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Government R&D expenditures and US technology advancement in the aerospace industry: a case study[☆]

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Abstract

Traditionally, the United States has not set a specific national technology policy or plan like those seen in many other nations. However, the US Government spends large amounts of money on research and development (R&D) through such agencies as Department of Defense (DoD) and National Aeronautics and Space Administration (NASA). This case study investigates the relationship between defense and space R&D expenditures and national technology advancement in the aerospace industry. The lag between R&D expenditures and technology advancement is also examined and modeled.

Keywords: Research and development; Technology development; Technology transfer; Technology policy; Historical analysis

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1. Introduction

The US Federal Government has made significant investments in research and development (R&D) in the United States. While the government still funds a great deal of research, its share of the total invested in R&D is decreasing. The National Science Foundation (NSF) reports that before 1978, the US Government-funded over 50% of all R&D in the United States. By 1996, government funding for R&D had dropped to 33.6% of all R&D expenditures in the US (NSF 96-333, 1996).

[☆] The views expressed in this article are those of the authors and do not reflect the official policy or position of the Air Force Research Laboratory, the United States Air Force, the Department of Defense or the US Government.

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In 1996, the US Government was projected to spend most of its R&D funds through the Department of Defense (DoD) (49%), National Institute of Health (NIH) (17%), National Aeronautics and Space Administration (NASA) (12%), Department of Energy (10%), and others key agencies (NSF 96-333, 1996, Appendix C25). It has been suggested that these federal investments represent a de facto technology policy. Alic et al. state:

> US technology policy has never been very clearly defined. In contrast to national security policy . . . technology policy has normally been a derivative category, shaped by decisions made on other grounds. Year-by-year, case-by-case budgetary decisions by DoD, NASA, and other mission agencies, by the Office of Management and Budget, and by Congress drive much of US technology policy (Alic et al., 1992, p. 45).

Alic et al. describes several ways military spending on R&D is linked to commercial technology. These include spin-off (commercial use of government developed technologies), procurement pull and commercial learning, dual use technologies, shared infrastructure for emerging commercial industries, development of general purpose techniques and tools, spin-on (government use of commercial technology), and technology diffusion from demonstration programs (Alic et al., 1992, pp. 54–81).

The importance of government-funded research to our national technological strength has recently been an issue. As recently as 22 September 1999, a coalition of scientists, university professors, and industrial leaders urged Congress to continue to support research in the US as the backbone of our economy (ENN, 1999). Neal Lane of the White House's Office of Science and Technological Policy further discusses these issues in recent statements (Lane, 1999). Clearly, there is a perceived link between government R&D funding and national technological advancement.

This study focuses on the relationships between government expenditures and progress in the aerospace industry. Data for the period 1977 to 1996 was used. Because of the focus on the effects of US Government expenditures on the US aerospace industry, US Air Force (USAF) R&D expenditures and aggregated DoD/NASA expenditures are considered. These agencies are the primary contributors to the aerospace sector.

In the remainder of the case study, the literature is reviewed to provide the basis for the proposed analysis. Next, sources for both input and output data are discussed. Known problems are documented on the output data and discussion is provided about how the outputs of R&D tend to lag the inputs of R&D. Analysis approaches are discussed and then results of the study are shown. Finally, conclusions will be drawn from the study.

2. R&D performance evaluation measures

Geisler suggests that R&D studies can be divided into: (1) input-related approaches; (2) output-related approaches; and (3) input–output approaches. He defines input–output approaches as “economic benefits and economic assessment of the R&D process and its performers” (Geisler, 1994, p. 190). This case study falls under Geisler's categorization as an input–output approach.

Geisler defines five categories for the innovation process. These categories are:

- inputs to the R&D process, immediate or direct outputs from R&D,
- intermediate outputs of R&D,
- outputs to social subsystems (preultimate), and
- ultimate outputs of R&D.

Inputs to R&D are resources and funding. Immediate outputs to R&D are "the classical output indicators that have been used to assess the "productivity" of the R&D activity .... They contain counts of patents, publications, plus other indicators" (Geisler, 1994, p. 193). Geisler's definitions suggest gross domestic product (GDP) is one indicator of ultimate outputs (Geisler, 1994, p. 195). Ultimate outputs are "things of value to the society in terms of contributing to its continued existence, its well-being, its growth, and the quality of life of its members" (Geisler, 1994, p. 193).

3. R&D data

In this section, the appropriateness and availability of the R&D input metric—R&D expenditures—and the R&D output metrics are evaluated. The R&D output metrics evaluated are: publication counts, citations to journal articles from journal articles, patent counts, citations to patents from patents, and citations to journal articles from patents. Two tables and a short summary describe the findings of the evaluation.

3.1. R&D inputs (R&D expenditures)

Federal R&D is broken up into basic research, applied research and development research. The National Science Foundation (NSF) defines each of these terms as follows.

(1) The objective of *basic research* is to gain more comprehensive knowledge or understanding of the subject under study, without a specific application in mind. In industry, basic research is defined as research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest.
(2) *Applied research* is aimed at gaining knowledge or understanding to determine the means by which a specific, recognized need may be met. In industry, applied research includes investigations oriented to discovering new scientific knowledge that has specific commercial objectives with respect to products, processes, or services.
(3) *Development* is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes (NSF 96-21, 1996).

The NSF collects this information each year from various federal agencies. The information is readily available on NSF's Internet site (National Science Foundation, Federal Funds Survey, Detailed Historical Tables, Fiscal Years 1951–1997, 1998a,b).

