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To What Extent did Demand and Supply Side Factors Influence Corporate R&D Expenditure in the US Aerospace and Defence Industry in 1970-2000?

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Abstract

Given the importance of R&D on productivity growth and the overall economy, the determinants of R&D have long been debated by scholars. Both demand side factor, namely government R&D procurements, and supply side factor, such as cost and availability of internal and external financing, could impact the firms' R&D intensity. This study regressed on a panel of 13 firms from an R&D and technology intensive industry, the Aerospace and Defence sector, in the US in 1970-2000. This essay concludes that firstly, demand side factor stimulated industrial research expenditure significantly. Particularly, in 1970-2000, every $1 government R&D contract leads to $0.05 higher R&D expenditure for the contractor in the corresponding year. Specifically, looking at decade segregated data, $1 extra government R&D contract awarded associates with $0.03 and $0.11 additional R&D expenditure from the contractor in 1980s and 1990s respectively. Furthermore, non-competitive R&D contracts are more effective in incentivizing private research outlays than competed contracts. Secondly, internal financing availabilities are influential to R&D, as $1 higher previous year cash holding associates with $0.1 higher R&D expenditure, and 1$ higher interest commitments leads to $0.09 lower R&D spending. In contrast, external cost of financing and investment opportunities had insignificant relationship with corporate R&D.

1.Introduction: Trend of US R&D and federal R&D procurement

R&D expenditure is particularly important to economic growth as it contribute to the firms' productivity growth.[1] As estimated by Griliches using a dataset of 911 firms in 1966-1977, the growth rate of R&D expenditure has a statistically significant 0.107 coefficient to the firms' productivity growth.[2] This implies that industrial R&D is critical in promoting productivity growth in the industry.

[1] Zvi Griliches, "Productivity, R&D, And Basic Research At The Firm Level In The 1970s." NBER Working Paper Series, no. 1547(1985): 1-27, doi: 10.3386/w1547, 23.

[2] Zvi Griliches, "Productivity, R&D, And Basic Research At The Firm Level In The 1970s." NBER Working Paper Series, no. 1547(1985): 1-27, doi: 10.3386/w1547, 32.

Furthermore, the benefits of high R&D may not be limited to the corresponding sector itself. For example, there could be second-order effects of increased aerospace industry R&D expenditure on productivity growth in the downstream industries, such as the airline industry.[3] Thus, it's clear that high R&D investment is an important contributor to overall economic growth by improving productivity.

Given the importance of R&D, the second half of 20th century has witnessed steady and continuous increase in total R&D spending in the US.[4] Particularly after 1970s, there's a nearly two-fold increase in the total value of industrial private R&D outlays from around 25 billion to over 40 billion in 1982 dollars in 1972-1987.[5] Especially in the late 1970s and early 1980s, there's a 7% annual real rate of growth in corporate R&D expenditure in the US.[6] Thus, the dollar values of total R&D spending had an upward trend after 1970s, as also evident in Graph 1.[7]

[3] Nestor E. Terleckyj. "Measuring Economic Effects of Federal Research and Development Expenditures: Recent history with Special Emphasis on Federal R&D Performed in Industry" in Papers Commissioned for a Workshop on the Federal Role in Research and Development. ed. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 151-172 (Washington, DC: The National Academies Press, 1985). https://doi.org/10.17226/942., 154

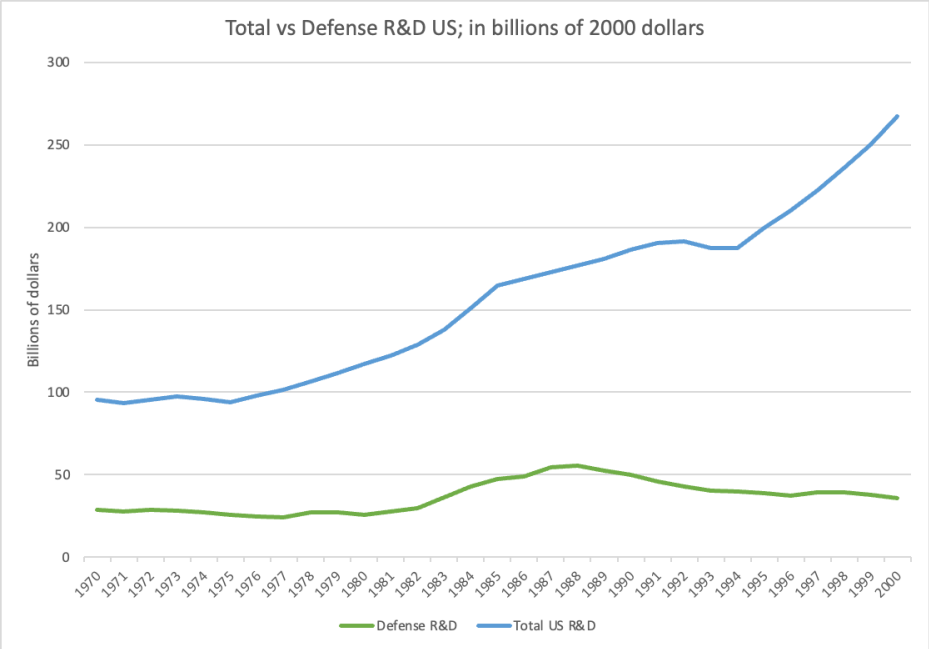
[4] Ngo, Phong T. H., and Jared Stanfield. "Does Government Spending Crowd Out R&D Investment? Evidence from Government-Dependent Firms and Their Peers." *Journal of Financial and Quantitative Analysis* 57, no. 3 (2022): 888–922. doi:10.1017/S0022109020000927., p889

[5] Hall, Bronwyn H., Ernst Berndt, and Richard C. Levin. "The Impact of Corporate Restructuring on Industrial Research and Development." Brookings Papers on Economic Activity. Microeconomics 1990 (1990): 85–135. https://doi.org/10.2307/2534781., 91.

[6] Hall, Bronwyn H., Ernst Berndt, and Richard C. Levin. "The Impact of Corporate Restructuring on Industrial Research and Development." Brookings Papers on Economic Activity. Microeconomics 1990 (1990): 85–135. https://doi.org/10.2307/2534781., 91.

[7] Michael Brzoska, "Trends in Global Military and Civilian Research and Development (R&D) and their Changing Interface", (2006): 1-25, https://ifsh.de/pdf/aktuelles/india_brzoska.pdf, 9.

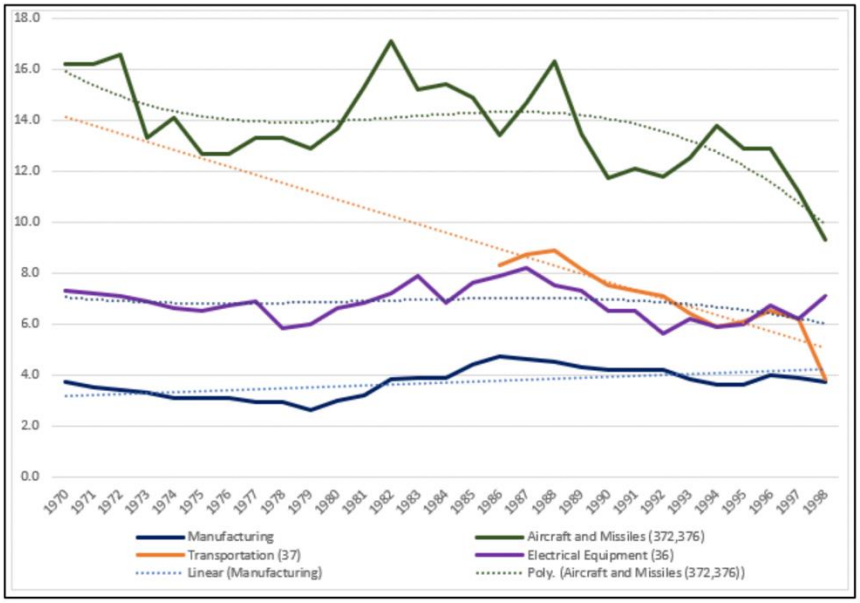
Graph 1[8]



Within the total US R&D, the proportion attributed to aerospace and defence industry is consistently significant. As evident in Graph 1, although the percentage of defence-related R&D to total R&D steadily declined, the absolute level of defence R&D was relatively stable, and it maintained over 13% of annual US R&D in 1970-2000.[9] The high R&D intensity in aerospace and defence related companies is also evident from comparison with other industries, as the industry consistently has higher percentage of R&D expenditure to total net sales than manufacturing, electrical equipment and transportation (Graph 2).[10] Thus, it's reasonable to state that aerospace and defence industry is traditionally a high-R&D sector.

[8] Graph created from data in: Michael Brzoska, "Trends in Global Military and Civilian Research and Development (R&D) and their Changing Interface", (2006): 1-25, https://ifsh.de/pdf/aktuelles/india_brzoska.pdf, 9-10.
[9] Calculated from data in: Michael Brzoska, "Trends in Global Military and Civilian Research and Development (R&D) and their Changing Interface", (2006): 1-25, https://ifsh.de/pdf/aktuelles/india_brzoska.pdf, 9-10.
[10] NPS Acquisition Research Program, "Volume I: Acquisition Research: Creating Synergy for Informed Change", Proceedings of the fifteenth annual acquisition research symposium SYM-AM-18-070 (2018): 631-647. https://nps.edu/documents/105938399/111460142/SYM-AM-18-032.pdf/52366b38-59f8-4e6d-9514-75c129592e81?version=1.0, 636

Graph 2[11]



When dissecting the driving forces behind the R&D in Aerospace and Defence sector, government demand on R&D projects has long been an important input.[12] Especially under the pursuit for superweapons during the Cold War, R&D was consistently emphasized by the US government.[13] The importance of federal funds to R&D in Aerospace and Defence is further illustrated by the fact that government funded R&D has occupied over 70% of total R&D in the industry in 1970-1988.[14] Thus, it's clear that government inputs were of particular importance for R&D in aerospace and defence.

Although public procurement has shown consistent contribution to R&D in the Aerospace and Defence industry, due to the significant growth in private

[11] NPS Acquisition Research Program, "Volume I: Acquisition Research: Creating Synergy for Informed Change", Proceedings of the fifteenth annual acquisition research symposium SYM-AM-18-070 (2018): 631-647. https://nps.edu/documents/105938399/111460142/SYM-AM-18-032.pdf/52366b38-59f8-4e6d-9514-75c129592e81?version=1.0, 636

[12] Keith Hartley, Aerospace: The Political Economy of an Industry. In: Progress in Intercalation Research, ed. Müller-Warmuth, W., Schöllhorn, R. (Springer, Dordrecht, 1993): 307-335. https://doi.org/10.1007/978-94-011-1733-3_11, 307

[13]JOHN A. ALIC. "Managing US Defense Acquisition." Enterprise & Society 14, no. 1 (2013): 1–36. http://www.jstor.org/stable/23701646., 25

[14] Economic Data Service, Aerospace Research Center, Aerospace Industries Association of America, Aerospace Facts And Figures 1980/1981. (Washington DC: McGraw-Hill, 1980), 1-160, 101; Economic Data Service, Aerospace Research Center, Aerospace Industries Association of America, Aerospace Facts And Figures 1990/1991. (Washington DC: MCGRAW-HILL, 1990), 1-178, 104

research outlays, private R&D has gained prominence against public R&D.[15] Specifically, the proportion of federal funded R&D in overall US R&D expenditures has declined from 65% in 1960 to 21% in 2019, and the proportion of private sector R&D has increased from 33% to 71%.[16] Consequently, the private sector has taken up a greater role in financing their R&D activities among the total US research expenditure.[17] This increasing role of private sector in R&D might imply that factors in the business environment potentially are also influencing the industrial R&D outlays. For example, the change in interest rates, exchange rates and oil prices in 1990s likely induced a favourable environment for equity financing and higher cash holdings, which possibly led to the R&D boom in the decade.[18] Thus, given the increased role of private sector in R&D, changes in supply side factors could also be critical for corporate R&D expenditure.

The importance of R&D, the steady government input for R&D, and the increasing prominence of private R&D outlays justifies the importance to investigate the influential factors that determines the corporate R&D levels. However, many literatures have focused on either assessing the role of procurement on R&D or the impact of financial environment individually instead of considering both factors simultaneously.[19] Additionally, many has focused on a shorter time span and utilized aggregate instead of firm-level data.[20] Thus, this

[15] John F. Sargent Jr., Marcy E. Gallo, "The Global Research and Development Landscape and Implications for the Department of Defense", The Global Context for Research and Development and Implications for the DOD (2021): 1-34., Summary
[16] John F. Sargent Jr., Marcy E. Gallo, "The Global Research and Development Landscape and Implications for the Department of Defense", The Global Context for Research and Development and Implications for the DOD (2021): 1-34, Summary
[17] John F. Sargent Jr., Marcy E. Gallo, "The Global Research and Development Landscape and Implications for the Department of Defense", The Global Context for Research and Development and Implications for the DOD (2021): 1-34, Summary
[18] Brown, James R., Steven M. Fazzari, and Bruce C. Petersen. "Financing Innovation and Growth: Cash Flow, External Equity, and the 1990s R&D Boom." The Journal of Finance 64, no. 1 (2009): 151–85. http://www.jstor.org/stable/20487966, 152, 158
[19] See demand side: Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152.; See supply side: Hall, Bronwyn H. "The Financing Of Research And Development." Oxford Review of Economic Policy 18, no. 1 (2002): 35–51. http://www.jstor.org/stable/23606869
[20] See macro analysis: Nestor E. Terleckyj. "Measuring Economic Effects of Federal Research and Development Expenditures: Recent history with Special Emphasis on Federal R&D Performed in

paper aims to base on 13 individual Aerospace and Defence firms' data in 1970-2000, and investigate the effect of both demand side factors, which refers to federal R&D procurement, and that of supply side factors, including cost of capital, interest expenses, cash holdings and investment opportunities, on corporate R&D expenditures. The Aerospace and Defence industry is chosen due to its aforementioned high R&D intensity and the prominent role of government demand in research within the sector.

This essay begins with a review in Section 2 on existing studies regarding the impact of demand and supply side factors on corporate research spending. Section 3 discusses the collection and preparation of the dataset derived from two main primary sources, namely the Records of Prime Contract Awarded by the Military Services and Compustat, and the study's methodology. Section 4 illustrates the strength and weaknesses of the primary sources; Section 5 provides descriptive statistics on the dataset collected. Section 6 illustrates the analysis and discussion on the regression findings, and Section 7 concludes.

2. Literature review

2.1 Demand side factors: government procurement

Many scholars have attempted to explore the decision-making mechanism that determines the R&D expenditure level in firms. The first line of argument states that government demand plays a crucial role in prompting private R&D investments as it provides the guaranteed market for certain products, such as advancements in jets, and this phenomenon of demand-pull R&D is especially

Industry" in Papers Commissioned for a Workshop on the Federal Role in Research and Development. ed. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. (Washington, DC: The National Academies Press, 1985). https://doi.org/10.17226/942., 159; See sum of different time frames: Nestor E. Terleckyj. "Measuring Economic Effects of Federal Research and Development Expenditures: Recent history with Special Emphasis on Federal R&D Performed in Industry" in Papers Commissioned for a Workshop on the Federal Role in Research and Development. ed. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. (Washington, DC: The National Academies Press, 1985). https://doi.org/10.17226/942., 158

prominent in the US space and defence program.[21] For example, using the aggregate state-level procurement data in 1997-2007, Viktor argued that higher government procurement in high-tech industries increased private sector R&D activities due to the R&D rewards provided by the government.[22] Similarly, Levy stated that in 1949-1981, every 1$ of government R&D-related contract leads to a $0.27 increase in the aggregate R&D spending in the corresponding industry.[23] Carmichael also estimated that each $1 of mission-orientated government R&D funding increases the private R&D spending in the US transport industry by $0.92.[24] Thus, it could be argued that government demand for R&D projects could be an important stimulus for private sector R&D outlays.

