variance of the data as the independent variable rises or a "fanning" pattern. It is unclear exactly why this is occurring, however this could possibly be caused by a variance in states' standard for what deserves a patent application. Alternatively, countries with economies more heavily tied to scientific and technological corporations may produce more patent applications simply by having more corporations to produce such patents. This could explain why South Korea and Japan, which have very strong technological corporate communities, are extreme positive outliers in Patents per Capita, however further research would be needed to confirm this.

The relationship between Scientific and Technological Journal Publications and R&D Expenditure as % of GDP is even stronger than that between Patents per Capita and R&D Expenditure as % of GDP (figure 26). This regression yields an R-Squared value of 0.55 with a p-value of 0.000. This, also, indicates that the dependent and independent variables are highly correlated and the data is significant. As opposed to the previous data, this regression does not demonstrate the same problem of heteroscedasicity. Thus, as R&D Expenditure as a % of GDP rises, on average, a country produces more Scientific and Technological Journal Publications. Although the bivariate analysis shows a very strong, positive, and significant relationship between dependent variable and R&D Expenditure as a % of GDP, it is possible that other intervening independent variables convolute or actually drive this relationship. Therefore, a multivariate analysis of the dependents variables and R&D Expenditure as a % of GDP was conducted that controls for GDP, corporatism, measures of education, and measures of military expenditure.

A regression analysis of the two dependent variables tests whether scientific and technological journal articles published per capita and patents per capita are also correlated (figure 27). The analysis yielded an R-squared value of 0.39 and a significance of 0.000. This indicates that, while theory does not support scientific and technological journal articles published as a causal source of variance in patent applications per capita, countries with high journal articles published also tend to have higher numbers of patent applications. This also reinforces the idea that both dependent variables are driven by changes in a mutual independent variable, R&D expenditure, which causes variance in scientific R&D outputs.

Multivariate Data Analysis

The multivariate analysis of Patents per Capita against R&D Expenditure as a % of GDP and the various other possible intervening independent variables is shown in Table 1. The first six models only incorporate one additional independent variable, thereby testing the effect that independent variable has upon the original regression. As seen in the table, only GDP and Tertiary School Enrollment (% Gross) yield data significant to the 90% confidence level. The trivariate regression with GDP produced an R-Squared value of 0.62, indicating a strengthening of the positive relationship between Patents per Capita and R&D Expenditure as a % of GDP. Thus, as both R&D Expenditure as a % of GDP and GDP increase, Patents per Capita a country produces similar increases at a higher rate than when only accounting for the effects of R&D Expenditure as a % of GDP. This means that a country's overall wealth also increases the number of Patents per Capita produced. This could simply mean that a countries with larger economies have more avenues of producing patent applications (more scientific and technologically focused corporations), thus expenditure on R&D is more effective at producing patent applications.

The trivariate regression with Tertiary School Enrollment (% Gross) produced an R-Squared value of 0.46—only a slight increase from the bivariate model. This indicates that while controlling for Tertiary School Enrollment certainly does weaken the relationship between R&D Expenditure as a % of GDP and Patents per Capita, it only strengthens it slightly. Thus, as more students are enrolled in tertiary school and R&D Expenditure as a % of GDP increases, Patents per Capita increases at only a slightly more predictable rate than when only accounting for the increases in R&D Expenditure as a % of GDP.