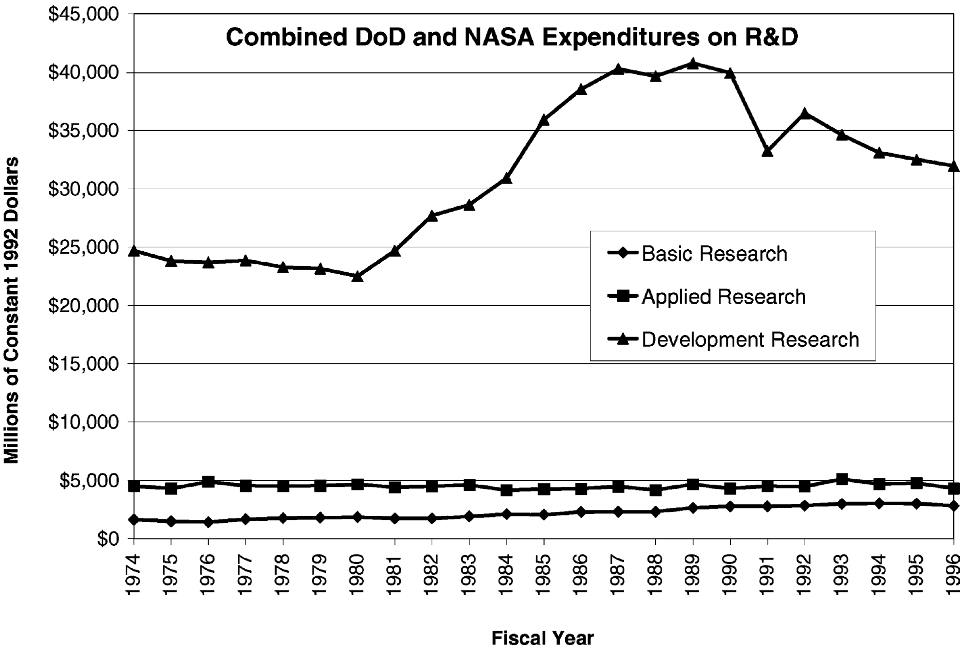


Fig. 1. Federal R&D expenditures.

The NSF data is reported in actual dollars and was converted to constant 1992 dollars to provide equitable comparison of R&D over the 22 years examined. The NSF provides easy access to 1992 deflator figures. Fig. 1 shows DoD and NASA combined expenditures in graphical form. Estimated expenditures beyond 1996 are available, but were not included restricting the study to only actual data. R&D expenditures before 1974 are available, but output data was not readily available before 1974.

3.2. R&D outputs (bibliometrics)

Measuring the outputs of R&D is a challenge. Difficulties in R&D measurement include uncertainties, multiple consequences, its cumulative nature, and transferability (Melkers, 1993, p. 44). Because evaluating the actual outputs of R&D is so difficult, bibliometrics, the study of publication-based data, serve as one often used proxy (Melkers, 1993, p. 44). Typically, publication data is used to estimate basic research outputs while patent data is used to measure “inventiveness, innovation, or technological change” (Papadakis, 1993, p. 99) or technological development (Holbrook, 1992, p. 268). As a measure of innovation or inventiveness, patents tend to measure outputs of applied research and development research.

Martin states that scientific production in basic research “refers to the extent to which this consumption of resources creates a body of scientific results. Those results are embodied both in research publications and in other types of less formal communication between scientists". Scientific progress "refers to the extent to which scientific activity results in substantive contributions to scientific knowledge". Some output indicators are linked with scientific production, but their relationship to scientific progress is less direct. Indicators of scientific progress are the critical measure for assessing the results of basic research, which is the production of new scientific knowledge (Martin, 1996, p. 347).

A number of authors assert that no one indicator is capable of measuring all aspects of R&D (Martin, 1996, p. 359; Melkers, 1993, p. 55; Pavitt, 1984, p. 22). Therefore, several partial indicators must be used for "true" R&D output (Martin and Irvine, 1983, p. 75). Five types of indicators of R&D output are considered in this study: publication counts, citations from journals articles to journals articles, patent counts, citations from patents to patents, and citations from patents to journals. Each of these types of indicators with their respective strengths and weaknesses are reviewed in the following sections.

3.2.1. Publication counts

Publication counts, the most basic of bibliometric measures, is best used to measure total research output but cannot discern the quality of these outputs (Melkers, 1993, p. 46). One problem Martin notes with publication is that publications are good measures of scientific production, but inadequate indicators of scientific progress. Most publications make only a small contribution to scientific knowledge, although a few seminal pieces make large contributions. A publications count indicator is unable to measure the quality of publication (Martin, 1996, p. 347).

Another problem noted by Martin is that publication counts reflect not only the level of scientific progress made by an individual or group, but also reflect institutional publication practices, the country of origin, research area, and emphasis on publications for obtaining research funds. Unfortunately, the variance in the publication counts due to effects other than scientific progress cannot be ignored. It is incorrect to assume the effect of scientific progress on publication counts is far greater than the effects of publication practices, country of origin, and so forth. There is also nothing to indicate the total effect of these other influences is random. Over large aggregations or periods of time, the effects cannot be canceled out (Martin, 1996, p. 348). Another problem with publication counts is each publication represents a different contribution to science. Some authors publish many papers, each representing a small contribution to science while other authors publish only a few papers representing large contributions (Martin and Irvine, 1983, pp. 65–66; Okubo, 1997, p. 24).

3.2.2. Citations to journal articles from journal articles

Melkers states that citation counts address questions of quality, influence, and transfer of knowledge. It is assumed that the most cited works contribute the most to science (Melkers, 1993, p. 47). The purpose of citation analysis is to serve as a proxy measure for the contributions to scientific progress (Martin, 1996, p. 348). "It is presumed that a paper must have a certain quality in order to have an impact on the scientific community" (Okubo, 1997, p. 25).

Some problems with citations include the count of critiques as independent works, failures to cite early works, variations of citation rates across fields and papers, and citations to an author's own work (Martin, 1996, p. 348). Some papers cite previous innovative work while other papers simply "pay homage to earlier work" (Okubo, 1997, p. 24). Other problems include highly cited elementary works (i.e. elementary statistical textbooks) and popular science which may not be critical science (Lindsey, 1989, pp. 193–195).