Specifically in the defence industry, R&D procurement potentially plays a significant role in inducing corporate R&D activity due to the contract bidding procedure between firms and the government.[25] For example, when the federal government has special R&D demand for innovations on military equipment or weapons, it puts forward the Request for Proposals and ask for technical proposals from different contractors.[26] These contracts could be specified for certain technologies or programs, such as for missiles and space engineering program, or just for general sciences and technology.[27] Subsequently, the contractors develop corresponding proposals to meet the technical requirement of

[21] Slavtchev, Viktor; Wiederhold, Simon (2012) : Technological Intensity of Government Demand and Innovation, ifo Working Paper, No. 135, ifo Institute - Leibniz Institute for Economic Research at the University of Munich, Munich, 1-53, 1
[22] Slavtchev, Viktor; Wiederhold, Simon (2012) : Technological Intensity of Government Demand and Innovation, ifo Working Paper, No. 135, ifo Institute - Leibniz Institute for Economic Research at the University of Munich, Munich, 1-53, 2
[23] Levy, David M., and Nestor E. Terleckyj. "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis." The Bell Journal of Economics 14, no. 2 (1983): 551–61. https://doi.org/10.2307/3003656., 551
[24] Carmichael, Jeffrey. "The Effects of Mission-Oriented Public R & D Spending on Private Industry." The Journal of Finance 36, no. 3 (1981): 617–27. https://doi.org/10.2307/2327522., 617
[25] Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152., 551
[26] Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152., 551
[27] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

the government, and the contract will be awarded to the most capable bidder, many based on their design and technology superiority.[28] In addition, the awarded firm benefits from follow-on contracts that come subsequently to the competitive contract.[29] This process implies that firstly, government demand for specific military technology sparks corporate R&D efforts to produce better technologically advanced proposals to win the contract.[30] Secondly, the successful bidder might have to devote additional R&D investments to fulfil the contract obligation.[31] Thus, the bidding and contracting procedure in the defence industry means that government demand could be an important driver for corporate R&D investments.

Another possible mechanism that federal procurement on R&D might have benefited private sector R&D is the spillovers effect. For instance, government R&D procurement could promote technological advancements and create learning experiences that make future R&D more feasible and efficient, which potentially induces higher R&D expenditure.[32] In the analysis for the Swedish Aircraft Industry, Elliason documented that the innovative procedures and know-how established from the government-funded R&D project for military aircraft has benefitted the R&D on civilian aircrafts.[33] Furthermore, Lach pointed out that R&D procurement could lower the future cost of private R&D projects if infrastructures and equipment were brought along with the

[28] Lichtenberg, Frank R. "The Effect of Government Funding on Private Industrial Research and Development: A Re-Assessment." The Journal of Industrial Economics 36, no. 1 (1987): 97–104. https://doi.org/10.2307/2098599., 100
[29] Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152, 551
[30] Lichtenberg, Frank R. "The Effect of Government Funding on Private Industrial Research and Development: A Re-Assessment." The Journal of Industrial Economics 36, no. 1 (1987): 97–104. https://doi.org/10.2307/2098599., 100
[31] Lichtenberg, Frank R. "The Effect of Government Funding on Private Industrial Research and Development: A Re-Assessment." The Journal of Industrial Economics 36, no. 1 (1987): 97–104. https://doi.org/10.2307/2098599., 100
[32] Eliasson, Gunnar. "Advanced Public Procurement as Industrial Policy: The Aircraft Industry as a Technical University." Economics of Science, Technology and Innovation 34, (2010): 1-312, doi: 10.1007/978-1-4419-5849-5, 89
[33] Eliasson, Gunnar. "Advanced Public Procurement as Industrial Policy: The Aircraft Industry as a Technical University." Economics of Science, Technology and Innovation 34, (2010): 1-312, doi: 10.1007/978-1-4419-5849-5, 89

procurement.[34] Thus, theoretically there could be both direct and indirect spillover stimulus on corporate R&D from government R&D procurement.

However, the net effect of government R&D expenditure on corporate R&D investments remains debatable due to the possible crowding-out effects, and different conclusions were made by scholars using different data sources, time frame, country, and industries. On one hand, Ngo proposed that an increase in R&D contracts awarded to procurement-dependent firms increases their earnings and performances, which induces negative impact on R&D expenditure of its peer firms, as the peer firms tend to preserve their earnings through cutting their R&D expenditures.[35] Another possible crowding out mechanism is proposed by Goolsbee, who suggested that government procurement on R&D projects increases the researchers' wages, which increases the cost of R&D and thus causing crowding-out in private R&D.[36] Furthermore, contract R&D might displace the expenditures that firms will otherwise spend on researching the products they provide for the private sector.[37] However, many scholars have found limited empirical evidence for the crowding-out effect. For example, based on a Finnish technology industry dataset, Ali-Yrkkö has found positive relationship between obtaining public R&D funding and private R&D outlays, with no signs of crowding-out.[38] Thus, there's mixed opinions on whether there's a crowding-out effect of government R&D projects on industrial R&D expenditure.

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[34] Ali-Yrkko, Jyrki. "Impact of Public R&D Financing on Private R&D: Does Financial Constraint Matter?" European Network of Economic Policy Research Institutes Working Paper, no. 30(2005):1-13, http://aei.pitt.edu/6736/1/1195_30.pdf, 2

[35] Ngo, Phong T. H., and Jared Stanfield. "Does Government Spending Crowd Out R&D Investment? Evidence from Government-Dependent Firms and Their Peers." Journal of Financial and Quantitative Analysis 57, no. 3 (2022): 888–922. doi:10.1017/S0022109020000927., 888

[36] David, Paul A. and Hall, Bronwyn H. and Toole, Andrew A. "Is public R&D a complement or substitute for private R&D? A review of the econometric evidence," NBER working paper 7373 (1999): 1-60, doi: 10.3386/w7373, 42

[37] Paul A David, Bronwyn H Hall, "Heart of darkness: modeling public–private funding interactions inside the R&D black box", Research Policy 29 no. 9(2000): 1165-1183, https://doi.org/10.1016/S0048-7333(00)00085-8, 1171

[38] Ali-Yrkko, Jyrki. "Impact of Public R&D Financing on Private R&D: Does Financial Constraint Matter?" European Network of Economic Policy Research Institutes Working Paper, no. 30(2005):1-13, http://aei.pitt.edu/6736/1/1195_30.pdf, 10

2.2 Supply side factors

The supply side factors, or the capability and willingness of firms to invest in R&D, could also be an influential consideration in the decision-making process of managers to determine the R&D level.

Firstly, there's reason to believe that firms could rely on external source of financing to fund R&D investments, thus making cost of external capital a potential explanatory factor for the R&D expenditure. This is because according to Auerbach, interest expenses from debt is tax deductible under the US tax system, while the retained earnings within the firm might be taxed as capital gains.[39] This means that there's a possibility for debt to be preferred as the source of financing over retained earnings due to lower required rate of returns.[40] Additionally, equity could also be a favourable source of financing due to improvements in equity market in the late 20th century, especially after the introduction of Nasdaq in 1971, which significantly increased young firms' accessibility to public equity.[41] Specifically, based on data from US publicly traded manufacturing firms in 1970-2006, Peterson has concluded that stock issuance has played an important role in financing R&D especially in 1990s.[42] It was also suggested that R&D could be the most equity-dependent type of investment, as R&D contains limited collateral value for debt financing.[43] Thus, it could be argued that external financing might have advantages in financing R&D.

[39] Bronwyn H. Hall, "Investment and Research and Development at the Firm Level: Does the Source of Financing Matter?", NBER Working Paper Series no. 4096(1992): 1-41, https://ssrn.com/abstract=226872, 6

[40] Bronwyn H. Hall, "Investment and Research and Development at the Firm Level: Does the Source of Financing Matter?", NBER Working Paper Series no. 4096(1992): 1-41, https://ssrn.com/abstract=226872, 6

[41] James R. Brown, Bruce C. Petersen, "Why Has the Investment-Cash Flow Sensitivity Declined so Sharply? Rising R&D and Equity Market Developments", Journal of Banking and Finance 33 no. 5(2009): 971-984, Available at SSRN: https://ssrn.com/abstract=1411230, 1-46, 1

[42] James R. Brown, Bruce C. Petersen, "Why Has the Investment-Cash Flow Sensitivity Declined so Sharply? Rising R&D and Equity Market Developments", Journal of Banking and Finance 33 no. 5(2009): 971-984, Available at SSRN: https://ssrn.com/abstract=1411230, 1-46, 4

[43] James R. Brown, Bruce C. Petersen, "Why Has the Investment-Cash Flow Sensitivity Declined so Sharply? Rising R&D and Equity Market Developments", Journal of Banking and Finance 33 no. 5(2009): 971-984, Available at SSRN: https://ssrn.com/abstract=1411230, 1-46, 6

Consequently, given the aforementioned advantages, external source of financing could be suitable for R&D, and thus an association between external cost of capital and R&D expenditure might be expected. For example, Grundfest has argued that the higher cost of capital in the US has resulted in less satisfying R&D expenditures when compared to that in Germany and Japan.[44] The connection between external cost of capital and R&D investments is that when managers are evaluating investment projects, they tend to pick higher NPV projects, in which the future cashflows would be discounted by the estimated cost of capital.[45] Subsequently, it could be inferred that when cost of capital is higher, managers might seek to reduce exposure to projects with risky and less predictable returns, such as R&D.[46] Thus, the decision-making process on corporate R&D level could be subject to external cost of capital.

Apart from external financing, firms could also choose to fund R&D projects from internal sources, such as directly from its cash holdings. This is because due to potential information asymmetry, limited collateral and uncertainty under R&D projects, external financing could be more expensive than internal financing for R&D investments.[47] Historically, it's observed that many R&D projects in the Aerospace industry were financed by internal cashflow.[48] For example, the Boeing 747 project in 1964, and the electra turboprop plane project from Douglas in 1952 were both financed by internal cashflow.[49] As argued by Hall using firm-

[44] Grundfest, Joseph A. "M&A and R&D: Is Corporate Restructuring Stifling Research and Development?" US Securities and Exchange Commission (1989), https://www.sec.gov/news/speech/1989/101189grundfest.pdf, 7
[45] NPV is Short for Net Present Value; Wesley L. Harris, Jarunee Wonglimpiyarat, "R&D Investments and Strategic Use of Financial Models", International Journal of Innovation and Technology Management 17 no.4(2020): 1-16, https://doi.org/10.1142/S0219877020500303, 7
[46] Grundfest, Joseph A. "M&A and R&D: Is Corporate Restructuring Stifling Research and Development?" US Securities and Exchange Commission (1989), https://www.sec.gov/news/speech/1989/101189grundfest.pdf, 7.
[47] Gerben Bakker, "Money for nothing: How firms have financed R&D-projects since the Industrial Revolution", Research Policy 42 no.10(2013): 1793–1814, https://doi.org/10.1016/j.respol.2013.07.017, 1803
[48] Gerben Bakker, "Money for nothing: How firms have financed R&D-projects since the Industrial Revolution", Research Policy 42 no.10(2013): 1793–1814, https://doi.org/10.1016/j.respol.2013.07.017, 1801
[49] Gerben Bakker, "Money for nothing: How firms have financed R&D-projects since the Industrial Revolution", Research Policy 42 no.10(2013): 1793–1814, https://doi.org/10.1016/j.respol.2013.07.017, 1801

level data in 1973-1987 across varies industries, the availability of cashflow instead of debt level or Tobin's Q is more influential in determining the corporate R&D expenditure.[50] Possible explanation for this phenomenon is the cheaper cost of internal capital compared to external financing, which induces managers to expense R&D directly through internal cash flows.[51] Consequently, firms with higher internal capital source could spend more on R&D projects.

Another source of constraint for using internal funding to finance R&D is firms' interest commitments. Specifically, higher interest commitments reduce the available free cash flow, making it more difficult for the firm to sustain its R&D level.[52] As stated by Opler, R&D firms with higher levels of debt could be more vulnerable to economic distress, potentially because high interest expenses prevent them from sustaining their R&D programs.[53] Consequently, the level of interest expense may act as a constraint on disposable cashflow, thus affecting the firm's research expenditure.

In addition to government demand for R&D and the cost of internal and external financing, the suitability of investment environment might also impact firms' attitude on R&D investments. For example, Tobin's Q ratio, which is the ratio between the market value of assets of a firm and the replacement costs, measures the availability of investment opportunities for a firm.[54] It's generally believed that higher Tobin's Q value indicates more suitable investment

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[50] Bronwyn H. Hall, "Investment and Research and Development at the Firm Level: Does the Source of Financing Matter?", NBER Working Paper Series no. 4096(1992): 1-41, https://ssrn.com/abstract=226872, 5

[51] Bronwyn H. Hall, "Investment and Research and Development at the Firm Level: Does the Source of Financing Matter?", NBER Working Paper Series no. 4096(1992): 1-41, https://ssrn.com/abstract=226872, 10

[52] Bronwyn H. Hall, Josh Lerner, "The Financing Of R&D And Innovation", NBER Working Paper Series no. 15325 (2009): 1-55, http://www.nber.org/papers/w15325, 13

[53] Opler, Tim C., and Sheridan Titman. "Financial Distress and Corporate Performance." The Journal of Finance 49, no. 3 (1994): 1015–40. https://doi.org/10.2307/2329214., 1032; Bronwyn H. Hall, Josh Lerner, "The Financing Of R&D And Innovation", NBER Working Paper Series no. 15325 (2009): 1-55, http://www.nber.org/papers/w15325, 13

[54] Josheski, Dushko and Sopova, Marija. "Market Value of the Firms and R&D Investment: Theoretical Overview and Empirical Estimation for the Panel of Countries." International Journal of Business Management and Administration 2, no. 3(2013): 55-63, http://dx.doi.org/10.2139/ssrn.2209759, 56

opportunities.[55] Specifically, additional investments is usually recommended when the Tobin's Q ratio is greater than 1, as it indicates that the profits of investments surpasses the cost price of assets invested.[56] Thus, higher Tobin's Q could potentially lead to higher R&D expenditure.

Summing up the literatures, government procurement could be the demand side explanatory factor the corporate R&D expenditure, while cost of capital, cash holdings, interest expenses and Q ratio are the supply side factors.

3. Research design

This section explains the selection of the time frame, sampled firms and data collection methods in this study.

3.1 Rationale for data sampling

The starting date of 1970 was selected since the disclosure of R&D expenditure as a separate line item in the financial reports was only made compulsory for public firms after 1972, and many firms only had consistent R&D data as reported on Compustat after 1970.[57] The sampled firms were selected following a four-step filtering method considering the industrial classification, availability of data, nature of the company, and merger & acquisition situations.

To start off, 77 firms classified under Aerospace/Defence industry in the latest Stern Industrial Classification has been selected as the original sample.[58] This

[55] Josheski, Dushko and Sopova, Marija. "Market Value of the Firms and R&D Investment: Theoretical Overview and Empirical Estimation for the Panel of Countries." International Journal of Business Management and Administration 2, no. 3(2013): 55-63, http://dx.doi.org/10.2139/ssrn.2209759, 56.
[56] Josheski, Dushko and Sopova, Marija. "Market Value of the Firms and R&D Investment: Theoretical Overview and Empirical Estimation for the Panel of Countries." International Journal of Business Management and Administration 2, no. 3(2013): 55-63, http://dx.doi.org/10.2139/ssrn.2209759, 56.
[57] Nix, Paul E., and David E. Nix. "A Historical Review Of The Accounting Treatment Of Research And Development Costs." The Accounting Historians Journal 19, no. 1 (1992): 51–78. http://www.jstor.org/stable/40698068, 57
[58] NYU Stern. "Regression Statistics By Industry (US)" Accessed May 6, 2023. https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/indreg.html

classification provides the complete range of firms listed either on Nasdaq, NYSE or OTCPK under the Aerospace and Defence section.[59]

Secondly, each firm was checked on the Department of Defense Military Prime Contracts National Archive for whether it has R&D-specific procurement records during the studied time frame. I also checked the firms on WRDS dataset to filter out those without a continuous disclosure of R&D and financial data in 1970-2000. This step has filtered out the majority of firms, since many either wasn't publicly traded persistently across the time frame or has few R&D-related procurement contracts. For example, most firms under the classification that was listed on OTC Pink stock exchange were excluded from this study, since many companies found on OTCPK are established relatively recent.[60]

Thirdly, I searched for the descriptions on firms to include only those with primary operations in the US. Firms originated and operating primarily in other countries, such as CAE in Canada, were excluded as this study mainly focuses on the US market.[61]

Fourthly, some firms which were active and publicly traded in 1970-2000 were omitted from the classification, as they were either merged or acquired by other firms. This condition was especially significant in the late 1990s, when there was a wave of consolidation among the aerospace and defence industry.[62] To minimize this omittance, major M&A activities in the sector in 1990s has been considered, and the merged or acquired firms were added to the sample, namely

[59] NYU Stern. "Regression Statistics By Industry (US)" Accessed May 6, 2023. https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/indreg.html
[60] NYU Stern. "Regression Statistics By Industry (US)" Accessed May 6, 2023. https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/indreg.html; most Over-the-Counter Pink traded companies were relatively new, e.g. American Defense Systems Inc, Applied Energetics Inc, thus didn't have financial records throughout 1970-2000.
[61] "CAE Inc.", Wikipedia, https://en.wikipedia.org/wiki/CAE_Inc., Accessed May 6 2023
[62] Boatner, Amy J. "Consolidation of the Aerospace and Defense Industries: The Effect of the Big Three Mergers in the United States Defense Industry." Journal of Air Law and Commerce 64 no. 3(1999): 913-940, 914

Grumman Corp, Martin Marietta and McDonnell Douglas.[63] M&A activities before 1990s weren't considered since companies merged beforehand wouldn't have any financial records in the 1990s, implying a limited consistency of data. Consequently, 11 firms with extensive R&D procurement and financial records were selected, with an additional 2 firms with consistent financial record but only a few R&D procurement contracts added to enlarge the dataset.