Models 7 and 8 attempt to test the effects of all the possible independent variable on Patents per Capita (using only one measure of education and military expenditure per model). While the R-Squared values were increased in both models 7 and 8 (0.50 and 0.52 respectively), only GDP as a control variable remained significant and the significance of R&D Expenditure as a % of GDP was reduced to a p-value of 0.106 and 0.162 respectively. This is likely because the inclusion of GDP strengthens the relationship between Patents per Capita and the independent variables, however, the other intervening variables mitigate this increase and convolute the significance of the relationship between R&D Expenditure as a % of GDP and Patents per Capita. Thus, model 9 attempts to incorporate only the most significant independent control variables, which in these analyses are GDP and Tertiary School Enrollment (% Gross). When including both GDP and Tertiary School Enrollment (% Gross) in the multivariate analysis, the R-Squared value rises to 0.63—only slightly higher than when only including GDP as a control variable. Furthermore, while R&D Expenditure as % of GDP and GDP are significant to a 99% confidence interval, Tertiary School Enrollment (% Gross) is insignificant. This reinforces the conclusion that, outside of R&D expenditure, GDP is the main driving force controlling for patent applications per capita produced by a country and that measures of education are not as important.

A multivariate regression analysis of Scientific and Technological Journal Publications per Capita against R&D Expenditure as a % of GDP and the various other possible intervening independent variables was similarly conducted and is shown in Table 2. The regression is run in an identical fashion to the Patents per Capita multivariate regression with the first six models only incorporating one additional independent variable and the final 3 testing different combinations. Of the six trivariate models, only GDP, Secondary School Enrollment (% gross), and Tertiary School Enrollment (% gross) are significant to a 95% confidence interval. Model 1, incorporating GDP as the intervening independent, has an R-Squared of 0.54, indicating that the inclusion of GDP in the analysis does not affect the strength of the relationship between Patents per Capita and R&D Expenditure as a % of GDP. Thus despite, controlling for GDP, this relationship remains strong—meaning the more a country spends on R&D as a % of GDP on average, the more patents per capita it will produce on average.

Models 3 and 4 demonstrate that both Secondary and Tertiary School Enrollment are significant as intervening independent variables and both increase the R-Squared values of the analysis to 0.67 and 0.60 respectively. This indicates that education has a significant impact on the relationship between R&D Expenditure as a % of GDP and Scientific and Technological Journal Publications per Capita. The inclusion of independent variables for school enrollment strengthens the aforementioned relationship, meaning that as both school enrollment and R&D Expenditure as a % of GDP rise, a country's Scientific and Technological Journal Publications per Capita, on average, will also rise.

Just as in the Patents per Capita multivariate analysis, Models 7-9 test the effects of many independent variables on Scientific and Technological Journal Publications per Capita. Once again only GDP and the two measure of school enrollment were statistically significant. Interestingly, in Model 9, which controls for GDP and Tertiary School Enrollment (% gross), the R-squared value (0.60) is almost the exact same as in Model 4, which only incorporates Tertiary School Enrollment (% gross). This means that increases in Scientific and Technological Journal Publications per Capita are more accurately predicted by increases in Tertiary School Enrollment (%

gross), and R&D Expenditure as a % of GDP than by Tertiary School Enrollment (% gross), GDP, and R&D Expenditure as a % of GDP alone. Moreover, this means that GDP has no particular controlling effect on scientific and technological articles produced, whereas controlling for variance in enrollment in tertiary school strengthens the relationship between R&D expenditure and scientific and technological journal articles published.

Avenues for Further Research

While study provides a solid foundation for exploring the topic of how national expenditure on scientific R&D affects R&D outputs, further research must be done to solidify the discovered relationships. First and foremost, research needs to be conducted into how and why the regression analysis of patents per capita yields a heteroscedastic pattern and why Japan and South Korea are such outliers. For this, a descriptive analysis of the patent approval procedures by country would shed light on the differences in such processes. While school enrollment was shown to have a significant positive effect that strengthens the relationship between national expenditure on scientific R&D and journal articles published, these are not necessarily perfect measures of the quality of a country's educational system. Other measures, such as the PISA study ought to be examined as another possible independent variable to be tested. Furthermore, this study should be deepened by examining the meanings of the B-coefficients and trying to establish a numerical amount by which increases in national expenditure on scientific R&D increases scientific R&D outputs.