These and other criticisms led MacRoberts and MacRoberts to reject citation analysis. They mention a lack of sensitivity to positive and negative credit, failures of authors to cite all influences, biases, and disproportionate citing of eminent scientist verse less well known scientists as problem areas (MacRoberts and MacRoberts, 1989, p. 8). Citations are a partial indicator of scientific impact and are influenced by "communication practices, the visibility of authors, their previous work and employing institution, and so on" (Martin, 1996, p. 349).

Despite all of the problems with publication citations as a technological indicator, it is

> ... necessary to have systematic data, however imperfect, because of the tremendous variance one finds across fields, sectors, firms, countries and time in science and technology. When you have large variance, generalizing from the particular is dangerous (Pavitt, 1984, p. 21).

Although various indicators of scientific output are flawed, use of these indicators is better than using no indicators at all (Martin and Irvine, 1983, p. 75).

3.2.3. *Patent counts*

Patent counts, similar to publication counts, are the number of patents produced by an organization. Papadakis states a patent is a minimum standard of "inventive significance" and represents a base unit. Counts of patent data are counts of patents categorized by firm, type of industry, patent class, nationality of inventor, or other category (Papadakis, 1993, p. 105).

At least two problems exist with patent data. For various reasons, not all work receives a patent (Papadakis, 1993, pp. 104–105). Some patents contribute more to technology than others do (Holbrook, 1992, p. 272).

3.2.4. *Citations to patents from patents*

Narin and Olivastro note citations to patents from patents are usually the references cited to US patents on the front page of a patent package and are typically the basis for citation analysis (Narin and Olivastro, 1988, p. 471). Since patent examiners, not the inventors, write these citations, questions arise as to the validity and the completeness of the citations (Okubo, 1997, p. 27). Narin and Olivastro observe it is assumed that highly cited patents are important advances in technology. Further, most patents are rarely, if ever, cited, with very few patents being cited as many as five times (Narin and Olivastro, 1988, p. 475).

3.2.5. *Citations to journal articles from patents*

Besides referencing other patents, patents also reference journal articles. Counting the number of references to journal articles is a means of linking science to technology (Narin and Olivastro, 1988, p. 479; Okubo, 1997, p. 29). Although patent applicants need to link their inventions to scientific literature to more easily obtain patents, they also often wish to conceal the essentials of their invention. This tendency of patent applicants to conceal the essentials of their inventions may disqualify this metric as a good indicator of scientific and technological advancement (Okubo, 1997, p. 29).

3.2.5.1. Output data collection.

Data for publication counts and journal article citations used in this study were obtained from the on-line science citation index (SCI) created by the Institute for Scientific Information available at the Air Force Institute of Technology (AFIT) Technical Library. Raw data for patents was obtained from the US Patent Office Internet site. Based on the discussion above, citation data on patents, either as journal articles or other patents was not used.

Publication counts were developed by searching the SCI by country of publication (USA), subject category (aerospace engineering) and publication year. The search was limited to articles, reviews and notes. Leydesdorff believes it is arbitrary to exclude notes, letters and other article types (Leydesdorff, 1989, p. 113), but SCI sells bibliometric indicators and provides data as articles, reviews, notes and conference proceedings (Institute for Scientific Research, Users Manual: National Science Indicators on Diskette, 1981–1997, Section 3.2).

Following Leydesdorff's recommendation, the year for the publication counts was developed using SCI database accession number rather than using publication year (Leydesdorff, 1989, p. 113). Journal citation counts were performed similarly to journal counts, except publication year was used.

The citation data shows a dramatic downturn starting in 1991 and beyond. This downward trend is assumed to be because more recent works will be cited in the future. Publication data and the citation data before 1990 appear to be correlated. These observations will be revisited later in Section 6.

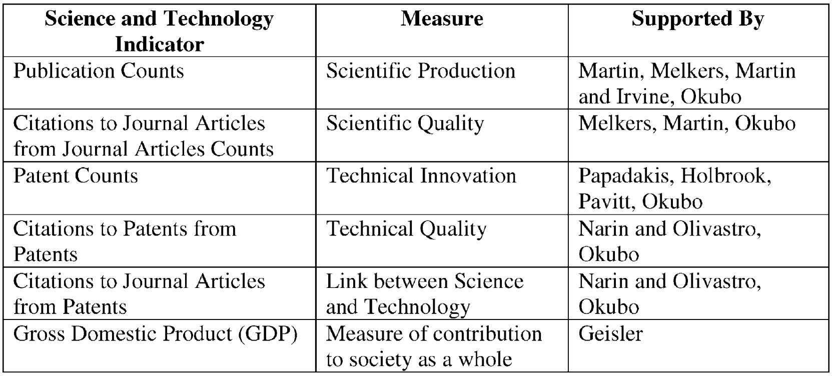
Patent counts come from the US Patent Office and are shown in (US Patent and Trademark Office, 1997). The Aeronautics patent class number is 244, and is defined on the web site. The definition of Aeronautics includes "machines or structures adapted to be completely or partially sustained by the air," and "machines or structures adapted to be placed in an orbit or which substantially operate outside the earth's atmosphere" (US Patent and Trademark Office, Patent Class Definitions, 6 July 1998).

3.2.6. Summary of input and output data

Fig. 2 summarizes the science and technology indicators examined in this study and how they are used. As stated earlier, not all of the indicators were used because data was not available in time to complete the study. Fig. 3 summarizes actual data sources used in the study and the sources of the information. All data sources except the citation and publication data are readily available to any user of the Internet. Generation of publication and citation data requires access to a technical library.

4. Time lags between R&D input and R&D output

Clearly, it takes time to perform research and publish results in journals or apply for patents. Depending upon the discipline, it often can take 2 years or more to publish a journal article once it is written. Similarly, the patent process has several formal and informal steps that must occur before a patent is issued (Miller and Davis, 1990, pp. 99–123).