In terms of the representativeness of the selected firms, it's worthwhile to look at the proportion of revenue generated by the listed firms within the total aerospace/defence industry. Although the specific industrial data for Aerospace and Defence industry was relatively scarce before 2000s, there's record for aerospace industry and defence industry separately. For example, the sum of sales in the selected firms is estimated to account for 84.88% of the total sales in aerospace industry in 1989.[64] The figure might look relatively large as some firms in the panel are agglomerates that also have weapons and arm sales.[65] Thus, another comparison is made with the aggregate sales of Arms and Weapons in the US in 1990, in which the sum of selected firms occupies 58.60%.[66] Furthermore, the defence R&D market has traditionally been relatively concentrated, with the top 10 contractors such as Boeing and Lockheed consistently occupying around 50% of overall defence R&D procurement.[67] This high concentration implies that a small panel of firms may provide high representativeness to the industry. Thus, given that the firms in our panel represents a great proportion of sales in the industry, and the high level of

[63] Boatner, Amy J. "Consolidation of the Aerospace and Defense Industries: The Effect of the Big Three Mergers in the United States Defense Industry." Journal of Air Law and Commerce 64 no. 3(1999): 913-940, 920.
[64] Calculated from revenue data in Compustat and industry data in: Economic Data Service, Aerospace Research Center, Aerospace Industries Association of America, AEROSPACE FACTS AND FIGURES 1990/1991. (Washington DC: MCGRAW-HILL, 1990), 1-178, 8
[65] For example, Lockheed also has arms & weapon products. "Lockheed Martin", Accessed May 6 2023, https://en.wikipedia.org/wiki/Lockheed_Martin
[66] Calculated from revenue data in Compustat and industry data in: J. Paul Dunne, Maria Garcia-Alonso, Paul Levine, Ron Smith, "Concentration in the International Arms Industry", Working Papers 0301, Department of Accounting, Economics and Finance, Bristol Business School, University of the West of England, Bristol(2002): 1-27, 4
[67] Edward J. Malecki, "Federal R and D Spending in the United States of America: Some impacts on metropolitan economies", Regional Studies 16 no.1 (1982): 19-35, https://doi.org/10.1080/09595238200185481, 24

concentration in defense R&D procurement, it's reasonable to state that the representativeness of the selected firms is satisfiable.

3.2 Data collection and preparation

After having a list of sample firms, the data representing the government demand for R&D is collected. Specifically, I searched for the corresponding Prime Military Procurement Contracts recorded for each firm in National Archives every year.[68] Both "research" and "RDTE" were filtered in the Federal Supply Classification description in the prime procurement contract record, which lead to a total of 53,523 contracts.[69] Research, Development, Testing & Evaluation (RDTE) was a general section of federal procurement introduced in the late 1970s to stand for most R&D related procurements.[70] For example, in Fiscal Year 2021 it was reported that around 97% of Department of Defense's research-related funding was labelled under the RDTE title.[71] Thus, by including all the contracts labelled as "RDTE" or "research", chances of omitting R&D related contracts is minimized. Contract information collected for each firm every year includes the dollar value, action date, federal supply class description (meaning the purpose of procurement) and extent of competition. Based on procurement contracts collected, a preliminary descriptive analysis on the characteristics and trend of R&D procurements is conducted. Furthermore, a panel regression between R&D expenditure and demand and supply side factors will be conducted to investigate the correlation and potential causation between the potential

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[68] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb2023; 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

[69] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb2023; 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

[70] "Defense Primer: RDT&E." Congressional Research Service (2022): 1-3, Accessed May 6, 2023, https://sgp.fas.org/crs/natsec/IF10553.pdf 1

[71] Defense Primer: RDT&E." Congressional Research Service (2022): 1-3, Accessed May 6, 2023, https://sgp.fas.org/crs/natsec/IF10553.pdf, 1

explanatory factors and corporate R&D outlays, using the procurement data as one of the inputs. Specifically, the regression item representing demand side factor will be:

$$\gamma_{procurement} P,$$

with γ being the coefficient and P being the annual inflation-adjusted procurement level for the corresponding firm. In addition to this demand side item, supply side items for R&D are added to the regression to explore if they are useful as explanatory factors to firm's R&D expenditure. Supply side data, namely the Cost of Capital, Tobin's Q, interest expenses and cash levels were collected and computed from sources including the WRDS Capital IQ, WRDS beta suite, Stern US historical market risk premium and Federal Reserve Economic Data.

Firstly, the proxy for weighted average cost of capital for individual firms was computed by the equation:

$$WACC_{before\ tax} = \left[\frac{E}{D+E}\right] \times Cost\ of\ Equity + \left[\frac{D}{D+E}\right] \times Cost\ of\ Debt$$[72]

Before-tax WACC is used because many selected firms are multinational companies, meaning that they might have different places of debt issuance and thus have different taxation standards, making tax rate calculations difficult.[73] The Cost of Debt was proxied by the annual rates of Aaa corporate bonds from Federal Reserve Economic Data.[74] This is because with the highest credit rating,

[72] "Cost of Capital: What It Is, Why It Matters, Formula, and Example", Investopedia, https://www.investopedia.com/terms/c/costofcapital.asp, (accessed May 6 2023)
[73] for example, Boeing had presence in Canada since 1929, see: "History", Boeing, https://www.boeing.ca/boeing-in-canada/history.page#:~:text=The%20Boeing%20Company%20began%20business,airplanes%20built%20in%20western%20Canada., (accessed May 6 2023); See how different taxation standards in countries affect places of debt issuance: Matteo P. Arena, Andrew H. Roper, "The effect of taxes on multinational debt location", Journal of Corporate Finance 16 no. 5(2010): 637-654, Abstract
[74] Moody's, 'Moody's Seasoned Aaa Corporate Bond Yield [AAA]', retrieved from FRED, Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/series/AAA, Accessed May 6, 2023

Aaa bonds tend to have the highest quality and thus have lower default risk and return, providing a lower-bound estimate for cost of debt in our model.[75] The Cost of Equity was computed from the CAPM equation:

$$Cost\ of\ Equity = r_{risk-free} + \beta \times\ Market\ Risk\ Premium$$[76]

in which the Treasury Bill rate was used as the risk-free rate, as it's also used by Green for cost of equity calculations.[77] The annual beta was derived from the WRDS Beta Suite.[78] The Market Risk Premium comes from the Stern US Market Risk Premium.[79] Since the cost of debt and equity for companies are essentially using the same input, they are only capturing the within-group, or time-related changes in the cost of capital. The between-firm differences are captured in the Weighted Average Cost of Capital by inputting the different leverage ratio of individual firms, retrieved from WRDS fundamentals annual.[80]

On the Tobin's Q ratio for individual firms, it's calculated from dividing the market value of assets over the book value of assets.[81] Since there's no readily available Q-ratio from WRDS dataset, the equation used by Connolly to calculate the Q-ratio from the Capital IQ entries was deployed:

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[75] Moody's, "Moody's Rating Scale and Definitions", Accessed May 6, 2023, https://www.moodys.com/sites/products/productattachments/ap075378_1_1408_ki.pdf
[76] "Cost of Capital: What It Is, Why It Matters, Formula, and Example", Investopedia, https://www.investopedia.com/terms/c/costofcapital.asp, (accessed May 6 2023)
[77] Green, Edward J., Lopez, Jose A., Wang, Zhenyu, "The Federal Reserve Banks' Imputed Cost of Equity Capital", (2000): 1-50, https://www.federalreserve.gov/boarddocs/press/boardacts/2000/200012212/researchpaper.pdf, 41; Stern NYU, "Historical Implied Equity Risk Premiums", Accessed May 6, 2023, https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/histimpl.html
[78] 'Beta Suite by WRDS', Accessed May 6 2023, https://wrds-www.wharton.upenn.edu/pages/get-data/beta-suite-wrds/
[79] Stern NYU, "Historical Implied Equity Risk Premiums", Accessed May 6, 2023, https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/histimpl.html
[80] 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023
[81] Adam Hayes, "Q Ratio or Tobin's Q: Definition, Formula, Uses, and Examples", Accessed May 6, 2023, https://www.investopedia.com/terms/q/qratio.asp

$$Q = \frac{[Total\ Assets + (No.of\ common\ shares\ outstanding\ \times\ final\ closing\ price) - Book\ Value\ of\ Common\ Stock]}{Total\ Assets}$$[82]

Apart from the three supply side factors of earnings, Tobin's Q and WACC, it's possible that there might be a size effect on the R&D expenditure of firms, since firms with larger size might be able to invest higher amount of capital to R&D.[83] Thus, the inflation-adjusted revenue of individual firms will be used as a proxy to adjust for the size effect in regression.[84] It is calculated from the revenue of firms from WRDS deflated by the Domestic Producer Prices Index (PPI) of Manufacturing in the US.[85] The same deflator was also applied to the dollar volume of procurement when looking at its absolute value. By setting the value of manufacturing PPI in 2000 as the base year, the annual sales revenue was deflated by the following equation.[86] An example of 1970 deflated revenue will be:

$$Revenue_{1970\ Inflation-adjusted} = Revenue_{1970} \times \frac{PPI_{2000}}{PPI_{1970}}$$

The cash and interest expenses are collected similarly as revenue and deflated using the same PPI mentioned above.[87] Subsequently, adding the supply side

[82] Connolly, Robert A. and Hirschey, Mark. "Firm size and the effect of R&D on Tobin's q." R&D Management 35 no. 2(2005): 217-223, https://doi.org/10.1111/j.1467-9310.2005.00384.x, p218
[83] Daniel Shefer, Amnon Frenkel, "R&D, firm size and innovation: an empirical analysis", Technovation 25 no.1(2005): 25-32, https://doi.org/10.1016/S0166-4972(03)00152-4, Abstract, 1
[84] 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023
[85] Organization for Economic Co-operation and Development, " Domestic Producer Prices Index: Manufacturing for the United States (USAPPDMAINMEI)", retrieved from FRED, Federal Reserve Bank of St. Louis, Accessed April 6 2023, https://fred.stlouisfed.org/series/USAPPDMAINMEI
[86] Equation derived from: "How To Adjust For Inflation In Monetary Data Sets", Time Series Reasoning, Accessed April 6 2023, https://timeseriesreasoning.com/contents/inflation-adjustment/#:~:text=The%20formula%20for%20inflation%20adjustment,multiplying%20the%20result%20by%20100.&text=This%20is%20an%20important%20formula.
[87] 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023; Compustate item name for cash: cash & short term investments; interest expenses: interest and related expenses

factors and size adjustments to the regression, the equation explaining the firm-level R&D expenditure level will be:

$$R\&D = \gamma_{procurement}P + \gamma_{WACC}WACC + \gamma_q Q + \gamma_{cash}C + \gamma_{interest}I + \gamma_{revenue}R + r.$$

With r being the residual of R&D expenditure that couldn't be explained by the aforementioned factors.

4. Source discussion

The primary sources as discussed before mainly comes from the US Department of Defense online archives within the National Archives and Records Administration, which provides digitalized summary on key information extracted from every military procurement contracts with a value above $10,000 before 1983, and contracts above $25,000 after 1983.[88] The purpose of DoD to create this archive of contracts was for its administration and management purposes, as well as creating reports to the Congress and the President.[89] This formal and government-related purpose brings the benefit of relatively satisfiable data accuracy and reliability from this source. This source is especially unique and valuable since the original contracts were destroyed shortly after completing the contract.[90]

The first issue with the dataset itself is the limited sample size. This is because although there's many firms with ample government procurement records after

[88] National Archives, "Frequently Asked Questions (FAQs), Records of Prime Contracts Awarded by the Military Service and Agencies (Defense Contract Action Data System (DCADS)), 7/1/1975 – 9/30/2006", Accessed May 6, 2023, https://aad.archives.gov/aad/content/aad_docs/rg330_dcads_faq_revised.pdf
[89] National Archives, "Frequently Asked Questions (FAQs), Records of Prime Contracts Awarded by the Military Service and Agencies (Defense Contract Action Data System (DCADS)), 7/1/1975 – 9/30/2006", Accessed May 6, 2023, https://aad.archives.gov/aad/content/aad_docs/rg330_dcads_faq_revised.pdf.
[90] National Archives, "Frequently Asked Questions (FAQs), Records of Prime Contracts Awarded by the Military Service and Agencies (Defense Contract Action Data System (DCADS)), 7/1/1975 – 9/30/2006", Accessed May 6, 2023, https://aad.archives.gov/aad/content/aad_docs/rg330_dcads_faq_revised.pdf

shortlisting, only a few had extensive R&D-related procurements.[91] Furthermore, many firms were initially excluded from the study due to limited or inconsistent financial reporting in 1970-2000, which is partly a trade-off for having a long-time frame of 30 years. Consequently, there's only 11 firms with significant level of R&D records. Thus, to enlarge the dataset, 2 additional firms (MOOG and Hexcel) with occasional R&D contracts were also included.

The second problem with the AAD archives is that the contracts were organized in the federal fiscal years, which is different from the corporate fiscal year referenced in the financial data. For example, as the federal fiscal year starts from the middle of the year, a contract with an action date of December 1970 will be classified as in 1971 federal fiscal year.[92] Thus, to better match the financial data with the procurement data, the contracts were reorganized by their corresponding Action Date.

The third problem is that there could be multi-year contracts encompassing several years, meaning that the value of a contract record in one single year might be expensed or completed in multiple years.[93] Initially, I tried to tackle the problem by spreading the value of a multi-year contract evenly in the years between the action and completion date of a contract. However, the completion date of contracts was not recorded in the 1980s, and it only resumed after 1990.[94] This inconsistency might cause certain inaccuracies when modelling the

[91] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

[92] For example, Fiscal Year 1971 file covers 7/1/1970 - 6/30/1971. File unit: Military Prime Contract File, 7/1/1970 - 6/30/1971 in: 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

[93] For example, contract number F047014C0538 for Boeing starts in 1974, estimated completion 1976. File unit: Military Prime Contract File, 7/1/1974 - 6/30/1975 in: 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

[94] For example, contract number F3361583C0150 for McDonnell Douglas didn't have completion date. File unit: Defense Contract Action Data System (DCADS), Fiscal Year 1984., 10/1/1983 - 9/30/1984 in: 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

regression. Thus, alternative solution of including a lagged variable on procurement level is tested in the regression, as multiyear contracts implies that contracts signed in previous years could have continued impacting the R&D level in subsequent years.

The fourth problem is with the contractor names recorded in the DoD records, as it sometimes still uses the old company's name as contractor after it has been acquired or merged.[95] To account for this problem, the procurement contracts of the acquired company after the year it ceases financial disclosure on WRDS is counted as the acquirer's procurement.

The other data source that this study heavily draws upon is the Compustat Capital IQ database from WRDS, from where the R&D expenditure, revenue, cash, interest expenses, Q ratio and capital structure are fetched. The Compustat data directly collects data from original financial filings of the corresponding firm, such as its balance sheet.[96] The benefit of using Compustat is that it allows efficient and standardized financial data collection.