Conclusion

Although the need for the public sector to supplement private sector under-funding for scientific research and development has been well-established in academic literature, it is nevertheless unclear to what degree public funding for R&D yields R&D outputs. This study examines the institutions of policy responsible for public funding of the sciences and compares them to the products of scientific research and development, in the forms of patent applications and journal articles published. The main independent variable tested is Research and Development Expenditure as a % of GDP. However several other potential intervening variables are tested including GDP, a corporatism scale designed to measure how conducive institutions of policy making are to coordination and cooperation with the institutions of the national economy (such as unions, private-sector employers, and public sector employers), measures of a country's school enrollment, military expenditures, and GDP are also examined for their role in affecting scientific R&D output.

This study finds that there is a strong, positive, and significant relationship between R&D Expenditure as a % of GDP and the two measures of scientific output, however the relationship with Patents per Capita is heteroscedastic. This means that as a country spends more on R&D as a % of GDP, scientific R&D output will, on average, increase at a fairly predictable rate. Furthermore, this relationship stays strong when controlled for possible intervening independent variables. Particularly, controlling for GDP strengthens the relationship for Patents per Capita such that increases in a country's Patents per Capita are more accurately predicted by both R&D Expenditure as a % of GDP and GDP than by R&D Expenditure as a % of GDP alone. Tertiary School Enrollment (% gross) as an intervening independent variable neither strengthens nor weakens the aforementioned relationship. Conversely, incorporating Secondary or Tertiary School Enrollment (% gross) as intervening independent variables strengthens the relationship between Scientific and Technological Journal Publications per Capita and R&D Expenditure as a % of GDP, while GDP does not particularly strengthen or weaken said relationship. Thus, while R&D expenditure as a % of GDP has a statistically significant, strong, positive relationship with the scientific output, accounting for changes in GDP strengthens the relationship with patents applications per capita while accounting for school enrollment (effectively a measure of the quality of a country's education system) strengthens the relationship with scientific and technological journal publications per capita.

These results seem to align with the theoretical framework because patents (used to measure scientific output from the private institutions) are mainly driven by the business community in a country, which is more directly tied to GDP, while journal publications (used to measure scientific output from the academic institutions) are more directly tied to the academic institutions of a country. It is therefore not surprising that patent applications, the measure of output most associated with private industry, was best controlled for using GDP, and that journal articles published, the measure of output most associated with universities and academia, was best controlled for with education.

While this study indicates that R&D outputs are significantly and positively impacted by changes in R&D expenditure, this idea is not commonplace in the policy-making community. As economies become more strained and national budgets become tighter, funding for the sciences is often one of the first items cut. Moreover, in such political environments politicians often want more oversight and control over what projects get funded to both increase funding allocated to their constituency and to decrease what is viewed as funding on superfluous projects. A recent bill being proposed in Congress provides an example of such attempts at restrictive oversight. Congressman Lamar Smith[5] is drafting a bill titled "The High Quality Research Act," which would limit grants provided by the NSF only to "groundbreaking" projects (Mervis 2013). However, as demonstrated with the Human Genome Project and countless other scientific research projects, it is often the projects with the least tangible benefits that yield the most innovative results.

Luckily, not all politicians agree with the idea of restricting the recipients of scientific and technological research grants. President Obama recently announced that the 2014 budget will include a large grant allocated to a brain-mapping project modeled after the Human Genome Project (Pathe 2013). Like the President, many politicians and policy-makers are still committed to the expansion of human knowledge by providing federal

[5] Lamar Smith (R-TX) is the same Congressman who introduced SOPA

grants for R&D that fill the market failure gap. Given that scientific R&D outputs such as new products and discoveries are known to aid economic development, and this study indicates that it can be increases in public funding for scientific R&D increase the scientific R&D outputs, hopefully it may become accepted knowledge that it is not in a country's best interest to cut and limit funding for the sciences. Instead, funding a robust and diverse scientific research community leads to only positive results.

Works Cited

Adams, James D. and Zvi Griliches. 1998. "Research Productivity in a System of Universities." *Annals of Economics and Statistics*, No. 49/50: 127-162.