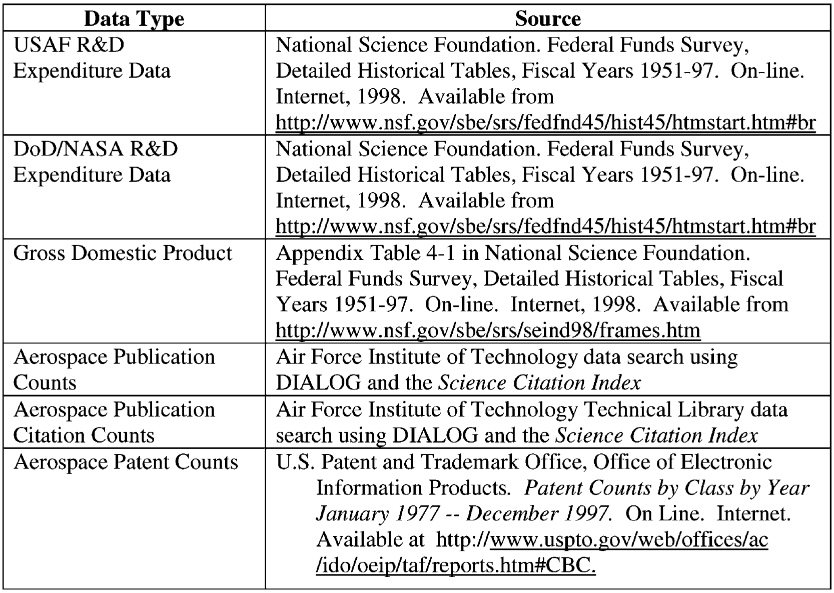


Science and Technology Indicator	Measure	Supported By
Publication Counts	Scientific Production	Martin, Melkers, Martin and Irvine, Okubo
Citations to Journal Articles from Journal Articles Counts	Scientific Quality	Melkers, Martin, Okubo
Patent Counts	Technical Innovation	Papadakis, Holbrook, Pavitt, Okubo
Citations to Patents from Patents	Technical Quality	Narin and Olivastro, Okubo
Citations to Journal Articles from Patents	Link between Science and Technology	Narin and Olivastro, Okubo
Gross Domestic Product (GDP)	Measure of contribution to society as a whole	Geisler

Fig. 2. Science and technology indicators.

The average time to perform research is not accounted for in the journal publication time or the patent application time. Another known lag in the data is the difference between calendar year and fiscal year for some of the data. The R&D input data (R&D expenditures) is in fiscal years while the output data is in calendar years, resulting in an automatic 3-month lag.

To analyze lags in the data, R&D expenditure data was lagged from 1 to 5 years. This caused a reduction of up to five points. While a reduction in points reduces the power of the analysis and could contribute to autoregressive errors, it is clear that R&D expendi-



Data Type	Source
USAF R&D Expenditure Data	National Science Foundation. Federal Funds Survey, Detailed Historical Tables, Fiscal Years 1951-97. On-line. Internet, 1998. Available from http://www.nsf.gov/sbe/srs/fedfnd45/hist45/htmstart.htm#br
DoD/NASA R&D Expenditure Data	National Science Foundation. Federal Funds Survey, Detailed Historical Tables, Fiscal Years 1951-97. On-line. Internet, 1998. Available from http://www.nsf.gov/sbe/srs/fedfnd45/hist45/htmstart.htm#br
Gross Domestic Product	Appendix Table 4-1 in National Science Foundation. Federal Funds Survey, Detailed Historical Tables, Fiscal Years 1951-97. On-line. Internet, 1998. Available from http://www.nsf.gov/sbe/srs/seind98/frames.htm
Aerospace Publication Counts	Air Force Institute of Technology data search using DIALOG and the *Science Citation Index*
Aerospace Publication Citation Counts	Air Force Institute of Technology Technical Library data search using DIALOG and the *Science Citation Index*
Aerospace Patent Counts	U.S. Patent and Trademark Office, Office of Electronic Information Products. *Patent Counts by Class by Year January 1977 -- December 1997.* On Line. Internet. Available at http://www.uspto.gov/web/offices/ac/ido/oeip/taf/reports.htm#CBC.

Fig. 3. Data types and their sources.

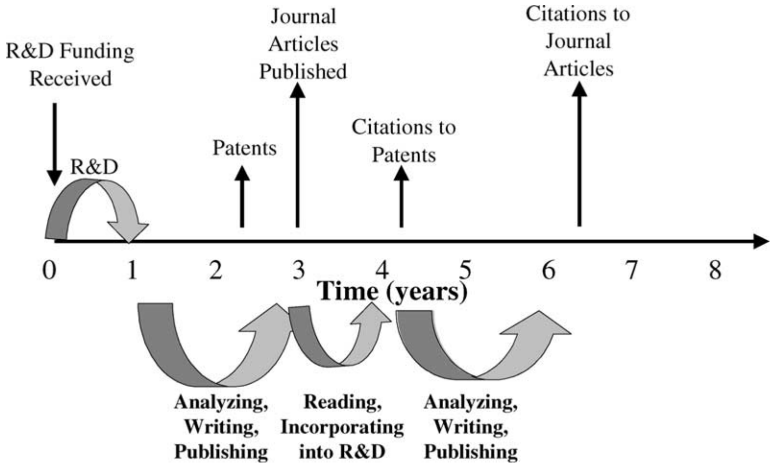


Fig. 4. example of possible lags of R&D advancement metrics compared to R&D funding received.

tures do not result in instantaneous scientific output. This lag effect must be allowed in the model.

4.1. *Publication citations analysis*

Close examination of the data caused the authors to suspect a relationship exists between aerospace publications and aerospace citations. Another concern was the drop in the citation count from 1990 to 1996. The downward trend observed is assumed to be primarily due to the lag in citations (see Fig. 4). Current and lagged aerospace publications were regressed with publication citations. A high correlation was found ($R^2 = 0.97$), with multicollinearity and autoregressive errors present in the regression. Because of the down trend in the recent citation data, the high correlation between publications and citations, the autoregressive errors of regressing the data, the known problems with citation data as cited in the literature earlier, and the small amount of useable data, this data was dropped from further consideration.