One limitation on using WRDS Compustat data as the main source of financial data is that there's occasional errors in reporting and filing. This problem is also noticed by Hall, who resolved the problem by deleting the outliers in the dataset.[97] To explore if there exist any outliers in the dataset, extreme values are sorted in Stata. However, it's difficult to distinguish whether the values are extreme or natural given that many are subject to changing circumstances of the firm, such as Boeing's extreme revenue surge in after 1997 might be directly

[95] For example, contract number F3361595D3216 for McDonnell Douglas in 1998, already merged but still under old name. File unit: Defense Contract Action Data System (DCADS), Fiscal Year 1998., 10/1/1997 - 9/30/1998 in: 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023
[96] 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023
[97] Bronwyn H. Hall, "Investment and Research and Development at the Firm Level: Does the Source of Financing Matter?", NBER Working Paper Series no. 4096(1992): 1-41, https://ssrn.com/abstract=226872, 11.

related to the acquisition of McDonnell in 1996.[98] Thus, this study only deleted some obvious outliers, such as cases of 0 cash holdings.[99]

The final piece of primary source is the historical annual reports for selected companies, namely General Dynamics, Boeing, and Textron. Annual reports are useful for the study as they provide narratives to explain some outlier financial data, such as sudden increase in debt due to acquisition in the year.[100] One limitation of the source is that it potentially contains some biased description in favor of the company to post positive influence on shareholders and the public. To avoid this bias, mainly factual descriptions are drawn from the annual reports.

5. Descriptive statistics

Before conducting regression to explore the possible explanatory variables for corporate R&D expenditure, descriptive statistics are provided to have a general impression on the trend and features of R&D expenditure, government R&D procurement and supply side factors for the studied firms.

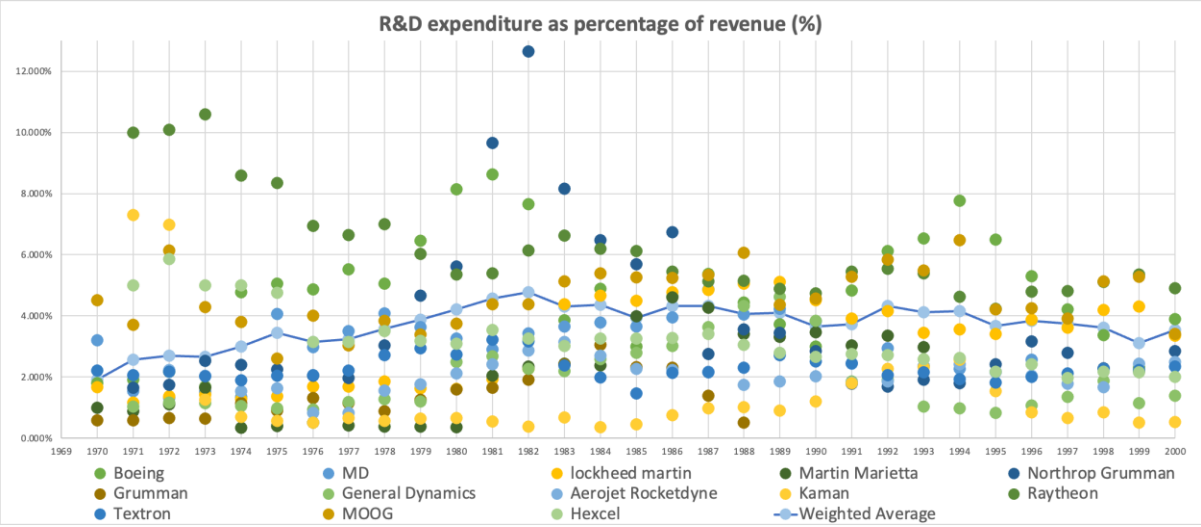
[98] 'Boeing Annual Report 1998' ANN ARBOR: ProQuest Annual Reports, 1998. https://www.proquest.com/reports/boeing-annual-report-1998/docview/88221418/se-2, Accessed May 6, 2023, 1

[99] For example, see Lockheed Martin 1996-1997 from: 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023

[100] For example, see Textron: 'Textron Annual Report 1990', ANN ARBOR: ProQuest Annual Reports, 1990. https://www.proquest.com/reports/textron-annual-report-1990/docview/88215046/se-2. (accessed May 6 2023), 2, 28

5.1 R&D expenditure overview

Graph 3[101]



As shown in Graph 3, the weighted average of R&D expenditure in percentage of the firms' revenue had a steady increase in 1970-1982, and it maintained steadily around 4% afterwards. This figure is relatively acceptable and steady over time, as it's estimated that for the top 10 global aerospace companies in 2016, the ratio between private research expenditure and revenue is 4-6%.[102]

For the lack of increase in R&D spending ratio to revenue after 1980s , one possible explanation is the increased tendency to shift R&D to smaller firms and labs, which implies that since our sampled firms are mostly large and established, they may experience relatively stagnated growth in R&D.[103] For example, as calculated by the National Science Foundation, 73% of the private R&D investments in the US in 1985 was covered by companies with over 10,000

[101] 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023

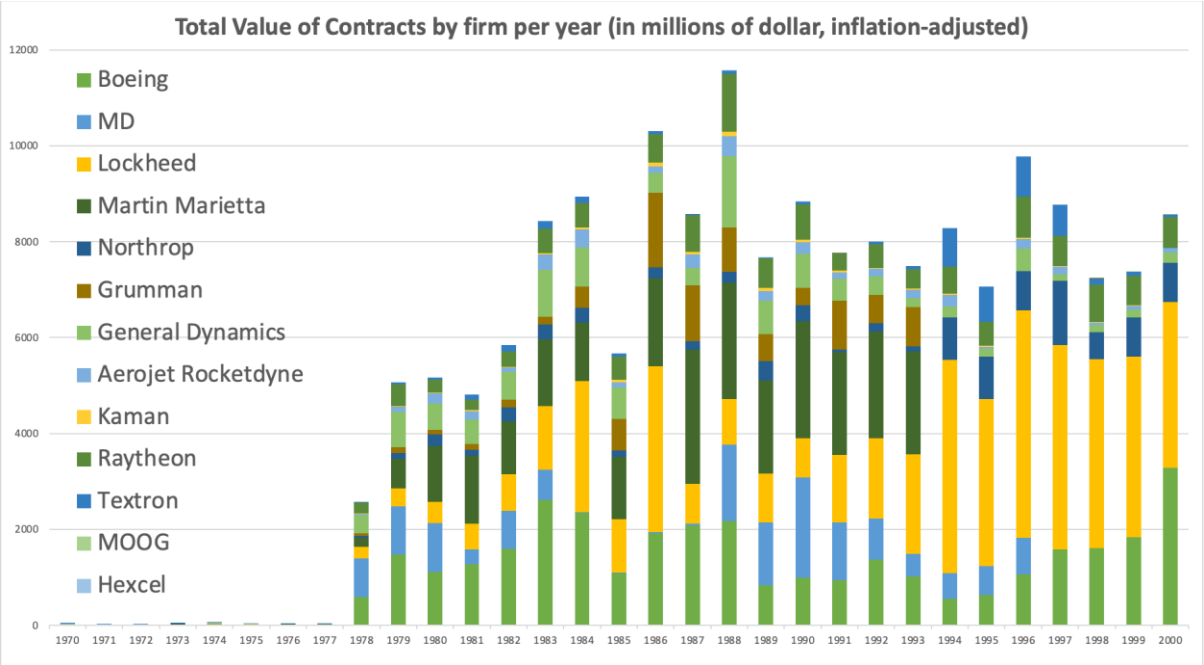
[102] Aerospace Technology Institute, "Insight 10 The Economics of Aerospace: The Evolving Aerospace R&D Landscape", December 2018, https://www.ati.org.uk/wp-content/uploads/2021/08/insight_10-the-evolving-aerospace-rd-landscape.pdf, 6.

[103] Ashish Arora, Sharon Belenzon & Andrea Patacconi, "Killing the Golden Goose? The Decline of Science in Corporate R&D", NBER Working Paper Series no. 20902 (2015): 1-31, http://www.nber.org/papers/w20902, 6.

employees, and the number declined to 54% in 1998.[104] Other than Hexcel, Kaman and MOOG, all firms in our panel had over 10,000 employees by 1990, meaning that our dataset is more representative for large firms.[105] Thus, the shift of research investments from large to smaller firms may explain the stagnation in R&D expenditure in our firm panel after mid-1980s.

5.2 Demand side

Graph 4[106]

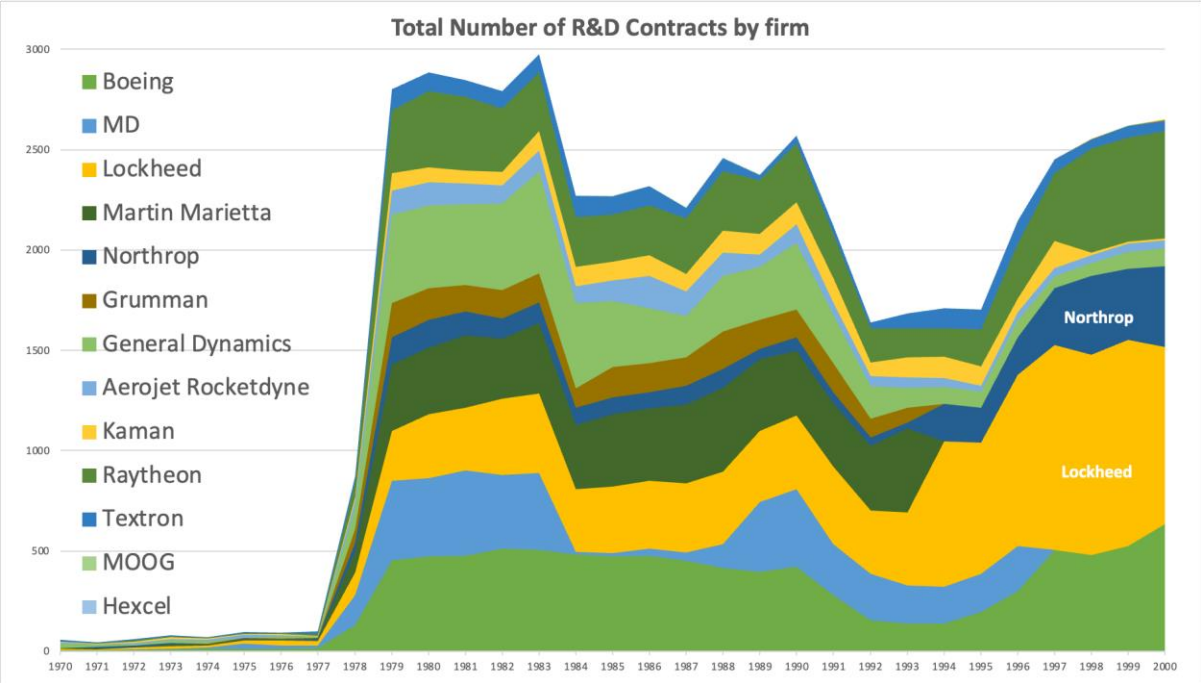


[104] Ashish Arora, Sharon Belenzon & Andrea Patacconi, "Killing the Golden Goose? The Decline of Science in Corporate R&D", NBER Working Paper Series no. 20902 (2015): 1-31, http://www.nber.org/papers/w20902, 6.

[105] 'Employees - Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023

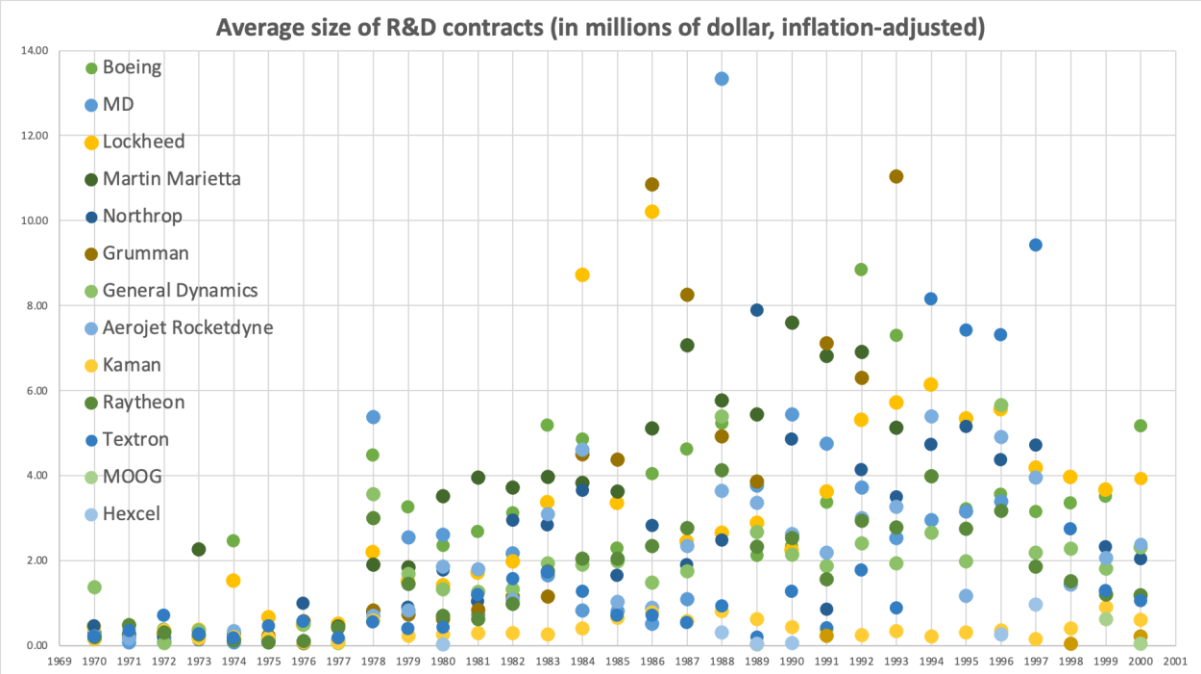
[106] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

Graph 5[107]



[107] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

Graph 6[108]



As shown by Graph 4&5, both the value and number of government R&D contracts awarded to each firm showed an increasing trend after 1978. In terms of the average size of R&D contracts on Graph 6, there's also a gradual increase starting from the early 1980s. This trend is in line with the drastic buildup of military forces after 1980s under Reagan's administration to confront the growing tensions with the Soviet.[109] The increase is also exaggerated by the low level of procurement in 1970s, as the military procurement decreased more than half from late 1960s to mid-1970s, partly due to the US extracting from the Vietnam War.[110] Consequently, drastic increase after late 1970s is observed in R&D procurement contracts received by the firms in our panel.

[108] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

[109] J. Ronald Fox, Defense Acquisition Reform, 1960–2009, An Elusive Goal, (Washington DC: Center of Military History United States Army, 2011), 101

[110] J. Ronald Fox, Defense Acquisition Reform, 1960–2009, An Elusive Goal, (Washington DC: Center of Military History United States Army, 2011), 100

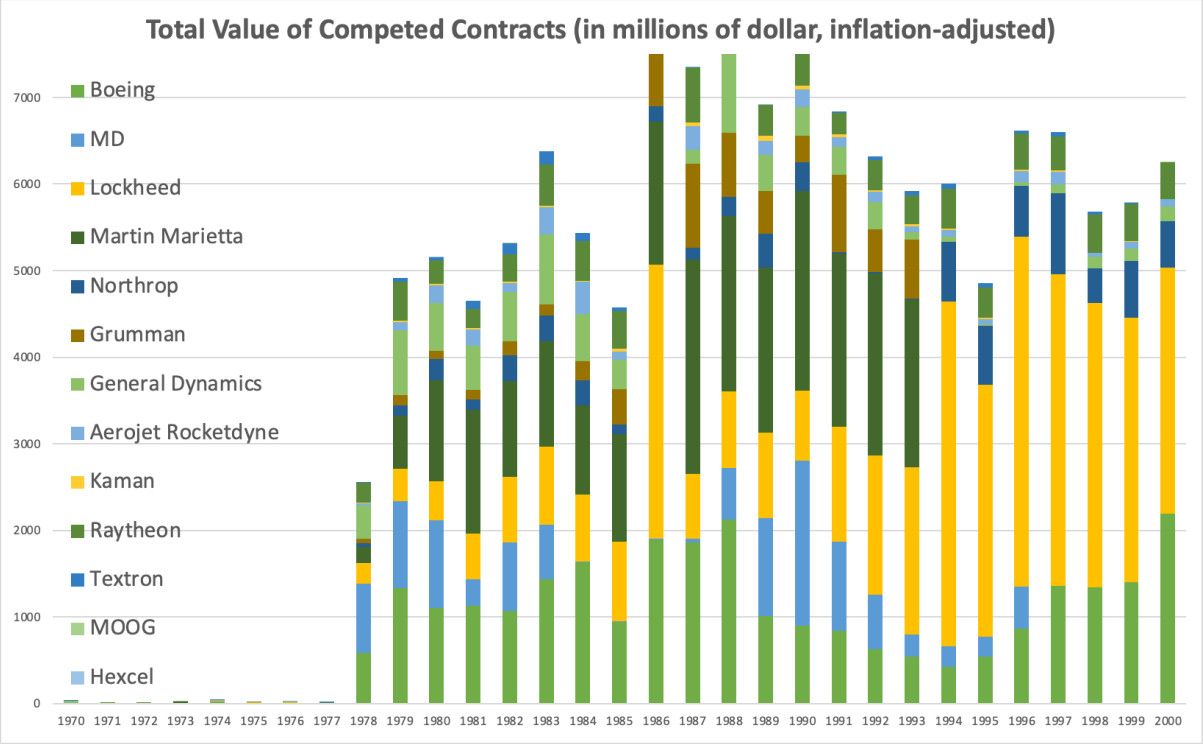
Another observation is that the total value of contracts before 1990s seems to be more widely distributed across the panel of studied firms, while Lockheed and Boeing became dominant across the panel at the end of the studied period. Particularly, Lockheed seemed to be the largest winner at the end of the decade, as also stated by the Pentagon that after Lockheed's merger with Martin Marietta in 1995, it's become the largest contractor for the defence department accounting for 25% of the defence budget.[111] Raytheon, Northrop Grumman, and Boeing also gradually gained dominance on the number of government R&D contracts in the second half of 1990s, and they likely benefited from the merger with Hughes (1997), Grumman (1994), and McDonnell Douglas (1996) respectively.[112] This confirms Boatner's argument that after the merger wave in 1990s, the defence contractors have consolidated to fewer number of firms.[113] Overall, R&D gained increased procurement budget after 1980s, and the contractors consolidated following the mergers wave in 1990s.