Cappelen, Adne, Nils Petter Gleditsch, and Olav Bjarkholt. 1984. "Military Spending and Economic Growth in the OECD Countries." *Journal of Peace Research* 21, No. 4: 361-373.

Carson, Carol S. and Jack Boorman. 2001. "Fourth Review of the Fund's Data Standards Initiative." *The International Monetary Fund*: 42-44.

Chang, Pao-Long and Hsin-Yu Shih. 2004. "The Innovation Systems of Taiwan and China: A Comparative Analysis." *Technovocation* 24, No. 7: 529-539.

David, Paul A., Bronwyn H. Hall, and Andrew A. Toole. 2000. "Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence." *Research Policy*, No. 29: 497-529

Epstein, Jonathan A. 2011. "Politicizing NIH Funding: A Bridge to Nowhere." *The Journal of Clinical Investigation*, 121, No. 9.

Hall, Bronwyn and John Van Reenen. 2000. "How Effective Are Fiscal Incentives for R&D? A Review of the Evidence." *Research Policy*, No. 29: 449-469.

Klein, Peter G. 1999. "New Institutional Economics." *Encyclopedia of Law and Economics*, chapter 0530.

Klette, Tor Jakob, Jarle Møen, and Zvi Griliches. 2000. "Do Subsidies to Commercial R&D Reduce Market Failures? Microeconometric Evaluation Studies." *Research Policy*, No. 29: 471-495.

Knight, Malcolm, Norman Loayza, and Delano Villanueva. 1996. "The Peace Dividend: Military Spending Cuts and Economic Growth." *World Bank Policy Working Research Paper* No. 1577.

Jaffe, Adam B. 2002. "Building Programme Evaluation into the Design of Public Research‐Support Programmes." *Oxford Review of Economic Policy* 18, No. 1: 22-39.

Jacob, Brian A. and Lars Lefgren. 2011. "The Impact of Research Grant Funding on Scientific Productivity" *Journal of Public Economics* 95, no. 9-10: 1168-1177.

Laredo, Philippe and Philippe Mustar. *Research and Innovation Policies in the New Global Economy* (Cheltenham, UK: Edward Elgar Publishing, 2001).

Mervis, Jeffrey. "US Lawmaker Proposes New Criteria for Choosing NSF Grants." *Science Insider*. April 28, 2013. http://news.sciencemag.org/scienceinsider/2013/04/us-lawmaker-proposes-new-criteri-1.html?rss=1.

McLelland, David C. 1966. "Does Education Accelerate Economic Growth?" *Economic Development and Cultural Change* 14, No. 3: 256-278.

Nelson, Richard R. *National Innovation Systems: A Comparative Analysis* (New York: Oxford Press, 1993).

Patel, Parimal and Keith Pavitt. 1994. “National Innovation Systems: Why They Are Important, And How They Might Be Measured And Compared.” *Economics of Innovation and New Technology* 3, No. 1: 77-95.

Pathe, Simone. “Obama Hopes Mapping Project Reveals Brain’s Mysteries.” *PBS Newshour*. April 8, 2013. http://www.pbs.org/newshour/extra/2013/04/obama-launches-project-to-understand-the-human-brain/.

Siaroff, Alan. 1999. “Corporatism in 24 Industrialized Democracies: Meaning and Measurement.” *European Journal of Political Research* 36: 175-205.

Walti, Sonja. 2004. “How Multilevel Structures Affect Environmental Policy in Industrialized Countries.” *European Journal of Political Research* 43: 599-634.

World Bank, “Data Overview.” Last Modified 2012. http://data.worldbank.org/about/data-overview

Zakharia, Fareed. 2012. “How Government Funding of Science Rewards US Taxpayers.” *The Washington Post*. http://www.washingtonpost.com/opinions/fareed-zakaria-how-government-funding-of-science-rewards-us-taxpayers/2012/06/20/gJQApDmJrV_story.html