5. Multivariate data analysis

Tijssen and de Leeuw observed that statistical methods are being used more and more to analyze bibliometric data. Multivariate analysis (MVA) methods are being used because of the need to draw statistical inferences “of quantitative data which consists of more than one distinct measurement (hereafter referred to as a variable) on each analysis unit” (Tijssen and de Leeuw, 1988, p. 708).

As Tijssen and de Leeuw note, most bibliometric analyses performed use non-experimental data. “If a bibliometric study focuses on the association between (two or more) sets of variables, say between a set of scientific input and bibliometric output variables, one can speak of the dependence-approach”. Three questions can be researched in the "dependence-approach: determining the degree of relationship among separate variables, determining the significance of differences between variables, and prediction of the variable-values based on values of other variables" (Tijssen and de Leeuw, 1988, p. 711).

Following Tijssen and de Leeuw's suggestion, this study has used multivariate techniques to study the relationship between defense and space expenditures. As evident from the review of the literature, there is no *single*, accepted measure for national scientific advancement. For this reason, a serious of proxies have been analyzed. These will be investigated individually using linear regression and then collectively, using canonical correlation. While correlation is not causation, it does provide insight if a relationship exists. A series of analyses was conducted for this study. Due to space limitations, only key findings are reported in this article. The software used for the analyses was SAS JMP version 3.2.1, run on a Pentium 200 MHz processor.

6. Analysis

Each test is discussed later. In some cases, multicollinearity created problems in the models. Multicollinearity was detected by examining the correlation matrices and by examining the variance inflation factor, VIF (Neter et al., 1996). Factor analysis was implemented to mitigate the problem, except when only one component was significant. In that case, a composite measure was made from the multicollinear variables. The factors found were then regressed rather than regressing the multicollinear variables.

The R&D expenditure data for USAF and for DoD/NASA was lagged in 1-year increments. The immediate output variables and GDP were not lagged, except with the citation data discussed later.

6.1. Analysis of basic research

The hypothesis for this first analysis is that basic research expenditures should be highly related to national aerospace basic research output. Journal article publication counts and journal article citations are used as proxies of basic research output.

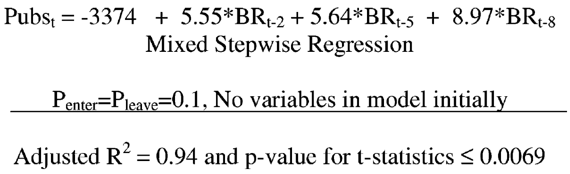
To determine if a relationship exists between USAF or DoD/NASA basic research expenditures and national aerospace technology advancement, the following general model is proposed:

$$\mathrm{Pubs}_t = \beta_0 + \beta_1 * \mathrm{BR}_t + \beta_2 * \mathrm{BR}_{t-1} + \beta_3 * \mathrm{BR}_{t-2} + \cdots + \beta_n * \mathrm{BR}_{t-(n-1)} + \varepsilon_t$$

where Pubs_t is the number of aerospace publications published in year t, BR_t the dollars spent by either USAF or DoD/NASA in year t, β_j the regression parameter, and ε_t is the residuals.

6.1.1. USAF basic research vs. national aerospace publications

USAF basic research variable expenditures, with 8 lags were stepwise regressed against national aerospace publications. It should be noted that not all of the USAF basic research funds are expended on aerospace issues. No attempt was made to adjust for this fact,



$$Pubs_t = -3374 + 5.55{*}BR_{t-2} + 5.64{*}BR_{t-5} + 8.97{*}BR_{t-8}$$

Mixed Stepwise Regression

$P_{enter}=P_{leave}=0.1$, No variables in model initially

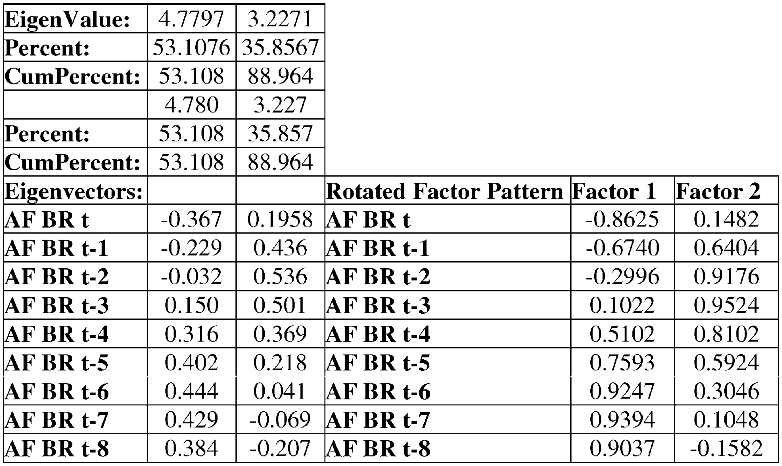
Adjusted $R^2 = 0.94$ and p-value for t-statistics ≤ 0.0069

Fig. 5. USAF basic research expenditures (with lags) vs. national aerospace publications.

however. A mixed, stepwise regression was conducted, allowing variables to enter and leave the model, with no variables initially in the model. The probability to enter and probability to leave the model were both set to 0.1. The results are shown in Fig. 5.

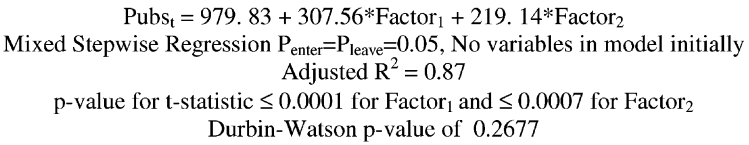
The R^2 of the resulting equation is 0.987 (adjusted R^2 of 0.943) with USAF basic research expenditures lagged 2, 5 and 8 years entering the stepwise regression as significant variables. Both the t- and F-tests indicate a significant relationship. Results of the Durban–Watson test had a P-value of 0.1825 showing failure to detect significant autoregressive error. However, multicollinearity, as measured by VIF, is a problem, although not severely so.