[111] Boatner, Amy J. "Consolidation of the Aerospace and Defense Industries: The Effect of the Big Three Mergers in the United States Defense Industry." Journal of Air Law and Commerce 64 no. 3(1999): 913-940, 924

[112] Boatner, Amy J. "Consolidation of the Aerospace and Defense Industries: The Effect of the Big Three Mergers in the United States Defense Industry." Journal of Air Law and Commerce 64 no. 3(1999): 913-940, 920-923; Hughes isn't included in the panel as it didn't have publicly available data on Compustat

[113] Boatner, Amy J. "Consolidation of the Aerospace and Defense Industries: The Effect of the Big Three Mergers in the United States Defense Industry." Journal of Air Law and Commerce 64 no. 3(1999): 913-940, 918

Graph 7[114]



As mentioned earlier, a common feature of government R&D contracts is that the contractor was selected through a competition of proposals amongst firms.[115] It's evident from Graph 7 that the total value of competed contracts increased after mid-1980s, which is potentially related to the increased emphasis on competition under Carlucci's Acquisition Improvement Program introduced in the early 1980s, who was the contemporaneous Deputy Defense Secretary.[116] Thus, it's evident and reasonable that there's increased volume of competed contracts after mid-1980s.

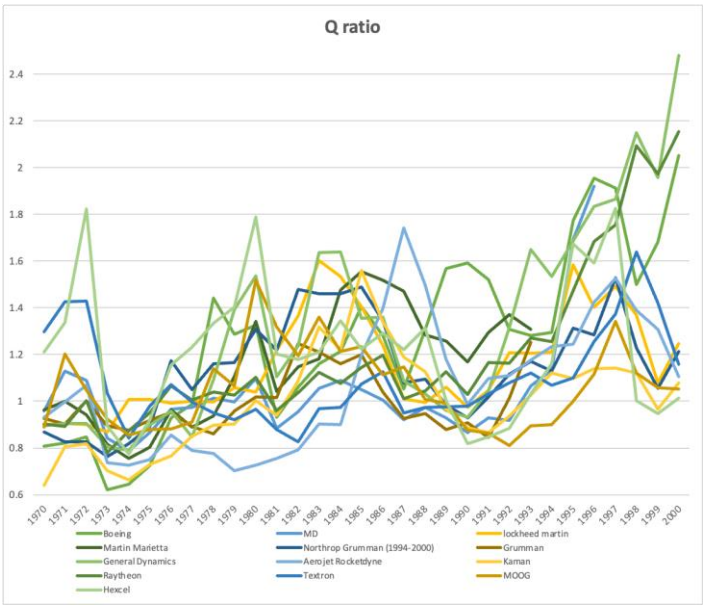
[114] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

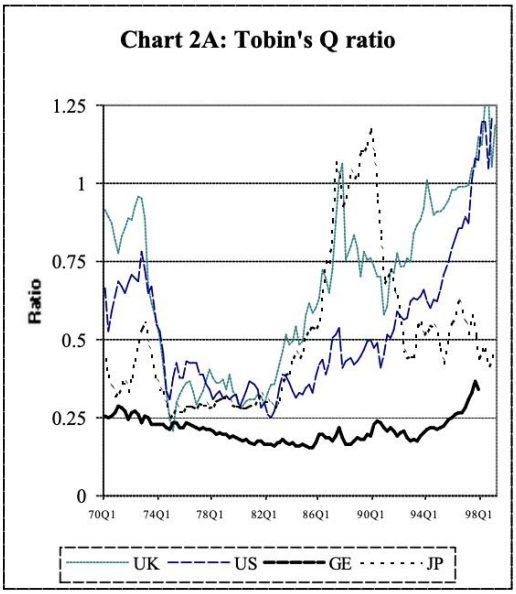
[115] Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152., 551

[116] J. Ronald Fox, Defense Acquisition Reform, 1960–2009, An Elusive Goal, Washington DC: Center of Military History United States Army, 2011, 110

5.3 Supply side factors – WACC, Q, Cash and interest

Graphs 8&9[117]





Graph 8 illustrates the Q ratio among the studied firms, with a downward trend in the beginning of 1970s and an upward trend in 1990s, consistent with the Q ratio data for the overall US economy during the time as observed from Graph 9.[118] This obvious upward trend in the 1990s is largely due to increased valuations on companies producing technology-related goods under increased investor demand for technology investment.[119] Consequently, as Tobin's Q is measured by dividing Market Value by its Book Value, with increased market value driven by higher investor demand, technology related companies such as

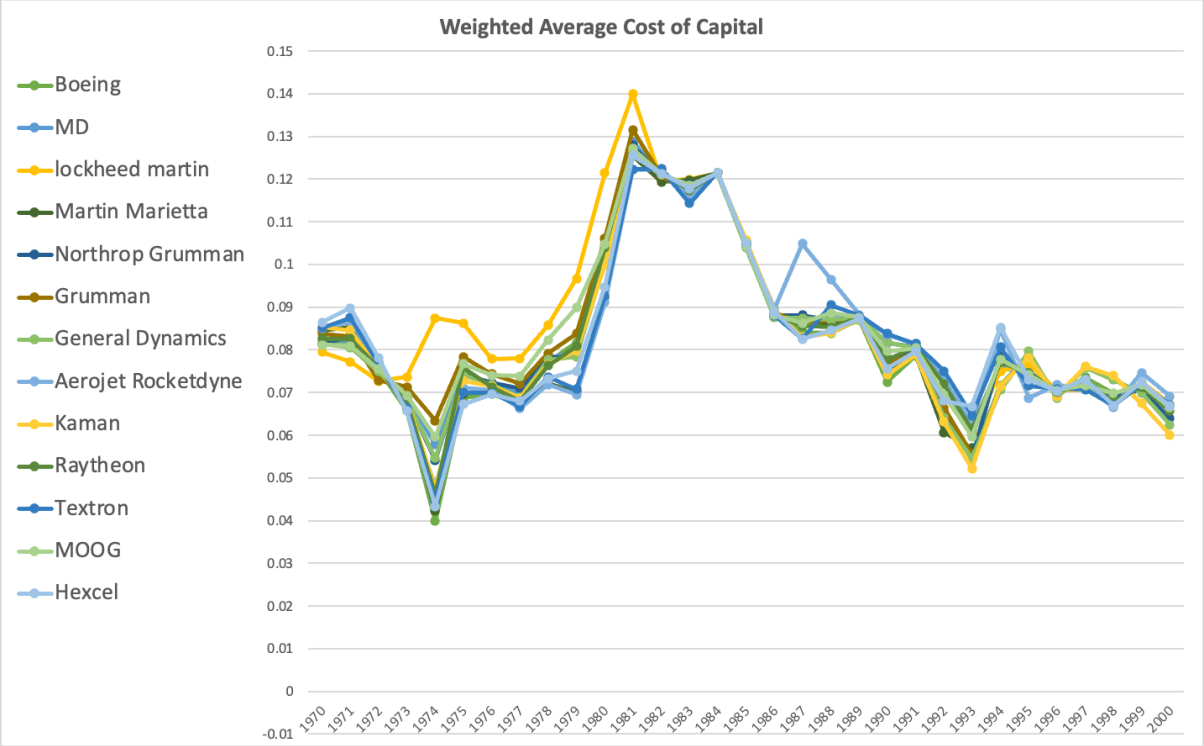
[117] Graph 8: 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023; Graph 9: Paul Ashworth and E. Philip Davis, "Some evidence on financial factors in the determination of aggregate business investment for the G7," National Institute of Economic and Social Research (NIESR) Discussion Papers 187, National Institute of Economic and Social Research (2001):1-38, 4

[118] Paul Ashworth and E. Philip Davis, "Some evidence on financial factors in the determination of aggregate business investment for the G7," National Institute of Economic and Social Research (NIESR) Discussion Papers 187, National Institute of Economic and Social Research (2001):1-38, 5

[119] Hali Edison, Torsten Slok, "New Economy Stock Valuations and Investment in the 1990s", IMF Working Paper WP/01/78 (2001): 1-17, https://www.imf.org/external/pubs/ft/wp/2001/wp0178.pdf, 4

Aerospace and Defense gained higher Q ratio.[120] Thus, it's reasonable to observe an increase in Q ratio especially in 1990s due to the technology boom.

Graph 10[121]



The weighted average cost of capital as illustrated by Graph 10 shows that the cost of external financing has a strong upward trend between 1973-1980, and gradually declined after 1980s. Firstly, by dissecting the components of Cost of Capital, it's observed that the upward trend in 1970s is mainly driven by the increased expected return from the Aaa bonds, which increased from around 7% in 1970-1973 to 14% in 1981.[122] This could be explained by the high inflation in the US around 1980, which reached a historical peak since the end of WWII.[123]

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[120] Hanna Mysaka, Ivan Derun, "Corporate Financial Performance and Tobin's Q in Dividend and Growth Investing", Contemporary Economics 15 no. 3(2021): 276-288, https://ssrn.com/abstract=3929437, 277

[121] 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023

[122] Moody's, 'Moody's Seasoned Aaa Corporate Bond Yield [AAA]', retrieved from FRED, Federal Reserve Bank of St. Louis, Accessed May 6, 2023, https://fred.stlouisfed.org/series/AAA

[123] Edward N. Gamber, "The Historical Decline in Real Interest Rates and Its Implications for CBO's Projections", Congressional Budget Office Working Paper Series 2020-09 (2020): 1-58, https://www.cbo.gov/publication/56891, 2

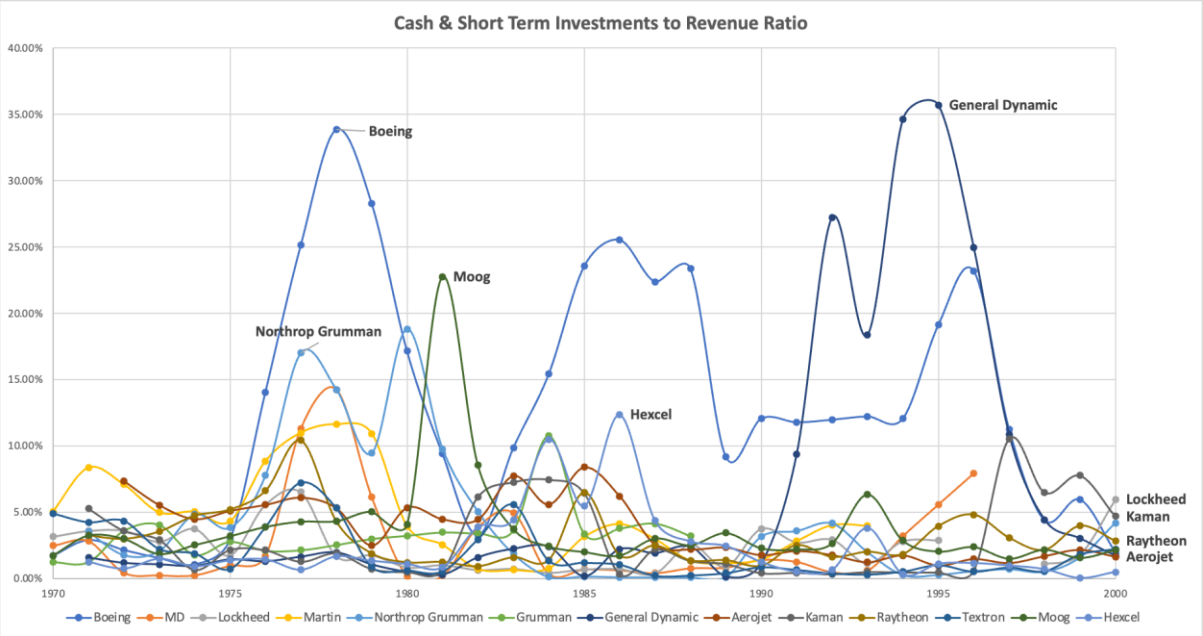
Specifically, in 1980s, the risk reflected by market beta for nominal bonds was significantly higher than that for inflation-indexed bonds, further proving the link between inflation and the high cost of debt.[124] Secondly, the decline after 1980s is similar to the Federal Reserve's estimate on cost of capital using the CAPM formula and the T-bill rates for a portfolio of bank holding companies in 1981-1998.[125] However, it's worth noticing that due to the different portfolios, industry, and the proxy for cost of debt, the numerical level of cost of capital could be different between this paper and other studies.[126] Thus, it's reasonable to compare the trend instead of the absolute level with secondary literature. In sum, the Cost of Capital was relatively high around 1980s due to high inflation, and steadily declined afterwards.

[124] Carolin Pflueger, "Back to the 1980s or Not? The Drivers of Inflation and Real Risks in Treasury Bonds", University of Chicago, Becker Friedman Institute for Economics Working Paper No. 102 (2022): 1-46, http://dx.doi.org/10.2139/ssrn.4179739, 1

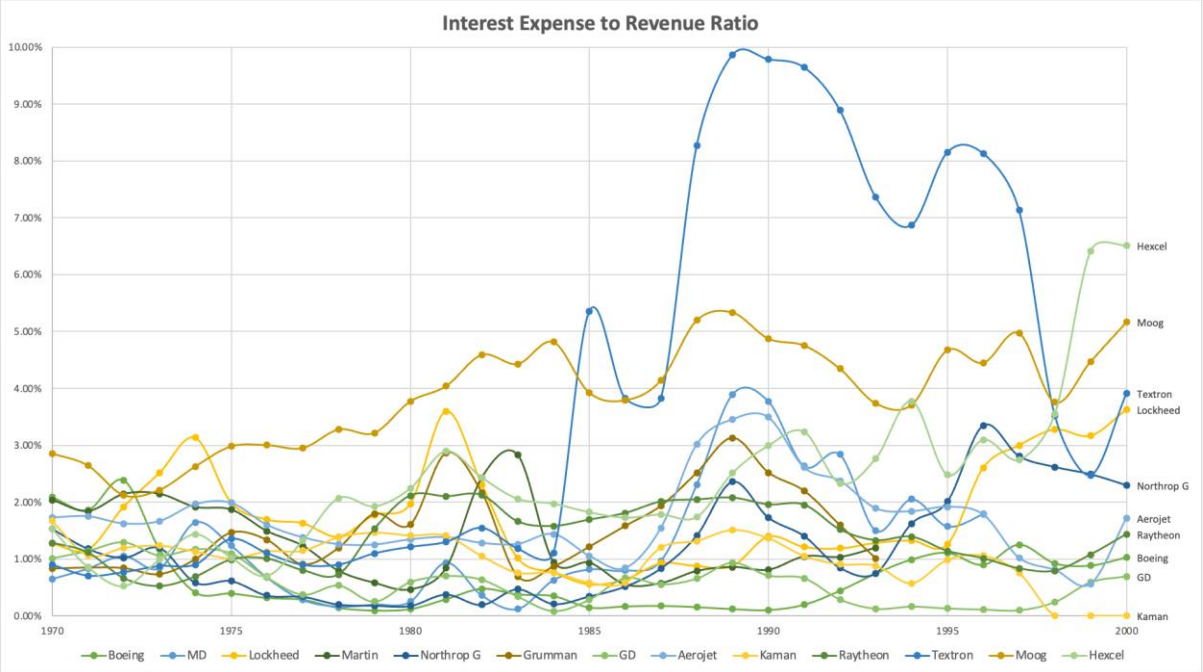
[125] See column "CAPM estimate" and "T-bill" in Table 3 in: Edward J. Green, Jose A. Lopez, Zhenyu Wang, "The Federal Reserve Banks' Imputed Cost of Equity Capital", (2000): 1-50, https://www.federalreserve.gov/boarddocs/press/boardacts/2000/200012212/researchpaper.pdf, 20

[126] For example, absolute level of cost of capital in this paper is different from: Edward J. Green, Jose A. Lopez, Zhenyu Wang, "The Federal Reserve Banks' Imputed Cost of Equity Capital", (2000): 1-50, https://www.federalreserve.gov/boarddocs/press/boardacts/2000/200012212/researchpaper.pdf, 20

Graph 11[127]



Graph 12[128]



[127] 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023

[128] 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, Accessed 8th April 2023

Graphs 11&12 represent the cash holdings and interest expenses to revenue ratio. Although absolute values are used in regression, ratio to revenue is displayed in the graph for illustration purposes. From Graph 11, it's clear that most firms have a relatively stable cash holding ratio to revenue within 0-10%, with some outliers such as Boeing in 1978 and General Dynamic in 1995. Both outliers are cross checked with the contemporaneous annual reports.[129] For Boeing, it may be justified by the 80% year-on-year increase in net earnings compared to 1977 in its Annual Report, and the consistently low interest expenses illustrated in Graph 12.[130] For General Dynamics, the surge in cash holdings is attributed to the high net earnings, income from Commercial Aircraft Sub-contractions, deferred income tax liability and minimal level of debt, which is also evident from the General Dynamics' low interest expenses.[131] The sub-contraction and tax liability was estimated to discontinue from 1996 onwards, which explains the downward trend in cash holdings starting from 1996.[132]

In Graph 12, the interest expenses ratio to revenue mostly fluctuates below 5%, with one outlier firm Textron reaching nearly 10% around 1990. This is partly justified by the interest incurred on the $250 million debt secured by Textron in 1989 for the acquisition on Avdel.[133] Additionally, since the transaction wasn't approved yet at the time by the Federal Trade Commission, the revenue from

[129] 'Boeing Annual Report 1979', Ann Arbor: ProQuest Annual Reports, 1979. https://www.proquest.com/reports/boeing-annual-report-1979/docview/88206820/se-2., (accessed May 6, 2023), 24; 'General Dynamics Annual Report 1995', ANN ARBOR: ProQuest Annual Reports, 1995. https://www.proquest.com/reports/general-dynamics-annual-report-1995/docview/88218798/se-2. (accessed May 6, 2023), 21
[130] 'Boeing Annual Report 1979', Ann Arbor: ProQuest Annual Reports, 1979. https://www.proquest.com/reports/boeing-annual-report-1979/docview/88206820/se-2., (accessed May 6, 2023), 19
[131] 'General Dynamics Annual Report 1995', Ann Arbor: ProQuest Annual Reports, 1995. https://www.proquest.com/reports/general-dynamics-annual-report-1995/docview/88218798/se-2. (accessed May 6, 2023), 2, 22.
[132] 'General Dynamics Annual Report 1995', Ann Arbor: ProQuest Annual Reports, 1995. https://www.proquest.com/reports/general-dynamics-annual-report-1995/docview/88218798/se-2. (accessed May 6, 2023), 22
[133] 'Textron Annual Report 1990', Ann Arbor: ProQuest Annual Reports, 1990. https://www.proquest.com/reports/textron-annual-report-1990/docview/88215046/se-2. (accessed May 6 2023), 2, 28.

Avdel cannot be included into Textron's annual report.[134] Consequently, this may result in an increased interest expenses to revenue ratio. Another observation from Graph 11&12 is that firms with exceptionally high cash holdings, such as Boeing and General Dynamics, tend to have low interest expenses, potentially supporting the argument of negative impact of debt financing on cash availabilities.[135]

5.4 Dataset within and between standard deviations

Table 1, Dataset min, max, mean and standard deviation[136]

Variables		obs	Mean ($mn)	std
R&D	overall	373	302.931	427.866
	between			369.794
	within			227.050
procurement	overall	373	457.352	789.212
	between			489.400
	within			627.500
Cost of Cap	overall	373	8.3%	0.019
	between			0.003
	within			0.019
Revenue	overall	373	7998.873	8919.730
	between			7225.154
	within			5406.877
Q ratio	overall	373	1.141	0.290
	between			0.102
	within			0.273
Cash	Overall	371	390.6701	894.4123
	Between			704.9118
	within			552.0954
Interest exp	Overall	370	125.2404	193.8773
	Between			118.7563
	within			154.892

[134] 'Textron Annual Report 1990', Ann Arbor: ProQuest Annual Reports, 1990. https://www.proquest.com/reports/textron-annual-report-1990/docview/88215046/se-2. (accessed May 6 2023), 2, 28.

[135] Hall, Bronwyn H., Ernst Berndt, and Richard C. Levin. "The Impact of Corporate Restructuring on Industrial Research and Development." Brookings Papers on Economic Activity. Microeconomics 1990 (1990): 85–135. https://doi.org/10.2307/2534781, 86

[136] The higher standard deviation among within and between-group is highlighted; 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, (Accessed 6th Feb2023); 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, (accessed 8th April 2023); 'Beta Suite by WRDS', https://wrds-www.wharton.upenn.edu/pages/get-data/beta-suite-wrds/, (accessed April 8 2023)

In addition to trend and features displayed by the dataset, it's also worthwhile to look at the statistical characteristics of the dataset. Table 1 provides a description on the between and within group standard deviations for each variable. Firstly, R&D, revenue and cash are having higher between-group variation than within-group. This means that the differences of the three variables between firms are more significant than that for the same firm across time. Secondly, interest expenses and the two calculated variables, namely q ratio and cost of capital, varies more along with time instead of between firms. This may imply that these three variables are more subject to changes in the external business environment along with time. However, it should be noted that as the cost of capital was calculated from the market average cost of equity and debt, the between-firm standard deviation might be under-stated.

To sum up the descriptive statistics, it's clear that R&D steadily increased in 1970s and maintained stable afterwards. Both overall R&D and competitive R&D contracts increased after 1980s, with a trend of consolidation due to merger activities among contractors.[137] On the supply side, there's an increase in Q ratio in 1990s possibly caused by the equity market boom.[138] The cost of capital surged around 1980 potentially due to historically high inflation.[139] The cash levels and interest expenses are mostly stable except for M&A activities, and higher cash holdings tend to correlate with lower interest expenses. Furthermore, interest expenses, Q and cost of capital may be more subject to external time-variant changes, while the others are more subject to within-group differences.

[137] Boatner, Amy J. "Consolidation of the Aerospace and Defense Industries: The Effect of the Big Three Mergers in the United States Defense Industry." Journal of Air Law and Commerce 64 no. 3(1999): 913-940, 920-923

[138] Hali Edison, Torsten Slok, "New Economy Stock Valuations and Investment in the 1990s", IMF Working Paper WP/01/78 (2001): 1-17, https://www.imf.org/external/pubs/ft/wp/2001/wp0178.pdf, 4

[139] Edward N. Gamber, "The Historical Decline in Real Interest Rates and Its Implications for CBO's Projections", Congressional Budget Office Working Paper Series 2020-09 (2020): 1-58, https://www.cbo.gov/publication/56891, 2

6. Regression and findings

6.1 General model

Firstly, since the dataset in this study includes time-series data for multiple individual firms, fixed effect panel regression with clustered standard error is deployed. This is because as fixed effects models allow different model intercepts for different subgroups, it accounts for the firm-specific effects.[140] Firms-specific characteristics, such as different manager compensation strategies and product diversity among firms, could influence the decision on R&D investments.[141] For example, companies with managers' compensation dominated by short term financial objectives and higher diversity of products tend to have lower R&D expenditure.[142] Thus, a fixed effect model is adopted. Secondly, clustered standard errors are included to control for heteroskedasticity within individual firms' data group.[143] Thirdly, all numerical values are deflated by the Producer Price Index and scaled to 2000 dollars.[144] Fourthly, to control for the time specific effects, dummy variables are introduced for each decade investigated. Finally, a lagged cash variable is also included, as it's identified by Hall as a useful proxy for previous cash holdings.[145]

Based on earlier arguments, it is expected that procurement level, revenue, Q and cash should have positive coefficients. WACC and interest expenses should have negative coefficients since lower WACC represents lower costs for external

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[140] Rizka Zulfikar, M. M. STp, "Estimation Model and Selection Method of Panel Data Regression: An Overview of Common Effect, Fixed Effect, and Random Effect Model", (2018): 1-10, doi: https://doi. org/10.31227/osf. io/9qe2b, 4

[141] Hoskisson, Robert E., Michael A. Hitt, and Charles W. L. Hill. "Managerial Incentives and Investment in R&D in Large Multiproduct Firms." Organization Science 4, no. 2 (1993): 325–41. http://www.jstor.org/stable/2635205., 325

[142] Hoskisson, Robert E., Michael A. Hitt, and Charles W. L. Hill. "Managerial Incentives and Investment in R&D in Large Multiproduct Firms." Organization Science 4, no. 2 (1993): 325–41. http://www.jstor.org/stable/2635205., 325

[143] "Clustered standard errors", Wikipedia, Accessed May 6 2023, https://en.wikipedia.org/wiki/Clustered_standard_errors

[144] For detailed calculation, see **Section 3.2**; PPI from: Organization for Economic Co-operation and Development, " Domestic Producer Prices Index: Manufacturing for the United States (USAPPDMAINMEI)", retrieved from FRED, Federal Reserve Bank of St. Louis, Accessed April 6 2023, https://fred.stlouisfed.org/series/USAPPDMAINMEI

[145] Bronwyn H. Hall, Jacques Mairesse, Lee Branstetter, Bruno Crepon, "Does Cash Flow Cause Investment and R&D?: An Exploration Using Panel Data for French, Japanese, and United States Scientific Firms", IFS Paper No. W98/11; Nuffield College Paper No. 142; Berkeley Dept. of Economics Paper No. 98-260, (1998): 1-37, http://dx.doi.org/10.2139/ssrn.105089, 5

funding, and interest expenses reduces the contemporaneous internal funding for R&D.[146] Table 2 illustrates the panel regression results based on 13 firms in 1970-2000. Regression (1) and (2) are the preferred models.

[146] Bronwyn H. Hall, Josh Lerner, "The Financing Of R&D And Innovation", NBER Working Paper Series no. 15325 (2009): 1-55, http://www.nber.org/papers/w15325, 13

Regression result Table 2[147]

Variable	R&D	R&D	R&D
	(1)	(2)	(3)
Constant	102.498	130.724	116.792
	(82.545)	(86.065)	(87.938)
Procurement	0.050***	0.049**	
	(0.016)	(0.020)	
Procurement Lag3			0.025
			(0.035)
Revenue	0.030***	0.026***	0.030***
	(0.002)	(0.005)	(0.003)
Ave Q	-41.407	-61.410	-35.463
	(30.629)	(36.267)	(33.597)
WACC	-262.537	-129.463	-288.377
	(601.633)	(728.137)	(642.125)
Cash	0.053***		0.031*
	(0.013)		(0.015)
Cash_lag1		0.100***	
		(0.030)	
Interest	-0.087***	-0.033	-0.032
	(0.016)	(0.060)	(0.050)
Year Dummies:	Included	Included	Included
Fixed effect	Yes	Yes	Yes
Clustered errors	Yes	Yes	Yes
rho	0.609	0.654	0.627
within r	0.710	0.734	0.664
between r	0.894	0.881	0.931
overall r	0.825	0.825	0.841
obs	368	355	329
groups	13	13	13

**** denotes significance level of 1%; ** denotes significance level of 5%; * denotes 10%; rho denotes intraclass correlation*

[147] See details in Section 3.2. Procurement data: 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, (Accessed 6th Feb2023); Financial data: 'Fundamentals Annual - North America - Compustat - Capital IQ', https://wrds-www.wharton.upenn.edu/pages/get-data/compustat-capital-iq-standard-poors/compustat/north-america-daily/, (accessed 8th April 2023); 'Beta Suite by WRDS', https://wrds-www.wharton.upenn.edu/pages/get-data/beta-suite-wrds/, (accessed April 8 2023); PPI: Organization for Economic Co-operation and Development, " Domestic Producer Prices Index: Manufacturing for the United States (USAPPDMAINMEI)", retrieved from FRED, Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/series/USAPPDMAINMEI, (accessed April 6 2023); WACC inputs: NYU Stern. "Regression Statistics By Industry (US)" https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/indreg.html, (accessed May 6, 2023); NYU Stern, "Historical Implied Equity Risk Premiums", Accessed May 6, 2023, https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/histimpl.html (accessed May 6, 2023)

Firstly, procurement has a 0.05 coefficient on firms' R&D expenditure statistically significant at 1% level. This is in line with the previous hypothesis that government R&D procurement has a positive impact on private R&D outlays. Specifically, this implies that in the present model, holding other supply side factors constant, every 1-dollar government R&D procurement could lead to a $0.05 increase in private firm R&D outlays. This result suggests that positive R&D incentive brought by government R&D contracts outweighs any potential crowding-out effects. This positive effect on R&D is in line with Levy's finding, who estimated that every $1 of government R&D contract procurement induces $0.27 private R&D spending.[148] The difference in number is likely due to different firm list, time span and variables, as Levy used industry-level data in 1949-1981, and the model included different variables, including corporate tax, industry output, unemployment and age of R&D stocks.[149] Similar findings is also found in Lichtenberg's regression model, which used the aggregate time series data in 1956-1983 and concluded that the Federal R&D-related procurement has a coefficient of 0.109 on corporate R&D.[150] Furthermore, he also regressed on the individual firm-level data of 169 industrial firms in 1979-1984, and concluded that for his panelled firms, $1 contract R&D contributes to $0.093 increase in private R&D spending.[151] Thus, it's reasonable to conclude that government R&D procurement has a positive contribution to firm level R&D expenditure.

The first direct explanation for the positive impact of R&D contract procurement on private R&D is that the government demand simply acts as additional input

[148] Levy, David M., and Nestor E. Terleckyj. "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis." The Bell Journal of Economics 14, no. 2 (1983): 551–61. https://doi.org/10.2307/3003656., 551
[149] Levy, David M., and Nestor E. Terleckyj. "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis." The Bell Journal of Economics 14, no. 2 (1983): 551–61. https://doi.org/10.2307/3003656., 553
[150] Lichtenberg, Frank R. "The Effect of Government Funding on Private Industrial Research and Development: A Re-Assessment." The Journal of Industrial Economics 36, no. 1 (1987): 97–104, https://doi.org/10.2307/2098599, 102
[151] Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152., 555

for firms' R&D outlays.[152] The second justification for the positive effect of government R&D contract is the intangible scientific knowledge spillovers that lowers the private costs of research and increases productivity of private R&D, which thus incentivizes more investment in research projects.[153] The third possible justification for the beneficial effect of government R&D procurement is that public R&D contracts could act as a complement to private research projects.[154] Specifically, when competing for government contracts, firms could develop R&D proposals and project plans that best accommodate their private plans for future research projects.[155] This hypothesis is supported by Mansfield, who found that firms participating in the project formulation for government R&D procurement are more likely to gain spillover benefits.[156] The first two explanation mainly focuses on the effect of overall R&D procurement, while the third explanation is more relevant to competitive contracts. The relative importance of competitive and non-competitive contracts is thus further explored in 6.4.