Due to the correlation between variables, factor analysis was performed. The results for the unrotated eigen values greater than or equal to one and the loadings for a factor analysis, conducted with an orthogonal VARIMAX rotation, are shown in Fig. 6. Examination of the factor analysis loadings shows factor 1 emphasizes the initial and final years of basic research investment while factor 2 emphasizes the middle years of USAF basic research investment. The regression of the rotated factors against publications is shown in Fig. 7. The R^2 of the resulting equation is 0.894 (adjusted R^2 of 0.870) with both of USAF basic research expenditures' two factors entering the stepwise regression as significant variables. Both the t- and F-tests indicate a significant relationship. The P-value for the Durbin–Watson test was 0.27, which indicates there is not enough evidence to reject the null hypothesis that the



EigenValue:	4.7797	3.2271			
Percent:	53.1076	35.8567			
CumPercent:	53.108	88.964			
	4.780	3.227			
Percent:	53.108	35.857			
CumPercent:	53.108	88.964			
Eigenvectors:			**Rotated Factor Pattern**	**Factor 1**	**Factor 2**
AF BR t	-0.367	0.1958	**AF BR t**	-0.8625	0.1482
AF BR t-1	-0.229	0.436	**AF BR t-1**	-0.6740	0.6404
AF BR t-2	-0.032	0.536	**AF BR t-2**	-0.2996	0.9176
AF BR t-3	0.150	0.501	**AF BR t-3**	0.1022	0.9524
AF BR t-4	0.316	0.369	**AF BR t-4**	0.5102	0.8102
AF BR t-5	0.402	0.218	**AF BR t-5**	0.7593	0.5924
AF BR t-6	0.444	0.041	**AF BR t-6**	0.9247	0.3046
AF BR t-7	0.429	-0.069	**AF BR t-7**	0.9394	0.1048
AF BR t-8	0.384	-0.207	**AF BR t-8**	0.9037	-0.1582

Fig. 6. Regression of rotated USAF basic research factors and national aerospace publications.



$\text{Pubs}_t = 979.83 + 307.56{*}\text{Factor}_1 + 219.14{*}\text{Factor}_2$

Mixed Stepwise Regression $P_{enter}=P_{leave}=0.05$, No variables in model initially

Adjusted $R^2 = 0.87$

p-value for t-statistic ≤ 0.0001 for Factor_1 and ≤ 0.0007 for Factor_2

Durbin-Watson p-value of 0.2677

Fig. 7. Regression of rotated USAF basic research factors and national aerospace publications.

factors are not auto correlated. The normality assumption for residuals held and the model was found to be significant.

The conclusion is USAF basic research expenditures strongly correlate with national aerospace R&D science production, as measured by aerospace publications.

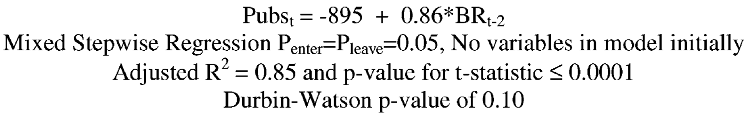
6.1.2. *DoD/NASA vs. national aerospace publications*

DoD/NASA basic research expenditures with lags was stepwise regressed against national aerospace publications. A mixed, stepwise regression was again conducted, allowing variables to enter and leave the model, with no variables in the model at the start. The probability to enter and probability to leave the model were both set to 0.05. The results are shown in Fig. 8. Only one variable (a 2-year lag on basic research expenditures) was found to be statistically significant. It should be noted that the DoD/NASA expenditures would include not only the USAF expenditures, but also the Army, Navy, and Marine basic research expenditures. These expenditures are for *all* basic research, not just aerospace expenditures. The coefficient of determination ($R^2 = 0.86$, adjusted $R^2 = 0.85$) was quite high. An analysis of residuals failed to reject the hypothesis of normality. Autoregressive error was not identified as a problem from the Durbin–Watson test with a P-value of 0.095. The conclusion is DoD/NASA basic research expenditures strongly correlate with national aerospace R&D science production, as measured by aerospace publications.

6.2. *USAF and DoD/NASA applied/development research vs. national aerospace patents*

As previously discussed, patent counts are considered a proxy for innovative activity. It is postulated that applied research and development research expenditures are related to aerospace technology advancement. The hypothesis for this test is given as follows.

H_0. Aerospace innovation is not related to USAF or DoD/NASA applied and development research expenditures.



$\text{Pubs}_t = -895 + 0.86{*}\text{BR}_{t-2}$

Mixed Stepwise Regression $P_{enter}=P_{leave}=0.05$, No variables in model initially

Adjusted $R^2 = 0.85$ and p-value for t-statistic ≤ 0.0001

Durbin-Watson p-value of 0.10

Fig. 8. DoD/NASA basic research expenditures vs. national aerospace publications.

$\text{Pats}_t = -3374 + 0.015*\text{DR}_{t-1}$
Mixed Stepwise Regression $P_{\text{enter}}=P_{\text{leave}}=0.1$, No variables in model initially
Adjusted $R^2 = 0.7$ and p-value for t-statistic ≤ 0.03
Durbin-Watson p-value of 0.6

Fig. 9. USAF applied and development research expenditures vs. patents.

H$_a$. Aerospace innovation is related to USAF or DoD/NASA applied and development research expenditures.