A reasonable concern on the existing regression is the previously mentioned multi-year contract, and the potential lag between the R&D contract and the effect on corporate R&D expenditure. Specifically, Mansfield and Switzer's survey has indicated a potential 3-year time lag on the effect of procurement on R&D.[157] However, both quantitative results, as shown in regression (3), and

[152] Paul A. David , Bronwyn H. Hall, Andrew A. Toole, "Is public R&D a complement or substitute for private R&D? A review of the econometric evidence", NBER Working Paper Series no. 7373 (1999): 1-60, http://www.nber.org/papers/w7373, 3
[153] Lichtenberg, Frank R. "The Effect of Government Funding on Private Industrial Research and Development: A Re-Assessment." The Journal of Industrial Economics 36, no. 1 (1987): 97–104. https://doi.org/10.2307/2098599., 99
[154] Levy, David M., and Nestor E. Terleckyj. "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis." The Bell Journal of Economics 14, no. 2 (1983): 551–61. https://doi.org/10.2307/3003656., 554
[155] Levy, David M., and Nestor E. Terleckyj. "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis." The Bell Journal of Economics 14, no. 2 (1983): 551–61. https://doi.org/10.2307/3003656., 554
[156] Levy, David M., and Nestor E. Terleckyj. "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis." The Bell Journal of Economics 14, no. 2 (1983): 551–61. https://doi.org/10.2307/3003656., 554
[157] Nestor E. Terleckyj. "Measuring Economic Effects of Federal Research and Development Expenditures: Recent history with Special Emphasis on Federal R&D Performed in Industry" in Papers Commissioned for a Workshop on the Federal Role in Research and Development. ed.

secondary literature, confirmed that the lag in the effect of procurement on R&D isn't significant. For the former, there's no statistically significant result generated from using a 3-year lagged R&D procurement variable (model 3). For the latter, Levy concluded that 64% of the R&D stimulating effect arise from government R&D procurement happens in the same year.[158] This indicates that most of the effect on corporate R&D from government procurement should be reflected in the annual dataset used in this study. Thus, the effect of time lag and multi-year contracts on the results should be relatively insignificant.

Another potential concern over the positive coefficient result of government R&D contract is that government R&D contracts could potentially increase the wages of scientists and engineers involved in research projects, making the R&D investments more expensive, thus overstating the positive effect of contract R&D.[159] Particularly, the wages of scientists could have a prominent proportion of 50% in the overall R&D expenditure.[160] However, this concern on price effects is partially addressed in the dataset by deflating the R&D data through the Producer Price Index.

It's also worth noticing that the characteristics of our panel firms, which consists of firms that's publicly trade in the majority of time in 1970-2000, indicates that they tend to be large and established firms, restricting the result regarding contract R&D to large firms. Contradicting results could be found for smaller firms, as Wallsten noticed that small firms receiving the Small Business Innovation Research grants provided by federal governments reduces their

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National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 151-172 (Washington, DC: The National Academies Press, 1985). https://doi.org/10.17226/942, 161

[158] Levy, David M., and Nestor E. Terleckyj. "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis." The Bell Journal of Economics 14, no. 2 (1983): 551–61. https://doi.org/10.2307/3003656., 554

[159] Lichtenberg, Frank R. "The Effect of Government Funding on Private Industrial Research and Development: A Re-Assessment." The Journal of Industrial Economics 36, no. 1 (1987): 97–104. https://doi.org/10.2307/2098599., 99

[160] Hall, Bronwyn H. "The Financing Of Research And Development." Oxford Review of Economic Policy 18, no. 1 (2002): 35–51. http://www.jstor.org/stable/23606869., 36

private R&D outlays.[161] Thus, it's reasonable to restrict the positive result on R&D from contract R&D on large and established firms.

A direct implication of the positive impact of contract R&D on private research expenditure is that R&D procurement could be an effective tool for government to increase research intensity in the industries. For instance, the result supports the recommendation to the European Union on using public procurement to encourage private research and innovations.[162] It's also in line with the suggestion for the US federal government to increase R&D spending on technologies that increases productivity. [163] Thus, the positive result implies that R&D procurement could be an effective tool in incentivizing private R&D.

Secondly, revenue had a 0.03 coefficient significant at 1% level, indicating that firms spend $0.03 on R&D for $1 extra revenue. This positive relationship is reasonable as larger firms are expected to spend more on research, confirming the inclusion of revenue as the size control.[164]

Thirdly, the cash level has a coefficient of 0.053, and lagged cash in regression (2) has a coefficient of 0.1, both significant at 1% level. This means that for every $1 additional cash holdings in the previous year, there's $0.1 increase in R&D expenditure in the current year. Furthermore, a $1 increase in current year cash holding correlates with 0.053 additional research spending. This suggests that cash levels, especially previous year cash holdings, are positively related to R&D spending, potentially because firms rely on cash as internal funding for research

[161] Paul A. David , Bronwyn H. Hall, Andrew A. Toole, "Is public R&D a complement or substitute for private R&D? A review of the econometric evidence", NBER Working Paper Series no. 7373 (1999): 1-60, http://www.nber.org/papers/w7373, p35
[162] The Expert Group, "Developing procurement practices favourable to R&D and innovation", (Luxembourg: Office for Official Publications of the European Communities, 2005): 1-46, https://ec.europa.eu/invest-in-research/pdf/download_en/edited_report_18112005_on_public_procurement_for_research_and_innovation.pdf, 9
[163] Robert D. Atkinson, "Why Federal R&D Policy Needs to Prioritize Productivity to Drive Growth and Reduce the Debt-to-GDP Ratio", (Information Technology & Innovation Foundation 2019): 1-30, https://www2.itif.org/2019-federal-rd-productivity.pdf, 1
[164] Daniel Shefer, Amnon Frenkel, "R&D, firm size and innovation: an empirical analysis", Technovation 25 no.1(2005): 25-32, https://doi.org/10.1016/S0166-4972(03)00152-4, Abstract, 1

projects.[165] Similar finding is suggested by Hall, who found a positive coefficient of 0.431 on lagged cashflow to R&D expenditure using a bivariate regression model for US manufacturing firms in 1978-1989.[166] This indicates that R&D is closely related to cash availabilities, as firms prefer to fund R&D projects by cash.[167]

Fourthly, interest expenses are negatively related to R&D expenditure with a coefficient of negative 0.087 significant at 1% level (model 1). This implies that with $1 additional interest expenses occurred in the year, the research expenses decrease by $0.087. Possible explanation for the negative relationship is that interest expenses incurred by debt financing reduces the available internal financing for firms, thus diverting the available internal funding away from R&D projects. [168] While there's limited literature directly linking interest expenses to R&D expenditure, ample secondary sources suggested that leverage ratio, which closely related to interest expenses, has a negative impact on research expenditure.[169] For example, Min has found a negative impact of leverage on firms' R&D outlays using a panel of South Korea firms in 2007-2012.[170] Similarly, Hall suggested that in 1980s, when firms increased their debt

[165] Gerben Bakker, "Money for nothing: How firms have financed R&D-projects since the Industrial Revolution", Research Policy 42 no.10(2013): 1793–1814, https://doi.org/10.1016/j.respol.2013.07.017, 1793
[166] Bronwyn H. Hall, Jacques Mairesse, Lee Branstetter, Bruno Crepon, "Does Cash Flow Cause Investment and R&D?: An Exploration Using Panel Data for French, Japanese, and United States Scientific Firms", IFS Paper No. W98/11; Nuffield College Paper No. 142; Berkeley Dept. of Economics Paper No. 98-260, (1998): 1-37, http://dx.doi.org/10.2139/ssrn.105089, 21, Table 6 bivariate
[167] Gerben Bakker, "Money for nothing: How firms have financed R&D-projects since the Industrial Revolution", Research Policy 42 no.10(2013): 1793–1814, https://doi.org/10.1016/j.respol.2013.07.017, 1793
[168] Hall, Bronwyn H., Ernst Berndt, and Richard C. Levin. "The Impact of Corporate Restructuring on Industrial Research and Development." Brookings Papers on Economic Activity. Microeconomics 1990 (1990): 85–135. https://doi.org/10.2307/2534781, 86
[169] Byung S. Min, Russell Smyth, "How does leverage affect R&D intensity and how does R&D intensity impact on firm value in South Korea?", Applied Economics 48 no. 58 (2016): 5667-5675, https://doi.org/10.1080/00036846.2016.1181836, 5674; Hall, Bronwyn H., Ernst Berndt, and Richard C. Levin. "The Impact of Corporate Restructuring on Industrial Research and Development." Brookings Papers on Economic Activity. Microeconomics 1990 (1990): 85–135. https://doi.org/10.2307/2534781, 121
[170] Byung S. Min, Russell Smyth, "How does leverage affect R&D intensity and how does R&D intensity impact on firm value in South Korea?", Applied Economics 48 no. 58 (2016): 5667-5675, https://doi.org/10.1080/00036846.2016.1181836, 5674

by over 1/2 of its total capital stock, its R&D investment ratio to total capital stock decreases 25% on average.[171] However, after substituting interest expenses with debt-to-asset ratio in our regression, there's no statistically significant result generated for leverage ratio due to high clustered errors.[172] While it's unthorough to conclude that leverage ratio is an irrelevant factor, it fair to state that it might not be as good a proxy as interest expenses in our model. Thus, it's reasonable to focus on interest expenses and conclude that there's a negative relationship between interest commitments and R&D expenditures.

Finally, it's clear that the Q ratio and WACC aren't statistically significant due to high clustered errors. One possible explanation for the high errors is collinearity. Thus, to investigate whether the two variables aren't statistically significant due to collinearity, permutated regressions with variables introduced individually is conducted in the following.

6.2 Permutated regressions

Table 3[173]

	(1)	(2)	(3)	(4)	(5)
Constant	44.306	70.311	28.117	45.455	45.541
	(43.852)	(64.673)	(39.259)	(53.942)	(45.247)
Procurement	0.050***	0.050***	0.048**	0.047**	0.054***
	(0.012)	(0.011)	(0.016)	(0.019)	(0.013)
Revenues	0.030***	0.030***	0.028***	0.025***	0.032***
	(0.002)	(0.001)	(0.002)	(0.004)	(0.001)
avg Q	-4.807				
	(36.035)				
WACC		-416.479			
		(654.765)			
Cash			0.053***		
			(0.013)		
Cash_lag1				0.095***	
				(0.029)	
Interest					- 0.120**
					(0.044)
Year dummies	Included	Included	Included	Included	Included
Fixed effect	Yes	Yes	Yes	Yes	Yes
Clustered errors	Yes	Yes	Yes	Yes	Yes
rho	0.635	0.637	0.614	0.657	0.628
within r	0.704	0.704	0.707	0.730	0.707
between r	0.896	0.897	0.895	0.884	0.899
overall r	0.813	0.813	0.824	0.825	0.817

[171] Hall, Bronwyn H., Ernst Berndt, and Richard C. Levin. "The Impact of Corporate Restructuring on Industrial Research and Development." Brookings Papers on Economic Activity. Microeconomics 1990 (1990): 85–135. https://doi.org/10.2307/2534781, 121

[172] See Appendix 1

[173] See Table 2 footnote.

Table 4, Correlation matrix[174]

	Proc	Revenue	Q	WACC	Interest	Cash	Cashlag	R&D
Proc	1							
Revenue	0.560	1						
Q	0.295	0.329	1					
WACC	0.093	-0.061	0.094	1				
Interest	0.322	0.577	0.073	-0.079	1			
Cash	0.365	0.606	0.312	-0.074	0.103	1		
Cashlag	0.369	0.650	0.325	-0.064	0.116	0.899	1	
R&D	0.499	0.907	0.296	-0.005	0.462	0.648	0.695	1

Firstly, from Table 3, it's clear that procurement, interest expenses, and cash-related indicators remained statistically significant in the permutated regressions, while that for Q and WACC are still not significant. Furthermore, the correlation matrix in Table 4 illustrates that the correlation of Q or WACC with other variables aren't noticeably large. This implies that their insignificance in the model may not be due to high correlation with other independent variables, suggesting that external financing and the availability of investment opportunities might be less relevant than internal financing and demand side factors for research expenditures.

This relative importance of internal financing on R&D and investments compared to external financing is supported by Triantis, who stated that the pecking order of financing methods that best enables managers to exploit investment opportunities is internal funds, debt, and then equity.[175] This implies that managers are more likely to finance R&D projects through internal sources of finance.[176] Potential explanation for the preference on internal funding is captured by the information asymmetry problem in raising external funds for

[174] See Table 2 footnote.
[175] Triantis, George G. "Financial Slack Policy and the Laws of Secured Transactions." The Journal of Legal Studies 29, no. 1 (2000): 35–69. https://doi.org/10.1086/468063., 37
[176] Gerben Bakker, "Money for nothing: How firms have financed R&D-projects since the Industrial Revolution", Research Policy 42 no.10(2013): 1793–1814, https://doi.org/10.1016/j.respol.2013.07.017, 1803

investment projects.[177] Specifically, due to the difficulties for investors to value the investment opportunities presented by firms raising new equities or debt, external investors could demand a premium in expected return.[178] This raises the cost of external financing compared to internal financing.[179] Furthermore, R&D is usually the extreme case in terms of high information asymmetry and uncertainty, thus making external financing even less favourable.[180] Thus, it's reasonable to observe a significant impact of internal financing indicators, and an insignificant effect of external cost of funding on R&D expenditure.

However, the reliance on internal funding may vary depending on the characteristics of sampled firms. For example, Hall has found that internal funding was especially preferred against external funding among established and large firms.[181] Similarly, Zhuang used a dataset consisting of US public firms in 7 high-tech industries in 1989-2010, and concluded that young firms tend to rely on internal and external equity financing, while mature firms tend to rely on cashflow and debt for R&D expenditures.[182] Thus, for our model, as most of the sampled firms are publicly traded in 1970-2000, they're more likely to be large and long-established, thus making the cash sensitivity more significant.

Secondly, it's observed that there's significant correlation (0.90) between current year cash and the lagged cash variable, suggesting potential collinearity problem

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[177] Gerben Bakker, "Money for nothing: How firms have financed R&D-projects since the Industrial Revolution", Research Policy 42 no.10(2013): 1793–1814, https://doi.org/10.1016/j.respol.2013.07.017, 1797
[178] Steven M Fazzari, R. Glenn Hubbard, Bruce C. Petersen, Alan S. Blinder, and James M. Poterba. "Financing Constraints and Corporate Investment." Brookings Papers on Economic Activity 1988, no. 1 (1988): 141–206. https://doi.org/10.2307/2534426., 150
[179] Fazzari, Steven M., R. Glenn Hubbard, Bruce C. Petersen, Alan S. Blinder, and James M. Poterba. "Financing Constraints and Corporate Investment." Brookings Papers on Economic Activity 1988, no. 1 (1988): 141–206. https://doi.org/10.2307/2534426., 150
[180] Gerben Bakker, "Money for nothing: How firms have financed R&D-projects since the Industrial Revolution", Research Policy 42 no.10(2013): 1793–1814, https://doi.org/10.1016/j.respol.2013.07.017, 1803
[181] Bronwyn H. Hall, Josh Lerner, "The Financing Of R&D And Innovation", NBER Working Paper Series no. 15325 (2009): 1-55, http://www.nber.org/papers/w15325, 40
[182]Zhong Zhuang, "What Finances R&D? R&D, Cash Flow Sensitivities, and Financing Constraints" (2012): 1-58. Available at SSRN: https://ssrn.com/abstract=1985836 or http://dx.doi.org/10.2139/ssrn.1985836, 1

within the two variables. To solve the problem, the lagged cash variable will be used as the only proxy for cash holdings in the later regressions.

To conclude, the permutations confirm that government R&D procurement, cash and interest expenses are important explanatory factors to R&D expenditure. On the other hand, external cost of capital and availability of investment opportunities are less relevant to R&D in our dataset.

6.3 Decade separated regression

To explore whether there's differences in influential factors on R&D in different time periods, separate regression for each decade in 1970-2000 is conducted. Given that WACC and Q are less relevant to the model, they will be dropped in the following regressions.

Table 5[183]

	1970-1980, R&D	1981-1990, R&D	1991-2000, R&D
constant	-16.170	126.576	238.783***
	(37.360)	(80.197)	(26.196)
procurement	-0.006	0.031**	0.111**
	(0.055)	(0.013)	(0.037)
revenue	0.034**	0.022*	0.002
	(0.014)	(0.012)	(0.005)
Cashlag1	0.131***	0.041*	0.127***
	(0.014)	(0.019)	(0.055)
interest expense	-0.440	0.025	0.105
	(0.526)	(0.086)	(0.161)
Fixed effect	Yes	Yes	Yes
Clustered errors	Yes	Yes	Yes
within	0.783	0.363	0.387
between	0.705	0.887	0.768
overall	0.708	0.833	0.755
obs	123	115	92
groups	13	13	12

The first observation from table 5 is that the lagged cash variable is the most significant in the first and third decade, and the coefficient is consistently in line

[183] See Table 2 footnote.

with the previous suggestion, confirming the positive relationship between cash holdings and R&D expenditure.