The proposed model for testing this possible relationship is as follows:

$$\begin{aligned}\text{Pat}_t &= \alpha_0 + \alpha_1 * \text{AR}_t + \alpha_2 * \text{AR}_{t-1} + \alpha_3 * \text{AR}_{t-2} + \cdots + \alpha_6 * \text{AR}_{t-5} + \beta_1 * \text{DR}_t \\ &\quad + \beta_2 * \text{DR}_{t-1} + \beta_3 * \text{DR}_{t-2} + \cdots + \beta_6 * \text{DR}_{t-5} + \varepsilon_t\end{aligned}$$

where Pat_t is the number of aerospace patents counted in year t, AR_t the applied research in year t, DR_t the developmental research in year t, α_i and β_j are the regression parameters, and ε_t is the residuals.

USAF applied/development research expenditures with lags were stepwise regressed against national aerospace patents. Only one variable was found to be statistically significant. Fig. 9 shows the results. The coefficient of determination (R^2) was high and an analysis of residuals failed to reject the hypothesis of normality. The conclusion is development research expenditures strongly correlate with national aerospace R&D innovation, as measured by aerospace patents, and the lag of the developmental expenditures is less than the lag found for basic research expenditures.

DoD/NASA applied/development research expenditures with lags were stepwise regressed against national aerospace patents. Only one variable was found to be statistically significant. Fig. 10 shows the results. The coefficient of determination (R^2) was again high and analysis of residuals failed to reject the hypothesis of normality. The analysis also showed the non-zero intercept to be insignificant. Fig. 10 shows the regression results. The conclusion is that development research expenditures is also strongly correlated with national aerospace R&D innovation, as measured by aerospace patents.

6.3. *USAF R&D expenditures vs. GDP*

GDP, an ultimate national output of R&D, especially for an economy that depends upon cutting edge technology, may be used as a single composite indicator of the outputs of R&D.

$\text{Pats}_t = 0.0079*\text{DR}_t$
Mixed Stepwise Regression $P_{\text{enter}}=P_{\text{leave}}=0.1$, No variables in model initially, no intercept
Root Mean Square Error = 42.44 and p-value for t-statistic ≤ 0.0001
Durbin-Watson p-value of 0.29

Fig. 10. DoD/NASA applied and development research expenditures vs. patents with no intercept.

If government R&D expenditures are highly correlated to GDP, then a link has been found between funding of technology advancement and the national effort. The change in GDP from year to year or change in Government technology policy could, in part, be related to the change in government R&D expenditures. Hence, this model would link changes in government technology policy to the national effort. It is paramount to identifying US national technology policy as it relates to aerospace. The hypothesis is given as follows.

H_0. ΔGDP is not related to USAF or DoD/NASA R&D changes in expenditures.

H_a. ΔGDP is related to USAF or DoD/NASA R&D changes in expenditures.

The proposed model for testing this possible relationship is given as follows:

$$\begin{aligned}\Delta\mathrm{GDP}_t = {} & \alpha_0 + \alpha_1 * \Delta\mathrm{BR}_t + \alpha_2 * \Delta\mathrm{BR}_{t-1} + \alpha_3 * \Delta\mathrm{BR}_{t-2} + \cdots + \alpha_6 * \Delta\mathrm{BR}_{t-5} \\ & + \beta_1 * \Delta\mathrm{AR}_t + \beta_2 * \Delta\mathrm{AR}_{t-1} + \beta_3 * \Delta\mathrm{AR}_{t-2} + \cdots + \beta_6 * \Delta\mathrm{AR}_{t-5} \\ & + \delta_1 * \Delta\mathrm{DR}_t + \delta_2 * \Delta\mathrm{DR}_{t-1} + \delta_3 * \Delta\mathrm{DR}_{t-2} + \cdots + \delta_6 * \Delta\mathrm{DR}_{t-5} + \varepsilon_t\end{aligned}$$

where $\Delta\mathrm{GDP}_t$ is the difference between gross domestic product in year t and year $t-1$, $\Delta\mathrm{BR}_t$ the difference between basic research in year t and year $t-1$, $\Delta\mathrm{AR}_t$ the difference between applied research in year t and year $t-1$, $\Delta\mathrm{DR}_t$ the difference between development research in year t and year $t-1$, α, β, and δ are the regression parameters, and ε is the residual.

The change in USAF R&D with lags was stepwise regressed against the change in GDP. All basic research (unlagged and 5 lagged years), applied research (unlagged and 5 lagged years), and three development research (unlagged and 2 lagged years) variables were initially entered into the stepwise regression. The stepwise regression was implemented in the mixed mode with probability of entering variable set to 0.1 and the probability of leaving variable set to 0.015. Fig. 11 shows the results. The coefficient of determination ($R^2 = 0.957$, adjusted $R^2 = 0.901$) was high. The VIF number indicates some cause for concern for multicollinearity, but all values are below the minimum criteria where severe effects would be experienced on the regression process. The Durbin–Watson test failed to reject the hypothesis that autocorrelation is not present (P-value $= 0.17$). This suggests that there is a relationship between the changes in GDP and changes in USAF R&D expenditures on basic, applied and developmental research. This result, while from a small sample, could have implications to future funding issues.

$$\begin{aligned}\Delta\mathrm{GDP}_t = 70.16 - 6.18{*}\Delta\mathrm{BR}_t + 9.05{*}\Delta\mathrm{BR}_{t-3} - 14.56{*}\Delta\mathrm{BR}_{t-4} + 2.73{*}\Delta\mathrm{BR}_{t-5} - 1.97{*}\Delta\mathrm{AR}_t \\ - 2.63{*}\Delta\mathrm{AR}_{t-1} - 2.53{*}\Delta\mathrm{AR}_{t-3} - 0.05{*}\Delta\mathrm{DR}_t + 0.13{*}\Delta\mathrm{DR}_{t-1}\end{aligned}$$

Mixed Stepwise Regression P_{enter}=0.1 P_{leave}=0.015
Most Variables up to 5 lags entered into model
Adjusted R^2 = 0.9 and p-value for t-statistic ≤ 0.0069
Durbin-Watson p-value of 0.18

Fig. 11. Change in USAF R&D expenditures vs. change in GDP.

$$\Delta GDP_t = 62.10 + 0.86*\Delta BR_t + 0.56*\Delta BR_{t-1} - 0.26*\Delta AR_{t-4} - 0.038*\Delta DR_{t-5}$$

Mixed Stepwise Regression $P_{enter}=0.1$ $P_{leave}=0.1$
Most Variables up to 5 lags entered into model
Adjusted $R^2 = 0.9$ and p-value for t-statistic ≤ 0.0066
Durbin-Watson p-value of 0.34

Fig. 12. Change in DoD/NASA R&D expenditures vs. change in GDP.

6.3.1. *DoD and NASA expenditures vs. GDP*

The change in DoD/NASA R&D with lags was stepwise regressed against the change in GDP. Four basic research (1, 2, 5 and no years of lags) variables, two applied research (1 and no years of lags) variables, and two development research (1 and no years of lags) variables were initially entered into the stepwise regression. The stepwise regression was implemented in the mixed mode with probability of entering the variable set to 0.1 and the probability of leaving the variable set to 0.1. Fig. 12 shows the results of regressing the resulting variables. The VIF's indicate little multicollinearity with all values below the minimum criteria. The Durbin–Watson test failed to reject the hypothesis that autocorrelation is not present (P-value $= 0.3369$). The conclusion is there is a relationship between the changes in GDP and changes in DoD/NASA R&D expenditures.

6.4. *Composite measure*

Finally, it is postulated that government R&D expenditures affect national aerospace technology advancement when measured by composite factors for both input and output. Because multiple input variables and multiple output variables exist, a canonical correlation analysis (CCA) was conducted. The object of canonical correlation is to "find linear combinations $\eta = \boldsymbol{a}^{\mathrm{T}}\boldsymbol{x}$ and $\phi = \boldsymbol{b}^{\mathrm{T}}\boldsymbol{y}$ such that η and ϕ have the largest possible correlation" (Mardia et al., 1979, p. 281). In this case, the vector $\boldsymbol{x}$ represents the input variables (Government R&D expenditures) and the vector $\boldsymbol{y}$ represents the output variables (science and technology indicators).

6.4.1. *Composite USAF expenditures and national science output*

CCA was used to determine if a relationship exists between USAF R&D expenditures and the combined national R&D aerospace outputs. CCA was first performed using a 5-year lag. The Wilks' lambda test was used to identify significant variables to be used in the CCA. The test measures the dispersion between two groups. The larger the dispersion between groups the smaller the value for of the parameter, which implies greater significance. The Wilks' lambda test can be approximated by an F-distribution (Hair et al., 1992, p. 161). The 5-year lag met the Wilks' lambda criteria with a P-value of 0.01 or better for all values. Results are as shown in Fig. 13.

The canonical correlation for both variates is significant. The high canonical correlation on both variates (0.947 and 0.833, respectively), suggests USAF R&D expenditures are highly related to National R&D aerospace outputs as represented by the composite measures created by the canonical variates.

	Variate 1	**Variate 2**
EigenValue	8.60	2.28
Canonical Corr	0.95	0.83
Pub t	0.0019	-0.00067
Pats	0.0028	0.0074
AF BR t-5	0.021	0.0094
AF AR t	-0.0034	0.011
AF DR t	0.000063	0.00016

Fig. 13. CCA for USAF expenditures with aerospace publications and patents with lags.

A comparison of the variates allows identification of what each variate represents. Basic research lagged 5 years loaded twice as much in variate 1 as it loaded in variate 2. Similarly, applied research and development research loaded much more than to variate 2 than variate 1. Aerospace publications loaded more in variate 1 than variate 2 and aerospace patents loaded far more in variate 2 than variate 1. The conclusion is variate 1 refers mostly to basic research while variate 2 refers to applied and development research.

6.4.2. Composite DoD and NASA expenditures and national science output

CCA was also used to determine if a relationship exists between DoD/NASA R&D expenditures and the National R&D aerospace outputs. Based on previous regression, basic research lagged 2 years and development research not lagged was modeled with publications and patents. The analysis met Wilks' lambda criteria and can be seen in Figs. 13 and 14. The canonical correlation for both variates is significant. With high canonical correlation on both variates, the conclusion of this test is DoD/NASA R&D expenditures are highly correlated to national R&D aerospace outputs as represented by publications and patents.

A comparison of the variates allows identification of what each variate represents. Basic research lagged 2 years loaded over twice as much in variate 1 as it loaded in variate 2. Similarly, development research loaded over five times in variate 2 than variate 1. Aerospace publications loaded more in variate 1 than variate 2 and aerospace patents loaded more in variate 2 than variate 1. The conclusion is variate 1 refers mostly to basic research while variate 2 refers to applied and development research.

	Variate 1	**Variate 2**
EigenValue	7.16	0.93
Canonical Corr	0.94	0.69
Pub t	0.0016	-0.00060
Pats	0.0025	0.0053
AF BR t-2	0.0015	-0.00069
AF DR t	0.000013	0.000072

Fig. 14. CCA for DoD/NASA expenditures with lagged aerospace publications and patents.

7. Conclusions

While we must again state that correlation is not causation, this case study has shown a strong relation exists between government R&D expenditures for the USAF and the aerospace industry. A strong relationship was also found between DoD/NASA R&D expenditures and the aerospace industry. A number of input and output measures were used as proxies for these factors. A composite measure was also developed using canonical correlation analysis. This relationship between the proxy measures of scientific output and federal government R&D expenditures suggests that recent decreases in federal funding *could* have a marked impact on national technological advancement. Of course, the actual outcome will depend upon what other funding sources begin to fill the void left by the reduction in national level funding. More study is required.

The results presented here suggest several areas for future research. A more detailed break down of expenditures would be desirable. A comparison with other industrial sectors would be important to see if these results hold. In addition, the well-known multiplier effect for government expenditures has not been considered. Additional research is needed to understand how to apply citation data from publications at the aggregate level and also additional citation data from patents could improve the analysis.

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