The second observation is that the procurement coefficient in 1970s is insignificant and negative. Similar problem was encountered by Terleckyj, who found that when using 1960-1976 data on aircraft and parts industry R&D expenditures, federal procurement had a -0.12 coefficient with no statistical significance.[184] This potentially implies that compared to 1980s and 1990s, the first decade investigated showed less impact of government procurement on industrial R&D. One possible explanation for the insignificance involvement of government in R&D procurement in 1970s is that at the beginning of the decade, the Vietnam War has diverted Department of Defense's(DoD) resources away from R&D toward military support.[185] This is also evident from descriptive statistics in Graph 4&5, suggesting that less contracts in 1970s may explain the insignificance of procurement to R&D compared to later decades.

The third observation is that the coefficient for R&D increased from 0.031 in 1980s to 0.111 in 1990s. This could potentially be due to increased government demand for defence R&D in the latter two periods, as proved both in the increased volume and number of government R&D contracts in Graph 4&5 and secondary literature. Specifically, the percentage of RDTE contracts in all DoD procurements fluctuated between 30-50% in 1970-1990, and the number increased to 50-70% after 1990 (Graph 13).[186] This implies that there's increased government emphasis on military R&D procurement in 1990s, making the procurement coefficient more significant in the later decades.

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[184] Nestor E. Terleckyj. "Measuring Economic Effects of Federal Research and Development Expenditures: Recent history with Special Emphasis on Federal R&D Performed in Industry" in Papers Commissioned for a Workshop on the Federal Role in Research and Development. ed. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 151-172. (Washington, DC: The National Academies Press, 1985). https://doi.org/10.17226/942., 158

[185] ALIC, JOHN A. "Managing US Defense Acquisition." Enterprise & Society 14, no. 1 (2013): 1–36. http://www.jstor.org/stable/23701646., 13

[186] ALIC, JOHN A. "Managing US Defense Acquisition." Enterprise & Society 14, no. 1 (2013): 1–36. http://www.jstor.org/stable/23701646., 5

One omitted variable in explaining the increased significance of procurement on R&D in 1980s might be the R&D tax credit introduced under the Economic Recovery Tax Act in 1981-1992, which provides tax exemption for the excessive amount of R&D above a certain threshold invested by a firm.[187] However, the effectiveness of this tax credit is proved to be limited.[188] Specifically, since the tax credit threshold is calculated based on the firm's previous year R&D, when the firm increases its R&D expenditure simply for the tax benefit purposes, it actually increases the threshold R&D level in the future and may incur higher taxes in the next year, reducing firm's incentive to increase R&D under tax credit.[189] Thus, since the effect of the tax credit is very limited, this omitted variable shouldn't cause severe concern for the argument.

Graph 13[190]

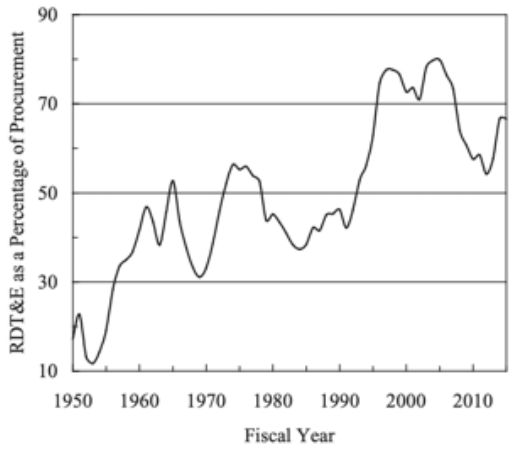

Figure 1 RDT&E Relative to Procurement. Note: Outlays. 2011–2015 estimated. Source: Office of the Under Secretary of Defense (Comptroller), *National Defense Budget Estimates for FY 2013*, table 6–11.

[187] Chris R. Edwards, "The Research & Experimentation Tax Credit", Tax Foundation Background Paper no. 5(1993): 1-16, https://taxfoundation.org/research-and-experimentation-tax-credit/, 1
[188] Eisner, Robert. "The R&D Tax Credit: A Flawed Tool." Issues in Science and Technology 1, no. 4 (1985): 79–86. http://www.jstor.org/stable/43308908., 81
[189] Eisner, Robert. "The R&D Tax Credit: A Flawed Tool." Issues in Science and Technology 1, no. 4 (1985): 79–86. http://www.jstor.org/stable/43308908., 81
[190] ALIC, JOHN A. "Managing US Defense Acquisition." Enterprise & Society 14, no. 1 (2013): 1–36. http://www.jstor.org/stable/23701646., 5

6.4 Competitive vs non-competitive contracts

To further investigate the relative contribution of competitive and non-competitive procurement to firms' R&D expenditures, the overall level of procurement is distinguished between competitive and non-competitive contract values as shown in table 6. Competitive contracts are identified as those labelled as 'competitive', 'competed', 'design/technology competition' or "follow-on" contracts to competed ones in the Federal Supply Class Descriptions.[191] Follow-on contracts are also included under the competitive section as they account for a great proportion in firm revenue generated from competed contracts.[192]

Table 6[193]

Variable	R&D	R&D
	(1)	(2)
constant	49.280	49.703
	(55.063)	(53.014)
competitive	0.044	
	(0.031)	
non competitive		0.127**
		(0.069)
revenue	0.026***	0.026***
	(0.005)	(0.007)
Cashlag	0.092**	0.101**
	(0.033)	(0.039)
interest	0.000	-0.015
	(0.064)	(0.064)
Year dummies	Included	Included
Fixed effects	Yes	Yes
Clustered errors	Yes	Yes
within	0.726	0.728
between	0.891	0.893
overall	0.828	0.830
obs	355	355
groups	13	13

[191] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb2023; 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

[192] Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152., 551

[193] See Table 2 footnote.

As illustrated by Table 6, the coefficient for competitive contracts isn't statistically significant, while that for non-competitive contracts is significant at 0.127. This implies that for every $1 non-competitive contract allocated to the firm, the company tend to spend $0.127 extra on private R&D outlays. The insignificance of the competitive coefficient is unlikely to be due to any issues in sample size, as over half of the total 53523 contracts recorded are marked as competitive.[194] Thus, it could be argued that competitive contracts in our dataset mattered less to R&D compared to non-competitive contracts. This different significance of competitive and non-competitive contract means that among the explanations provided before for the positive relationship between R&D and procurement, the first two explanations, which states that government R&D procurement increases private R&D by causing additional input for R&D and generating knowledge spillovers, is more applicable in our model.[195] The explanation on how competitive contracts is benefiting private R&D by allowing firms to develop R&D proposals that better suit their own R&D plans is not as applicable in our dataset.

Different results, in contrast, was generated by Lichtenberg, who regressed on 169 firm data in 1979-1984 using an instrumental variable model.[196] Specifically, he concluded that competitive R&D contracts positively incentivized private R&D with a coefficient of 0.54, while non-competitive contracts' effect on R&D is negative and insignificantly different from zero.[197] The different results is

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[194] 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1965 - 6/30/1975, documenting the period 7/1/1965 - 6/30/1975 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb2023; 'Records of Prime Contracts Awarded by the Military Services and Agencies, created, 7/1/1975 - 9/30/2006, documenting the period 7/1/1975 - 9/30/2006 - Record Group 330', https://aad.archives.gov/aad/series-list.jsp?cat=GS29, Accessed 6th Feb 2023

[195] Paul A. David , Bronwyn H. Hall, Andrew A. Toole, "Is public R&D a complement or substitute for private R&D? A review of the econometric evidence", NBER Working Paper Series no. 7373 (1999): 1-60, http://www.nber.org/papers/w7373, 3; Lichtenberg, Frank R. "The Effect of Government Funding on Private Industrial Research and Development: A Re-Assessment." The Journal of Industrial Economics 36, no. 1 (1987): 97–104. https://doi.org/10.2307/2098599., 99

[196] Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152., 555

[197] Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152., 555

possibly due to different model, variable, time span and industry selected.[198] Particularly, Lichtenberg utilized contracts *potentially awardable* to the firm as a proxy for competitive contracts, which essentially covers competitive contracts awarded to all firms in a given year, instead of *actual awarded* contracts.[199] Thus, it's reasonable to conclude that when restricting firms to Aerospace and Defence industry in the 1970-2000 time span and looking at competitive contracts that was actually recorded for each firm, non-competitive R&D contracts had more significant impact on firm-level R&D than competitive R&D contracts.

6.5 Testing for reverse causality

One concern over the effect of procurement and cash on R&D expenditure is the reversed causality. For example, R&D intensive firms might be more likely to win R&D contracts and have higher volume of R&D procurement, especially competitive ones.[200] Furthermore, R&D may have reversed effect on cash as it's argued that higher R&D levels may incentivize firms to increase their precautionary cash holdings due to the risk and time lag in return from research projects.[201] Thus, regressions are conducted separately using overall contracts, competitive contracts, and cash as dependent variables, and change of R&D at time t from the previous year **(ΔRD_t)** , R&D expenditure of the previous year **(RD_{t-1})** as independent variables. Revenue is included among the independent variables to control for the size effect. This method of using lagged R&D to test for reverse causality is also employed by other scholars.[202]

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[198] Lichtenberg, Frank R. "The Private R and D Investment Response to Federal Design and Technical Competitions." The American Economic Review 78, no. 3 (1988): 550–59. http://www.jstor.org/stable/1809152., 555

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[200] Viktor Slavtchev, Simon Wiederhold, "Government Demand Composition and Innovative Behavior in Industries", 7th European Meeting on Applied Evolutionary Economics (EMAEE)(2011): 1-53, https://www.lem.sssup.it/WPLem/documents/papers_EMAEE/slavtchev.pdf , 2

[201] Guido Baldi, André Bodmer, "R&D investments and corporate cash holdings", Economics of Innovation and New Technology 27 no. 7(2018): 594-610, https://doi.org/10.1080/10438599.2017.1378191, 594

[202] Viktor Slavtchev, Simon Wiederhold, "Government Demand Composition and Innovative Behavior in Industries", 7th European Meeting on Applied Evolutionary Economics

Table 7, reverse causality[203]

Variable	Procurement	Competitive Contract	Cash
constant	112.995	78.607	193.371
	(219.697)	(182.602)	(132.737)
RD_{t-1}	0.72	0.570	0.767**
	(0.617)	(0.562)	(0.310)
ΔRD_t	0.774	0.692	0.888*
	(0.668)	(0.552)	(0.446)
Revenue	0.029***	0.023***	0.004
	(0.008)	(0.007)	(0.006)
Year dummies	Included	Included	Included
Fixed effect	Yes	Yes	Yes
Clustered errors	Yes	Yes	Yes
within	0.397	0.351	0.136
between	0.307	0.254	0.560
overall	0.349	0.303	0.392
obs	360	360	360
groups	13	13	13

As shown in Table 7, the reverse causality of R&D records with procurement or competitive R&D contracts is rejected as none of the coefficients is statistically significant other than revenue as the size control. This insignificance of reverse causality between private research expenditure and R&D contracts is also confirmed in secondary literature based on lagged industry-level US R&D procurement data in 1999-2007.[204] Furthermore, due to the nature of the aerospace and defence industry where most procurements come from military purposes, it's reasonable to observe a negligible reverse causality since R&D procurements are likely induced by exogenous reasons.[205]

Additionally, it's clear that cash is subject to reverse causality, with a positive coefficient of 0.77 for 1-year lagged R&D significant at 5% level. This indicates that if the previous year R&D expenditure is increased by $1, the cash holdings

(EMAEE)(2011): 1-53, https://www.lem.sssup.it/WPLem/documents/papers_EMAEE/slavtchev.pdf, 32

[203] See Table 2 footnote.

[204] Viktor Slavtchev, Simon Wiederhold, "Government Demand Composition and Innovative Behavior in Industries", 7th European Meeting on Applied Evolutionary Economics (EMAEE)(2011): 1-53, https://www.lem.sssup.it/WPLem/documents/papers_EMAEE/slavtchev.pdf, 35

[205] Viktor Slavtchev, Simon Wiederhold, "Government Demand Composition and Innovative Behavior in Industries", 7th European Meeting on Applied Evolutionary Economics (EMAEE)(2011): 1-53, https://www.lem.sssup.it/WPLem/documents/papers_EMAEE/slavtchev.pdf, 32

of the firm in the subsequent year might increase by $0.77, which potentially could be explained by the precautionary cash holdings.[206] The reversed relationship between R&D and cashflow is also found by Hall, who conducted bivariate regression using lagged cashflow and lagged R&D against current cashflow, and concluded that reversed causality generated a coefficient on lagged R&D half the size than the coefficient for cashflow against R&D (0.226 compared to 0.431).[207] Thus, cash holdings is subject to reversed causality in our model.

To conclude, the regressions suggest that firstly, there's a positive and significant impact of government R&D contract procurement on private R&D expenditures without significant reversed causality, and non-competitive contracts seem to be relatively more influential. Secondly, the R&D stimulating effect of procurement contracts is the most significant in 1990s. Thirdly, cash is found to be positively related to R&D expenditure, supporting the hypothesis that internal funding is important for R&D investments, but it's subject to reversed causality. Fourthly, interest expenses are negatively related to research expenses possibly due to the reduction in available funding under interest payment commitments.[208]

7. Conclusion

Firstly, this essay provides descriptive statistics from the procurement contracts awarded to 13 Aerospace and Defence firms in 1970-2000, and their corresponding financial data. The descriptive statistics suggests that there's increased emphasis on federal R&D procurement and competitive R&D contracts after 1980s, and the R&D level in the industry has remained stable after slight

[206] Guido Baldi, André Bodmer, "R&D investments and corporate cash holdings", Economics of Innovation and New Technology 27 no. 7(2018): 594-610, https://doi.org/10.1080/10438599.2017.1378191, 594
[207] Bronwyn H. Hall, Jacques Mairesse, Lee Branstetter, Bruno Crepon, "Does Cash Flow Cause Investment and R&D?: An Exploration Using Panel Data for French, Japanese, and United States Scientific Firms", IFS Paper No. W98/11; Nuffield College Paper No. 142; Berkeley Dept. of Economics Paper No. 98-260, (1998): 1-37, http://dx.doi.org/10.2139/ssrn.105089, 21
[208] Bronwyn H. Hall, Josh Lerner, "The Financing Of R&D And Innovation", NBER Working Paper Series no. 15325 (2009): 1-55, http://www.nber.org/papers/w15325, 13

increase in 1970s. An increase in the industry concentration is observed, especially after the merger wave in 1990s. Additionally, firms with higher cash holdings tend to be those with low levels of interest commitments. Furthermore, Interest, Q and WACC are more subject to time-variant changes, while revenue, cash and R&D has higher between-firm variance.

Secondly, the demand and supply side factors influencing corporate decisions on R&D expenditure is explored by the regression on the financial data and procurement contract records from the 13 firms. This essay concludes that government R&D procurement is a positive demand side factor that induces higher private R&D expenditures, without significant reverse causality. Particularly, $1 extra R&D contracts awarded to the firm induces $0.05 higher R&D expenditure. This result refutes the argument of potential crowding-out effect of government R&D contract, and implies that R&D procurement could be an effective tool for governments to incentivize private R&D.

Furthermore, the decade segregated regression proved that R&D procurement gradually gained importance in prompting private research investments, with the most significant impact illustrated in 1990s, potentially explained by the increased emphasis on federal R&D contract in the later decades. Additionally, by separating competitive and non-competitive contracts in regression, non-competitive contracts were more significant in encouraging private R&D expenditures. This indicates that government contract R&D encouraged industrial R&D by acting as an additional input for company research and creating knowledge spillovers.

Moreover, the availability of internal financing, namely cash holdings and interest commitments, are important supply side factors that influences firms' decision on R&D investments, with cash holdings subject to reversed causality. In contrast, external financing and the investment opportunities as proxied by WACC and Q ratio, are proved to be less relevant to R&D expenditure in our model. This proves that for R&D expenditures, internal financing is favored

instead of external financing especially for large and established firms, potentially due to cheaper cost of internal funding.

Appendix 1[209]

Variable	R&D
proc	0.046***
	(0.012)
rev	0.029***
	(0.002)
cc	-271.433
	(584.743)
dtoa	-106.317
	(101.876)
q	-30.512
	(33.333)
cashinf	0.053***
	(0.013)
Within	0.710
Between	0.897
Overall	0.827
Observations	371
Groups	13

[209] Source see Table 2

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